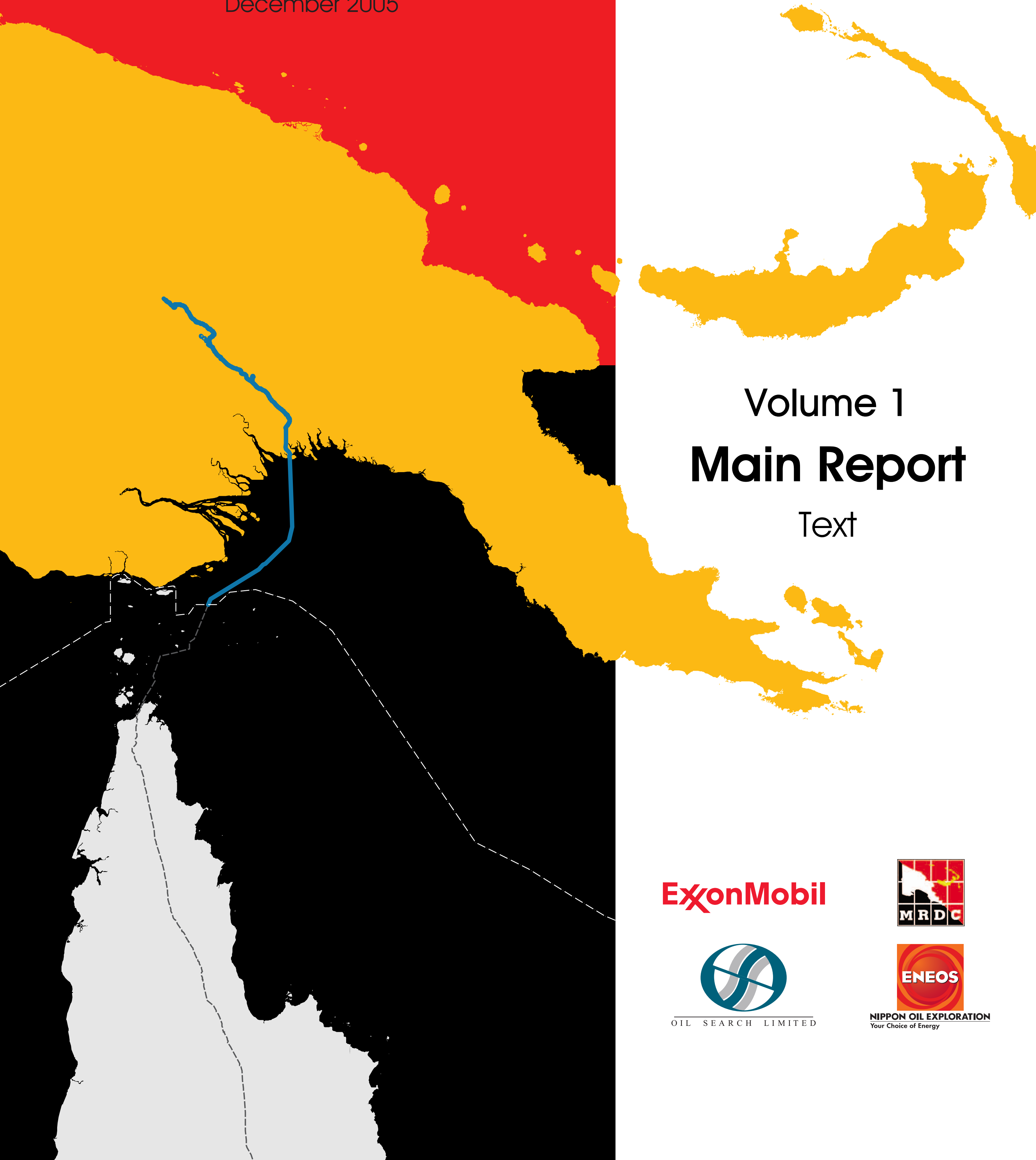
PNG Gas Project

Environmental Impact Statement

December 2005

PNG GAS



Volume 1

Main Report

Text

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PNG Gas Project

Environmental Impact Statement
Volume 1:
Main Report Text

December 2005
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PNG Gas Project

Environmental Impact Statement

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1. Introduction

Esso Highlands Limited (Esso) as Operator and Esso's co-venturers are advancing a proposal to develop the PNG Gas Project ('the project'). The development involves gas production and processing facilities in the mountains of Southern Highlands Province, pipelines to further processing facilities at Kutubu and a sales gas pipeline running through the foothills and lowlands of Gulf Province alongside the Kikori River to the Omati River delta. From landfall, the pipeline runs offshore across the Gulf of Papua to Papua New Guinea's international border with Australia near Pearce Cay in Torres Strait (Figure 1.1). At the international border, the sales gas pipeline owner becomes the AGL Petronas Consortium (APC), who will build the continuation of the pipeline to markets in Australia. (The APC development is called the PNG – Queensland Gas Pipeline Project.)

Esso, the PNG Gas Project Operator, has prepared this Environmental Impact Statement (EIS) as the statutory basis for the environmental assessment of the project. This will enable a ministerial decision on whether the project should proceed and, if so, under what conditions. Enesar Consulting Pty Ltd was commissioned to assist Esso in the preparation of this EIS.

The EIS is founded on a series of supporting studies (see Section 1.7.3). Hard copies of the EIS and its supporting studies can be obtained on request from:

Mr Gary Morony
Managing Director, Esso Highlands Limited
Credit House, Cuthbertson Street
Port Moresby, NCD, Papua New Guinea

The EIS sets out a development proposal intended to enable engineering, cost, environmental, commercial and social implications to be assessed:

- By the co-venturers in their decision to sanction the project to proceed.
- By the public in formulating their responses to the EIS.
- By the relevant government agencies of the Independent State of Papua New Guinea in evaluating the project's public interest credentials and in formulating conditions under which it might proceed.

In other words, the intention of this EIS has been to define and assess the project's major risks and benefits.

The development proposal will continue to evolve as engineering work proceeds through the detailed design phase. The Operator does not expect these changes to materially affect the conservative findings of this EIS but will assess these variations as a matter of course and report any potentially significant change to the relevant government agencies.

1.1 Background

Oil was first discovered in Papua New Guinea in 1911, but it was not until the 1980s that substantial reserves of oil and gas were found in Southern Highlands Province. Gas production began at Hides for the Hides Gas to Electricity Project in 1991, followed by oil production at Kutubu (Kutubu Petroleum Development Project) the following year. The first variant of the PNG Gas Project was conceived in 1995 to build on this established petroleum production infrastructure and to export gas by pipeline to Australia.

The PNG Gas Project underwent a series of feasibility, socioeconomic and environmental investigations in the years that followed. During this time, the PNG Gas Project also implemented a significant number of scope changes in order to simplify the project concept, to reduce projected capital cost and to improve the project's economic outlook.

By 2004, eastern Australia's tightening gas supply and growing gas demand had improved the PNG Gas Project's competitive position and, in late 2004, the current project participants proceeded to undertake front-end engineering and design (FEED) and an environmental assessment. This work will provide the basis for a decision by the project participants on whether to proceed to development and to seek environmental and petroleum approvals and licences from the Independent State of Papua New Guinea ('the State') in 2006 ('project sanction'). This would allow financial arrangements to be finalised ('financial close'), followed by detailed engineering design and construction. First gas deliveries to Australia are envisaged to occur in 2009.

1.2 Purpose of the Development

The PNG Gas Project has two interdependent objectives:

- To commercialise the gas reserves of the Kutubu, Gobe and Moran oil fields and of the Hides gas field and, in so doing,
- To maximise oil recovery from existing oil and gas fields and facilities.

Figure 1.2 shows the size of the gas resource compared to the oil resource in question and how the PNG Gas Project might meet the two objectives above.

The other stakeholders in the PNG Gas Project have their own related interests and objectives. The Independent State of Papua New Guinea is understood to be of the position that the purpose of the development is to implement the State's resource development policy in a manner consistent with current legislation that both enables the project to proceed and appropriately regulates its development and impacts (see also Chapter 4.)

As far as the customary landowners in the project impact area are concerned, they have consistently expressed their support for the project in a series of attitude and opinion surveys conducted in 1997, 2004 and 2005. In the most recent survey (for this EIS), levels of support ranged from 68% at Hides to more than 95% everywhere else. By inference, the foundation of this support lies in the project's potential to maintain and extend existing benefits and promote socioeconomic development (see Section 15.1.3).

1.3 PNG Gas Project Participants

1.3.1 Equity

The PNG Gas Project is being matured through a joint venture between Esso and its affiliates (Esso, as Operator, 39.4%), Oil Search Limited and its affiliates (Oil Search, 54.2%), Nippon Oil Exploration Limited through its subsidiary Merlin Petroleum Company (Nippon Oil, 3.4%) and subsidiaries of Mineral Resources Development Company Limited (MRDC, 3%). The project involves the respective resources of the co-venturers in petroleum development licences PDL-1 (Hides), PDL-2 (Kutubu and Moran) PDL-4 (Gobe) and PDL-5 (Moran) and petroleum retention licence PRL-12 (Hides).

The PNG Gas Project Agreement (2002) ('Gas Agreement') was executed by the co-venturers, the State and the Bank of Papua New Guinea and sets out the parameters for the PNG Gas Project, including State participation. Amendments to the Gas Agreement are currently under consideration, in order to incorporate modifications to the project scope since the execution of the original Agreement in 2002.

1.3.2 Proponents

The commercialisation of PNG's gas resources is in fact a project of two parts, each with its own proponent:

- 'PNG Gas Project': the proponent of the PNG component of the project is the PNG Gas Project Joint Venture, with Esso as the Operator on behalf of its co-venturers.
- 'PNG – Queensland Gas Pipeline Project': the proponent of the Australian component of the project is the AGL Petronas Consortium (APC), which will operate and own the sales gas pipeline from the international border between Papua New Guinea and Australia in Torres Strait to markets in Australia.[1]

1.3.3 PNG Gas Project Co-venturers

The participants in the PNG Gas Project Joint Venture operated by Esso at the date of this EIS are listed below and are part of the groups referred to in the headings and described in this section. The identity of these co-venturers will change over time to include parties joining the project such as AGL, Petroleum Resources Moran Limited and Eda Oil Limited.

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[1] The PNG–Queensland Gas Pipeline Project is subject to the applicable legislation of Australia. This project has been the subject of an environmental impact assessment approved by Australian Commonwealth and Queensland ministers in 1998.

ExxonMobil
Esso Highlands Limited (Operator)
Ampolex (PNG Petroleum), Inc.
Ampolex (Highlands) Limited
Merlin Pacific Oil Company Limited

Oil Search
Oil Search Limited
Oil Search (Gobe) Limited
Oil Search (Kutubu) Limited
Oil Search (Moran) Limited
Oil Search (Tumbudu) Limited
Orogen Minerals Gobe Limited
Orogen Minerals Kutubu Limited
Orogen Exploration Inc

Nippon Oil Exploration
Merlin Petroleum Company

Mineral Resources Development Corporation
Petroleum Resources Gobe Limited
Petroleum Resources Kutubu Limited

1.3.3.1 ExxonMobil

Esso, the Operator of the PNG Gas Project joint venture, is a wholly owned subsidiary of Exxon Mobil Corporation, the world's largest energy-related publicly traded company. ExxonMobil[2] businesses operate in almost 200 countries and territories, principally in:

- Oil and gas exploration and production.
- Refining, supply and marketing of petroleum products.
- Manufacture and marketing of petrochemicals.

The ExxonMobil group of companies is the largest non-government marketer of equity (own production) natural gas and crude oil in the world.

1.3.3.2 Oil Search

Oil Search is a public company incorporated in Papua New Guinea in 1929. The company has explored for petroleum in Papua New Guinea since then and became a producer of gas and then oil with the commissioning of production facilities respectively at Hides (1991) and Kutubu (1992). In 1998, Oil Search acquired the PNG oil and gas interests of BP Petroleum Development Limited and with them operatorship of the

[2] A reference to 'ExxonMobil' in this document is a reference to Esso and the ExxonMobil group of companies.

existing production operations associated with the Hides Gas to Electricity Project. In 2002, Oil Search acquired the interests of Chevron Niugini Limited and the operatorship of the Kutubu, Gobe and Moran petroleum development projects. Oil Search is currently developing the oil reserves of the South East Mananda field. Oil Search also operates the Kutubu crude oil export pipeline and the Kumul Marine Terminal.

In 2003, Oil Search merged with the PNG resource company, Orogen Minerals Limited.

Oil Search is Papua New Guinea’s most active oil and gas explorer, holding the most extensive acreage position and now the country’s largest reserves of both oil and gas.

1.3.3.3 Mineral Resources Development Corporation

Mineral Resources Development Corporation Limited holds equity as follows: in the Kutubu Petroleum Development Project (PDL-2 and PL-2) through its subsidiary, Petroleum Resources Kutubu Limited; in the Gobe Petroleum Development Project (PDL-4) through Petroleum Resources Gobe Limited; and in the Moran Petroleum Development Project (PDL-5) through Petroleum Resources Moran Limited and Eda Oil Limited. MRDC is wholly owned by the State, and these subsidiary companies are in effect the trustees of trusts under which landowner and provincial-government interests in relevant licences are held.

1.3.3.4 Nippon Oil

Nippon Oil Exploration Limited is exploring for, developing and producing oil and gas, with activities in ten countries based around four core areas: the UK North Sea, the Gulf of Mexico, South East Asia and Australia.

1.4 Project Concept

The PNG Gas Project will be developed mainly within or adjacent to the footprint of existing oil production facilities (‘brownfield development’). New development (‘greenfield development’) mainly comprises gas field production facilities at Hides, some 125 km to the northwest of the Kutubu Central Production Facility, new onshore pipelines between Hides and Kutubu and Kopi to the Omati River landfall, and a new offshore pipeline from the PNG landfall to Papua New Guinea’s international border with Australia.

The main project elements are as follows:

- Field production facilities at Hides: new wells, gathering system, gas processing facilities and pipelines to Kutubu.
- A new Central Gas Conditioning Plant to be located adjacent to the Kutubu Central Production Facility (the existing crude oil stabilisation plant).
- Sales gas pipeline from the Central Gas Conditioning Plant to Australia.

The Gas Agreement provides for the PNG Gas Project to complete construction access ways (roads and rights of way [RoWs]) as public roads so as to link Gulf and Southern Highlands provinces.

The PNG Gas Project's capital investment in Papua New Guinea is of the order of K8.3 billion (US$2.5 billion in 2005 dollars), with approximately the same again estimated for recurrent expenditures over a nominal project life of 30 years (approximately to 2040).

1.5 Project Principles and Values

The co-venturers' social, economic and cultural objectives for the PNG Gas Project are to deliver the engineering and commercial components of a project that has the potential to benefit local and wider communities in Papua New Guinea, Australia and the Asia-Pacific region by:

- Recognising local amenity, values and culture of those people directly affected by the project.
- Managing environmental impacts.
- Contributing to the economy and human wellbeing.
- Enabling and facilitating social infrastructure.

The co-venturers' environmental objectives are to plan, build and operate the project according to sound industry practice and to meet applicable government requirements and appropriate community expectations of environmental performance.

These environmental objectives are underpinned by the principles and values of the Operator, the other co-venturers and their financiers. They are also framed and moderated by the laws and governmental processes of the Independent State of Papua New Guinea in accordance with the customs and priorities of the country (see Section 4.1).

1.6 Environmental Setting and Main Issues

1.6.1 Onshore

The environmental setting of the PNG Gas Project ranges from the ridges and ravines of the volcanic and karst landforms of the PNG highlands at elevations up to 2,800 m down to the Kikori River basin lowlands and the Gulf of Papua.

The project area features extensive tracts of relatively little disturbed and sparsely populated montane, lowland hill and lowland forest with a diverse variety of plants and animals.

Remoteness, soil infertility and endemic malaria have kept human populations at low densities, and so there has been limited hunting or clearing pressure to date except around habitations. The conservation values of the project area are generally high.

Figures 1.3 and 1.4 are digital elevation models of the Hides to Kutubu area and the Kikori River basin respectively, and there is a fuller account of the physical and biological environment of the project area in Chapter 9.

The main onshore environmental issue of the PNG Gas Project involves its effects on biodiversity. These and other onshore impacts are addressed in Chapters 13 and their possible future interactions with other developments in Chapter 16.

1.6.2 Offshore

The offshore sales gas pipeline runs through the low-lying, swampy prograding delta complexes at the head of the Gulf of Papua out across the muddy seabed of the Gulf itself and around the delta front of the Fly River to the reefs, cays, small continental islands and shoals of Torres Strait. Chapter 10 describes more fully the features and processes of the offshore environment.

Subsistence and commercial prawn trawling and various small-scale coastal fisheries are the main activities along the offshore pipeline route, and conflict with these activities is the main question to be addressed in the offshore area. These and other impacts are addressed in Chapter 14.

The fisheries and other customary and commercial uses of Torres Strait are managed under a joint authority of Australia and Papua New Guinea. These arrangements are described in Section 4.1.5.

1.6.3 Social and Cultural Environment

As described in Chapter 11, the project area is one of the most remote and least accessible parts of Papua New Guinea. The region supports a sparse local population, which operates a generally subsistence economy based on sago palm cultivation, slash-and-burn agriculture, and hunting, gathering and fishing.

The project area has a diverse sociocultural character, with numerous tribal and language groupings. Social organisation is mainly based on patrilineal descent, which determines all of the important relationships of people to people, people to land, and people to their spiritual beliefs.

The area has a very low potential for commercial agriculture, and none has developed.

For the proponents of new projects, the most important feature of PNG society is the primacy of small clan groups. These groups have a moral authority to speak for their interests and place, grounded in the customary ownership of land. This situation applies to Papua New Guinea to a degree that is probably unprecedented in the developing world.

The key social issues associated with the PNG Gas Project fall into two groups. On the positive side are the incomes, services and personal opportunities that development brings (see Section 1.6.4 below). On the negative side are the effects that these changes bring to social organisation, behaviour and the relationships and conflicts between people in the project area and with outsiders.

In addition, there will be limited physical impacts of project construction activities on places and artefacts of archaeological, cultural or religious significance (see Chapter 15). The project will appropriately manage known cultural heritage sites.

Public consultation is mandatory and has been, and will continue to be, both extensive and focused on the resolution and ongoing management of social and cultural issues in the project impact area (see Chapter 5).

1.6.4 Economic Setting

The principal sources of cash income in the project area are wages and royalties from the oil developments and, to a lesser extent, from commercial logging in the Gulf lowlands. Before these developments, the lifestyles of the local people had remained relatively unchanged for centuries. Since then, however, oil revenues have accrued to provincial governments and some local landowners.

The PNG Gas Project will not represent a dramatic increase in benefits realised by local landowners in the project area over what is occurring at present. The project will, however, extend the scope (to reflect the increase in production from Hides) and term of these benefits (for several decades beyond the point when oil production and its associated revenues alone would have ended). As far as all those who own or have an interest in land are concerned, the amount, destination and use of project revenue streams is the PNG Gas Project's single biggest socio-economic issue.

The negotiation of project benefits between the different levels of government and landholders is mandated and codified by the *Oil and Gas Act 1998*, under which a structured process has been established to enable the State to manage the distribution of benefits (see Section 4.1.1).

1.6.5 Political Context

The diversity and fractious politics of PNG societies are well known. They bring the strengths of local self-determination and independence and the weaknesses and potential intractability of disunity.

The project area is no exception to this ubiquitous feature of PNG life, with three main issues creating the political framework within which the project's social interface will need to be managed:

- Grass-roots confidence in governments' ability to deliver on promises of social services and infrastructure provision.
- The structure, ownership and governance of two companies to respectively:
  - Hold landowners' equity.
  - Take advantage of the business opportunities that the PNG Gas Project will bring.

  (Underlying this issue of corporate organisation are the challenges that local landowner groups will face; i.e., to put precedent behind them and adopt an approach based on cooperation and sharing versus competition.)

- The push by mainly Southern Highlanders to create a new, resource-rich province called Hela.

These issues are all concerned, directly or indirectly, with the distribution of economic benefits to PNG citizens. These challenges are not to be underestimated, but nor too are the financial and social development drivers related to their ultimate resolution.

1.7 This Report

1.7.1 Statutory Context

This report constitutes an Environmental Impact Statement (EIS) as required under Section 53 of the *Environment Act 2000*. The EIS process is described in Section 4.1.2.

1.7.2 EIS Scope

The Kutubu, Gobe, Moran and Hides fields continue to operate under existing environmental approvals granted progressively since 1990. The PNG Gas Project is an increment to the footprint of the existing operations and can extend oil and gas recovery by several decades or more.

The Gas Agreement stipulates that operations involving gas recovery at Kutubu, Gobe, Moran and Hides be part of a coordinated development under the *Oil and Gas Act 1998*.

This EIS seeks approval to construct and commission the PNG Gas Project (with Esso as the Operator). Existing production operations that will form part of the project would continue under their respective licences, approvals and permits with variations where necessary.

1.7.3 Report Structure

The EIS consists of three parts:

- The EIS Executive Summary, which provides an overview of the project impact assessment and stakeholder consultation for non-technical readers. This summary is available in English and Tok Pisin.
- The EIS Main Report (this report), which is intended to be understood without reference to the technical supporting studies on which it is based. This report documents the potential direct and indirect biophysical and sociocultural impacts of the project and details the project's proposed mitigation and management measures, the benefits to be derived from the project, the stakeholder consultation program and residual impacts.
- A series of supporting studies.

The EIS does not disclose information that is confidential for cultural or commercial reasons, but the Operator may provide the latter in confidence to DEC upon request.

Table 1.1 provides a guide to the substantive chapters of the EIS.

Table 1.1 Guide to the EIS

EIS Chapter		Summary of contents
1.	Introduction	The project in outline and its background, owners, principles and values; the environmental setting and issues; and the purpose of the development.
2.	Project Description and Schedule	Project description; schedule and sequencing; gas resource and project life; production facilities, pipelines construction access and supporting facilities.
3.	Project Substantiation (Alternatives Analysis)	The project as currently proposed: feasibility and viability; implications of no project; strategic alternatives and tactical options for project elements and pipeline routing; completion of construction access ways as a public road.
4.	Policy, Legal and Administrative Framework	Applicable PNG legislative requirements, applicable international environmental agreements and the environmental approval process.
5.	Public Consultation	Identification of stakeholders; program for public consultation and disclosure; what has happened to date and the results; go-forward program.
6.	Project Construction–Onshore	Civil works: construction access ways, facility and drilling sites and sequencing; well drilling, pipeline construction, special construction circumstances, commissioning; environmental, health and safety aspects of construction.
7.	Project Construction–Offshore	Pre-pipelay seabed preparation, methods and equipment to make landfall and to lay, stabilise, test and commission the offshore pipeline; safety for other vessels.
8.	Operations and Decommissioning	Staff requirements, training and employment; monitoring and control; inspection and maintenance, decommissioning.
9.	Onshore Environment	The existing onshore physical and biological land and water environment; subsistence uses; regeneration after disturbances.
10.	Offshore Environment	The existing offshore physical and biological environment and resource use; shipping and quarantine issues.
11.	Sociocultural Environment	People of the project area, social organisation and political representation; service and industry sectors. Project context in Papua New Guinea's economy and government; oil and gas industry governance and benefits management.
12.	Route Description	Environmental setting of project production and processing facilities and pipelines as a travelogue from Hides Ridge down to Lake Kutubu, then across and down ridges to the Kikori River floodplain, to the landfall and then offshore.
13.	Environmental Impacts and Mitigation Measures–Onshore	Impacts, proposed mitigation measures and residual impacts on the onshore environment: landform, soils, water quality and resources, aquatic ecology, biodiversity, air quality, greenhouse gases and noise.
14.	Environmental Impacts and Mitigation Measures–Offshore	Impacts, proposed mitigation measures and residual impacts on offshore habitats, water quality and resources; disturbance by construction activities to marine life; maritime safety; quarantine; waste management and emergency response; operations impacts.
15.	Sociocultural Impacts and Mitigation Measures	Economic impacts: benefit streams to land owners and governments; sector impacts; implications for representative community organisations, archaeology, cultural heritage and land use. Negotiation of monetary and governance issues between governments and landowners; proposed mitigation measures in the purview of the Operator.
16.	Cumulative and Associated Impacts	Speculative discussion of impacts arising from other parties' activities that might interact with the PNG Gas Project or that will or could use sales gas for various purposes in Papua New Guinea or Australia.
17.	Waste Management	Waste management strategy for the project.
18.	Environmental Management, Monitoring and Reporting	The project's environmental management system: the series of EMPs; organisational structure and performance standards; monitoring and reporting; summary of proposed mitigation measures.
19.	Glossary	
20.	References	
21.	Study Team	

The documents comprising the EIS's supporting studies are set out in Table 1.2.

Table 1.2 PNG Gas Project EIS – Supporting Studies

No.	Supporting Study Title	Author
1	Biodiversity Studies for the PNG Gas Project	Francis Crome Pty Ltd
2	Botanical Results from a Floristic Survey of the Montane Environments within the PNG Gas Project Area	W. Takeuchi
3	Report for an Assessment of Terrestrial Mammals for PNG Gas Project, Papua New Guinea	WWF KICDP
4	The Papua New Guinea Gas Project: A Study of Bat Faunal Biodiversity and an Assessment of Potential Impacts	Greg Richards and Associates Pty Ltd
5	A Report on the Avifauna of the Papua New Guinea Gas Project Area	Francis Crome Pty Ltd
6	Biodiversity and Conservation Status of Herpetofauna of the Papua New Guinea Gas Project Area	S. Richards
7	*Nothofagus* in Papua New Guinea: A Brief Review for the PNG Gas Project EIS	Booyong Forest Science
8	Fire and Dieback in Papua New Guinea's Forests: A Brief Review for the PNG Gas Project EIS	Booyong Forest Science
9	PNG Gas Project Marine Environment	Enesar Consulting Pty Ltd
10	PNG Gas Project 2005 Social Impact Assessment	Laurence Goldman
11	Assessment of Regeneration, Rehabilitation and Degradation along the Oil Export and Implications for the PNG Gas Project RoW	Booyong Forest Science
12	Onshore Aquatic Environmental Impacts	David Balloch & Associates Pty Ltd
13	Erosion and Sedimentation in the Lower Omati River	Moroka Pty Ltd
14	Air Quality and Greenhouse Gas Assessment: PNG Gas Project	Holmes Air Sciences
15	Noise Impact Assessment: PNG Gas Project	Holmes Air Sciences
16	Papua New Guinea Gas Project Collateral Forestry Impact Assessment	Booyong Forest Science
17	PNG Gas Project Road Background Report	Kramer Group Limited

1.8 Areas Defined

This EIS discusses the issues and impacts associated with the PNG Gas Project in a range of spatial contexts; in particular:

- The project area (also called the project impact area) is used in discursive text to refer generally to the areas affected directly or indirectly (see the introduction to Chapter 13) by the PNG Gas Project. For the purposes of impact assessment, the spatial scale of impacts is defined according to specific criteria set out in Chapters 13 and 15.

- The project footprint refers to the area physically occupied by project facilities (including pipeline RoWs and access ways).

- The regional context of the project is generally discussed in terms of the area of the Kikori Integrated Conservation and Development Program (KICDP) (see Section 9.1). The KICDP area is defined by the catchment of the Kikori River. The Kikori rises in the Tari Basin as the Tagari River, becomes the Hegigio River at the Tagari–Kondari confluence and becomes the Kikori River at the confluence of the

Hegigio and Mubi rivers. The catchment area is approximately 2,160,000 ha in size. The KICDP area was adopted by the World Wide Fund for Nature (WWF) for its conservation and development planning activities in Papua New Guinea.

2. Project Description and Schedule

The initial development of the PNG Gas Project will be constructed progressively over approximately 3 years, with further developments as required over the life of the project (Section 2.1). Like any gas development project, the PNG Gas Project involves a resource (Section 2.2), production facilities (Section 2.3) and pipelines (Section 2.4). The production facilities and pipelines are designed in accordance with principles, standards and site-specific information and incorporate safety and security measures (Section 2.5), and their construction and operation involves various supporting facilities (Section 2.6).

This chapter describes these aspects of the project, and Figure 2.1 shows the localities of the features discussed in this chapter. This information reflects the project information available as at the date of issue of this EIS and remains subject to approvals.

2.1 Schedule and Project Sequencing

The PNG Gas Project schedule, as described below and as shown in Figure 2.2, is predicated on producing 225 petajoules per year of sales gas over some 30 years (to 2040). To accomplish this, the Operator and its co-venturers plan to sequence the project construction activities to bring various sources of gas on line over the project life. The initial development provides gas production from the Hides and Kutubu fields, with first gas scheduled to be available for delivery in June 2009. The further developments contemplated add either additional wells and/or compression at Hides or sources of gas from existing oil fields and will come on stream between 2009 and 2029.

This progressive development plan is based on reservoir studies that have prioritised and scheduled production of gas reserves from reservoirs that meet any or all of the following criteria:

- The gas reserve is rich in condensate and natural gas liquids.
- The crude oil reservoir is ready for gas-cap blowdown per the depletion plan as determined by reservoir studies or reservoir stimulation.
- The wells are connected to existing or planned oil and gas processing facilities and infrastructure.

2.1.1 Preliminary Activities

The project's preliminary activities, as shown in Figure 2.2, begin with front-end engineering and design (FEED), which identifies the most likely project design and leads to a decision on the feasibility of the project. The technical FEED activities are substantially completed.

The environmental impact assessment process draws information from the FEED process and from environmental studies. The environmental impact assessment process, including approval of the EIS, is anticipated to be completed in February 2006.

Other preliminary activities that are key to the overall project schedule include negotiations of landowners agreements (scheduled to be completed in March 2006), the lender's commitment (scheduled to be completed in August 2006), and applications for new facility and pipeline licences (scheduled to be approved in August 2006). Full funding for the project is tentatively anticipated in August 2006.

2.1.2 Initial Development Activities to First Gas

Detailed engineering is scheduled to start in June 2006 and be completed by January 2008. Procurement and mobilisation for early works are scheduled to start in February 2006, with early works construction scheduled to start in September 2006 and be completed by June 2007.

Initial development activities will focus on the installation of facilities required to process rich gas, with associated sales gas production. The initial development activities currently comprise:

- Modifications to the existing Kutubu Central Production Facility and construction of a Kutubu Central Gas Conditioning Plant (scheduled to occur from January 2007 to February 2009).
- Development of the Hides gas field, including the first drilling campaign in which three wells will be drilled and three existing wells will be recompleted (scheduled to occur from late 2007 through 2009).
- Construction of a new Hides Production Facility and a glycol return line, a liquids pipeline and a rich gas pipeline between Hides and the Kutubu Central Gas Conditioning Plant (scheduled to occur from late 2007 to March 2009).
- Construction of the onshore sales gas pipeline (scheduled to occur from February 2007 to June 2009), and construction of the offshore sales gas pipeline (scheduled to occur from June 2007 to February 2009).

On the basis of the above, first gas is scheduled to occur in June 2009.

2.1.3 Further Developments

Further development activities are planned to comprise:

- Continued production from the initial development areas.
- Future processing plant modifications at the Gobe Production Facility to process gas from Gobe and a pipeline to connect this facility to the sales gas pipeline where provisions will be made for the future tie-in (by 2015).
- A second drilling campaign (from 2012 to 2013) in the Hides gas field.
- Upgrading of the Hides Production Facility to add gas compression equipment and a third drilling campaign in the Hides gas field (from 2016 to 2017) to maintain sales gas volume commitments as the Hides reservoir pressure declines.
- Modification of the Agogo Production Facility (from 2021 to 2022) to connect existing gas injection compressors to a new Agogo rich gas pipeline, which will transport gas from the Agogo and Moran fields to the Kutubu Central Gas Conditioning Plant.

- Upgrading of the Hides Production Facility with further gas compression equipment (from 2027 to 2029).

2.2 Gas Resources

Drilling in the Papuan Fold Belt has confirmed a significant oil and gas province. Past development has primarily focused on oil production, resulting in a significant undeveloped gas resource. The following sections describe the geology (Section 2.2.1), licensing history (Section 2.2.2) and production history (Section 2.2.3) of the oil and gas fields currently proposed to supply gas to the PNG Gas Project. Section 2.2.4 discusses the additional fields that may supply gas to the PNG Gas Project at a future date.

2.2.1 Geological Overview of the PNG Oil and Gas Fields

2.2.1.1 Regional Overview

The oil and gas fields involved in the PNG Gas Project are situated within the country's Southern Highlands and Gulf provinces. Each hydrocarbon field consists of a reservoir in a shape that will trap hydrocarbons and that is covered by an impermeable, sealing rock stratum.

The rugged mountainous terrain of the area is a product of recent compressional tectonics and the formation of the Papuan Fold Belt. Uplift commenced approximately four million years ago and is continuing today. Large anticlines with surface expression associated with thrust faults form the main hydrocarbon traps within the southwest-vergent Papuan Fold Belt. Such traps are generally fault dependent and can have internal segmentation. Local detachment above the reservoir adds to geological complexity. Topographic elevation can exceed 3,000 m above sea level (ASL), with local relief being as high as 1,500 m. The topographic elevation for the majority of the oil and gas fields is between 1,000 m and 2,800 m ASL.

Fields discovered to date typically have large hydrocarbon columns (in excess of 1,240 m at Hides), and most fields contain both oil and gas.

2.2.1.2 Stratigraphy

Rocks of Mid to Late Jurassic to Tertiary age dominate the drilled stratigraphic succession within the Papuan Fold Belt (Figure 2.3).

Late Jurassic marine siltstones and mudstones of the Koi-ange and Imburu formations are considered to be the source of the reservoir hydrocarbons. Source rocks within the interval contain a variable mixture of terrestrial and marine-algal organic material and are variably early mature to mature (late oil-to-gas window) within the PNG Gas Project area.

The Toro, Digimu and Iagifu reservoir units (Section 2.2.1.3) are Late Jurassic to Early Cretaceous age and represent the primary reservoirs for the PNG Gas Project.

The marginal marine to estuarine siliclastic Toro Sandstone is regionally extensive and forms the dominant reservoir unit within the fold belt. The reservoir is sealed by a thick sequence (generally greater than 1,000 m) of locally overpressured marine shales and siltstones of the Ieru Formation. The top of the Ieru Formation is marked by a regional unconformity that is a result of rifting in the Coral Sea at the end of the Cretaceous period.

Deposition recommenced in the Late Oligocene and continued through the Miocene with the formation of the thick Darai Limestone carbonate succession and the clastic deposition of offshore mudstones of the Orubadi Formation. Plate collision during the Pliocene resulted in the progressive development of the present-day fold and thrust belt that forms the hydrocarbon traps in the area. The uplift resulted in local erosion and syntectonic deposition of the Strickland Formation (a sequence of volcaniclastic sandstones, conglomerates, siltstones and basalts).

2.2.1.3 Reservoir Units

Distribution of the Toro Sandstone is widespread. Reservoir quality is generally good, although finer-grained rocks with correspondingly lower permeability and porosity occur to the northwest in the vicinity of the Hides field. The reservoir interval in this area has a gross thickness of approximately 140 m. In the Kutubu fields, the Toro Sandstone has excellent reservoir properties and an average gross thickness of approximately 110 m.

The Digimu Sandstone is well developed in the Kutubu and Moran fields. The gross thickness of the Digimu Sandstone is generally 30 to 35 m. The unit thins to the northwest and is not deposited southeast of the Iagifu-Hedinia field (part of the Kutubu fields).

The Iagifu Sandstone is the dominant reservoir at Gobe. The unit exists as a lower-quality upper unit and a good-quality lower unit with an average gross thickness of 120 m.

2.2.2 Licensing of the PNG Oil and Gas Fields

Papua New Guinea has a long history of oil and gas exploration, from the first discovery of hydrocarbon seeps in 1911 to the present day.

The fields discovered to date typically have large hydrocarbon columns and can contain oil with a significant gas cap, undersaturated gas, or saturated oil. Most fields contain both oil and gas.

The fields that are to supply gas to the PNG Gas Project are confined to the central portion of the Papuan Fold Belt and are contained within petroleum development licences (PDLs) or petroleum retention licences (PRLs) as outlined in Table 2.1 and Figure 2.4.

The Hides Gas to Electricity Project was the first gas development in the country and the first petroleum development, commencing production in December 1991. It has been producing gas from two wells in the Hides field through the Hides Gas Plant to provide fuel gas to the Porgera Power Plant located adjacent to the Hides Gas Plant. The power plant, in turn, provides power to a local mining operation.

Table 2.1 Fields and their current petroleum licences and operators

Field	Licence No.	Operator	Date Issued
Hides	PDL-1 PRL-12	Esso	27 September 1990 22 March 2003
Iagifu-Hedinia, Agogo, Usano*, SE Hedinia*, SE Mananda* (Kutubu fields)	PDL-2	Oil Search	10 December 1990
Gobe Main, Gobe 2X, SE Gobe* (Gobe fields)	PDL-4	Oil Search	24 December 1996
Moran Moran Unit**	PDL-2 PDL-5 PDL-2/PDL-5	Oil Search Esso Oil Search	10 December 1990 17 February 2001 March 2001

Sources: PNG Gas Project Gas Agreement (2002), Schedules 6 and 10, and Petroleum Retention Licence 12 issued by the Independent State of Papua New Guinea.
*Field is not currently assigned to the PNG Gas Project. **Moran field was unitised in March 2001 to optimise development. The unit is operated by Oil Search.

The Kutubu Petroleum Development Project was the first oil development in the country and began operation in 1992. Oil, water and gas from the Kutubu central fields (Iagifu and Hedinia) and liquids from the Agogo and Moran fields via the Agogo Production Facility are processed into saleable crude oil, reinjection gas and reinjection water at the Kutubu Central Production Facility. The crude oil is transported via a 260-km, DN 500, crude oil export pipeline to the Kumul Marine Terminal located approximately 50 km offshore in the Gulf of Papua. The gas is reinjected into the Kutubu fields to maintain reservoir pressure, and this reinjection has been ongoing since shortly after oil production began in 1992.

The Gobe Petroleum Development Project commenced production at the Gobe Production Facility in 1998 from the Gobe Main and SE Gobe fields. The facility produces crude oil and reinjection gas; and, as at Kutubu, the crude oil is transported via the Kutubu crude oil export pipeline to the marine terminal, and the gas is used for reinjection in the Gobe fields.

The Moran Petroleum Development Project followed. The Moran field contains high-pressure saturated oil and lacks a significant gas cap. Development drilling commenced in 2001 and is continuing. Preliminary processing of Moran oil occurs at the Agogo Production Facility, and gas from the adjacent Agogo field is used to supplement solution gas from Moran to maintain pressure in the reservoir.

2.2.3 Production History and Forecast

Following commercial studies in the mid to late 1990s, the participants in the Kutubu (PDL-2) oil fields recognised that commercialisation of the major gas reserves in the PNG Fold Belt offered the best opportunity to realise long-term, sustainable hydrocarbon resource development. The most volumetrically significant of these reserves are the Iagifu-Hedinia and Hides fields.

Table 2.2 provides a summary of the current and cumulative production histories for the main fields.

Table 2.2 Production history for the main PNG fields

Field	Number of Wells	Current Production			Cumulative Production		Technically Recoverable Reserves
		Oil (kbd)	Water (kbd)	Gas (kSm^3/h)	Oil (MBO)*	Gas (BSm^3)	Wet Gas EUR† (BSm^3)
Kutubu fields (excluding Agogo)	50 (approx.)	20	n/a	177	212	12.9	27.7
Agogo	14	2.5	1.5	47	28	4.1	10.1
Gobe fields	13	5.5	4	35	19	1.4	6.1
Moran	8 (5 producers, 3 injectors)	12	0	35	17	1	12
Hides	4 (only 2 producers)	Not applicable	0	18	Not applicable	1.3	143.2

*Million barrels of oil. †Estimate of ultimate recovery.
Source: ExxonMobil data on cumulative production to August 2002.

The gas production forecast by year from 2008 to 2038 for the Hides field is shown in Figure 2.5.

2.2.4 Future Fields and New Discoveries

Any new gas discoveries in the prospective region of Southern Highlands Province could potentially be tied into the PNG Gas Project. Where ownership and joint-venture arrangements of new developments vary from those of the PNG Gas Project, the processing of the ‘new’ gas through the PNG Gas Project’s facilities will be subject to the negotiation of relevant commercial agreements and approvals.

2.3 Production Facilities

After a petroleum resource has been identified via exploration drilling, it is put into production by drilling wells, installing a gathering system, and constructing one or more facilities to process the raw product from the wells into saleable products, such as crude oil and natural gas. This section describes these facilities.

New gas production facilities and modifications to existing oil and gas production facilities, as well as new gas wells, will be required to support the PNG Gas Project. The drilling and construction activities will occur over some 25 years.

The design life of the new facilities will be 30 years; but it is probable that, with proper maintenance and the availability of confirmed reserves, the operating life of the project will be much longer.

2.3.1 Hides

The Hides field is a large gas field that produces relatively dry gas from the Toro Sandstone. Figure 2.6 shows an overview of the existing and proposed features of the Hides area.

2.3.1.1 Hides Wells

The current plan for development of the Hides gas field for the PNG Gas Project involves the drilling of eight new wells and the workover of existing wells over three drilling campaigns from 2008 to 2017. Chapter 3 provides a discussion of the alternatives to the proposed drilling activities.

The three drilling campaigns will comprise:

- First drilling campaign (2008): workovers of existing wells and three new wells.
- Second drilling campaign (scheduled to come into production in year 3 after first gas, or 2012 based on the current project schedule): Three new wells.
- Third drilling campaign (scheduled to come into production in year 8 after first gas, or 2017 based on the current project schedule): Two new wells.

The campaigns are expected to involve four new wellpads. In addition, the recompletion of the disused Hides 3 appraisal well as a deep drilling-waste injector is being evaluated (see Section 6.5.2). If this is done, there would be an additional facility adjacent to the well for receiving and grinding drill cuttings. However, this should not require any additional land clearing.

Reservoir performance data gained during the life of the project may indicate the need to change the number or location of wells and the number of drilling locations. If such changes are required, relevant approvals will be sought from the appropriate State agencies.

Drilling Plans and Location of Wells

Eleven well sites will be developed in the Hides gas field as part of the PNG Gas Project with plans for a spare well in the event of a production-rate or reliability issue with the other wells.

The selection of a wellpad location is primarily driven by the bottomhole location, or target, of the well, which is determined by geological investigations. For the development of the Hides gas field, it is planned that, where possible, pairs of wells will be drilled from a common wellpad to access two bottom targets. This will limit the environmental footprint and reduce the site preparation costs.

Preparation of Drilling Sites

The current development plan for the Hides gas field requires the preparation of seven wellpads for the 11 wells.

Limited additional land clearing is expected to be required where existing wellpads are used. While some additional fill areas will probably be required (depending on the final drill rig footprint), these will most probably involve minor levelling of the existing wellpad.

Each new wellpad will require clearing and site preparation. The exact area of new clearing will depend on local topography and will be customised for each site to provide a wellpad that allows safe and efficient operations while limiting to the extent practicable earthworks and vegetation clearing. The total area cleared for the new wellpads will be between 6 and 10 ha.

2.3.1.2 Hides Gathering System

The existing Hides gathering system consists of flowlines from the Hides 1 and Hides 2 wells to the Hides Gas Plant (see Section 2.3.1.3).

The new gathering system to transport gas to the Hides Production Facility (Section 2.3.1.4) will consist of above-ground flowlines that will connect the wells to a buried spine line. Production from Hides 1 and 2 wells will tie directly into the new spine line, and an existing flowline will transport gas to the Hides Gas Plant.

The spine line will run in a southeasterly direction and will be buried within a (nominal) 12-m-wide right of way, nominally 7 m of which will remain clear of vegetation for the life of the project to provide an all-weather access way for completion of drilling, pipeline pigging, and inspection and operations access to the wellheads. This access way will be gated at the Hides 4 wellpad to manage access[1]. The access way will be extended to wells as and when required. When the gas field is decommissioned, the access way will be made impassable.

A DN 100 freshwater line will run above ground adjacent to the access way to provide water for drilling activities over the life of the project.

The field safety system will be designed for appropriate wellhead shut-in tubing pressure and to meet peak pressures anticipated in the gathering system, while delivering rich gas at full wellstream production via the spine line to the Hides Production Facility.

Well utilities will include control telemetry, glycol and corrosion inhibitor injection equipment, one diesel-powered generator (with battery backup) per wellpad, and an open-air drain sump. Each well will have facilities for flow, temperature and pressure monitoring, sand detection, and corrosion probes and coupons. In most scenarios that require pressure relief of the spine line, the gas will be sent to the new flare system at Hides. However, each wellhead will be equipped with a full-flow relief valve and knock-out drum that can be used if the spine line flow is obstructed and relief via the flare system is not possible.

2.3.1.3 Hides Gas Plant

The existing Hides Gas Plant, which is not a PNG Gas Project facility, is located northeast of the Hides 1 and Hides 2 wells at an elevation of approximately 1,300 m ASL. It has been producing gas from two wells in the Hides field through the Hides Gas Plant to provide fuel gas to the Porgera Power Plant located adjacent to the Hides Gas Plant (Plate 2.1). The power plant, in turn, provides power to a local mining operation. The gas plant also has the capacity to distil condensate into diesel, naphtha and residue.

Gas is expected to continue to flow to the Hides Gas Plant until at least 2012.

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[1] The management of access and activities on Hides Ridge involves customary land. All such measures will require the understanding and agreement of the customary landowners.

2.3.1.4 Hides Production Facility (Initial Development)

As explained in Section 2.1 (Schedule and Project Sequencing), initial development of the PNG Gas Project will occur over 3 years, with ongoing construction in the future. This section describes the initial development of the Hides Production Facility. Section 2.3.1.5 describes the changes that are planned to occur later to allow continued gas production at required rates from the Hides field.

Proposed Site and General Description

A possible site for the Hides Production Facility is at an elevation of approximately 1,250 m in the Tagari River valley, approximately 6.5 km north of the Hides 4 well, 10 km southeast of the existing Hides Gas Plant, and 125 km northwest of Kutubu. The site to be acquired and prepared during the initial development will be sufficiently large to accommodate the equipment required for the further developments. Figure 2.7 shows the site layout.

The Hides Production Facility will receive and separate Hides well products into gas and liquids (mostly condensate with some water and glycol). The separated rich gas and liquids will flow through two separate pipelines (Section 2.4.2) to the Kutubu Central Gas Conditioning Plant (Section 2.3.2.4). The process description, utilities, and controls required for the initial development are described in more detail below.

Hides Production Facility Process Description (Initial Development)

The Hides process flow diagram is shown in Figure 2.8.

Well fluids from all Hides wells will flow down the Hides ridge through the gathering system to the Hides Production Facility. At the Hides Production Facility, fluids will be separated into two phases (rich gas and liquids) in the three inlet separators.

Some of the rich gas will be used in the fuel gas system, which will provide fuel for various items at the facility, such as the generators.

The remaining rich gas will have glycol (to prevent hydrate formation) and corrosion inhibitor injected into it prior to being sent on to the Kutubu Central Gas Conditioning Plant via the Hides rich gas pipeline (Sections 2.3.2.4 and 2.4.2 respectively).

The liquids from the inlet separators will be sent to the flash vessel to separate additional gas from the liquids. The liquids from the flash vessel are then pumped to Kutubu through the Hides liquids pipeline (Section 2.4.2). The liquids pipeline will be of sufficient pressure to maintain the liquids above the bubblepoint (the temperature/pressure combination at which the liquids would become gas).

The rich gas from the flash vessel is sent to the flash gas compressor and compressed, which allows this gas to be combined with the rich gas from the inlet separator and sent on to Kutubu in the Hides rich gas pipeline.

To prevent corrosion and hydrates formation in the gathering system and in the Hides rich gas pipeline, a corrosion inhibitor and glycol will be injected upstream of the chokes at the wellhead locations and into the rich gas pipeline at the Hides Production Facility. The glycol and corrosion inhibitor will be stored separately in tanks at the production facility. From the storage tanks, the glycol and corrosion inhibitor for the wells will be pumped to a DN 50 glycol line, which will be buried in the same trench as the spine line. The injection of these chemicals into the Hides rich gas pipeline will also occur at the production facility downstream of the fuel gas take-off, between the gas metering and the rich gas pipeline pig launcher.

The corrosion inhibitor adheres to the inside wall of the pipeline, and no attempt will be made to recover it. The glycol will be recovered via a glycol regeneration system at the Central Gas Conditioning Plant (Section 2.3.2.4).

Free water production in the early stages of the Hides field operation is predicted to be limited; hence, initial water production will consist of condensation from the vapour phase only; this water will be entrained in the rich glycol (glycol mixed with water) and will be transported to the glycol regeneration system at Kutubu via the Hides liquids pipeline.

Hides Production Facility Utilities (Initial Development)

Power at the Hides Production Facility will be provided by two Centaur 40 generators. They will operate on fuel gas with diesel fuel as a backup. The site will also have one essential-services diesel engine generator for use when all other power supply sources are unavailable.

The flare system will consist of a free-standing flare stack, sized to flare the full wellstream production, with high-pressure and low-pressure tips and continuous purge.

Additional utilities at the Hides Production Facility will include:

- Glycol storage and distribution.
- Corrosion inhibitor and glycol injection.
- Diesel storage and distribution.
- Open drain system for managing site rainfall runoff.
- Closed drain system.
- Instrument/utility air system.
- Utility water system.

Hides Production Facility Controls (Initial Development)

A control room will be located at the Hides Production Facility capable of monitoring and controlling all the Hides wells (including adjusting the chokes) and the plant processes when operations personnel are present. The ability to control the Hides Production Facility and its associated wells from the Kutubu control room will be achieved through microwave communications. A fibre-optic cable will be buried with the spine line to control the wells from the Hides Production Facility.

2.3.1.5 Hides Production Facility (Further Developments)

As production continues, the average reservoir pressure in the Hides field will decline to a point where gas production from the wells will not flow to the Kutubu Central Gas Conditioning Plant. In year 11 after first gas (or 2020 based on the current project schedule), three SOLAR Titan 130 turbine compressors with associated scrubbers and coolers will be installed at the Hides Production Facility to meet the minimum inlet pressure requirements of the Hides rich gas pipeline.

In addition to the compressors, a fourth inlet separator will be added to handle the added volumetric flow at the lower operating pressure.

Due to the reduced operating pressure in the inlet separators, the flash vessel and the associated flash gas compressor will become redundant and will be decommissioned.

The Hides Production Facility will continue to be an unmanned facility with the same controls and communications as for the initial development.

2.3.2 Kutubu

This section describes the existing and new facilities at Kutubu. Figure 2.9 provides an overview of their locations.

2.3.2.1 Wells

The Kutubu complex comprises approximately 50 existing wells in total, including producing and shut-in oil wells, gas injection wells, and a produced water injection well. No new wells are currently planned to be drilled in the Kutubu fields for the PNG Gas Project. Associated gas is currently being produced with the oil from the existing producing wells. Some of this gas is used for gas lift, which involves the injection of a recirculated gas stream into wells to assist in reducing static pressure in the well tube, thus allowing the flow of liquids to increase. Most of the gas is currently being reinjected into a number of injection wells, with flaring where permitted. The gas from the Central Production Facility that is currently being reinjected or flared will be directed instead to the new Central Gas Conditioning Plant for processing once this facility becomes operational. Some of this gas will then be directed to the gas-lift or gas reinjection system after compression.

Two existing wells will be modified for liquefied petroleum gas (LPG) reinjection, and two wells will be modified for condensate reinjection. Produced water from the new Central Gas Conditioning Plant will be reinjected into the existing produced water injection well. The existing reinjection and gas-lift wells will continue their current functions but at increased rates.

2.3.2.2 Gathering System and Distribution System

An above-ground gathering system transports well fluids to the Central Production Facility from the Iagifu-Hedinia fields. No change is anticipated to this gathering system.

The existing distribution system for gas reinjection will be upgraded to allow for increased injection rates. A new 1.5-km, DN 100 pipeline and two 1.3-km, DN 150 pipelines will be installed to upgrade the reinjection network to accommodate 313 kSm^3/h of gas. A new 7.7-km, DN 150 LPG reinjection pipeline will be installed from the new Central Gas Conditioning Plant to the existing wells. A new 1-km, DN 150 condensate reinjection pipeline will be installed between the new Central Gas Conditioning Plant and the existing wells. The new pipelines will all generally follow existing pipeline easements. Compression at the Central Production Facility and the new Central Gas Conditioning Plant (Section 2.3.2.4) will enable flow through these pipelines.

2.3.2.3 Existing Kutubu Central Production Facilities

The Kutubu Central Production Facility (Figure 2.10) was developed as part of the Kutubu Petroleum Development Project and has been producing oil for export since 1992. The Central Production Facility:

- Receives oil, water and gas from the central fields (Iagifu and Hedinia wells).
- Receives liquids from the Moran and Agogo fields via the Agogo Production Facility.
- Separates gas from liquids using slug catchers, test separators and inlet separators.
- Dehydrates gas prior to compression for gas lift and reinjection.
- Stabilises crude oil.
- Provides crude oil storage, pumping and metering facilities for the crude oil export pipeline.
- Treats produced water for injection.

The current operation at the Central Production Facility involves production of stabilised crude oil and gas-lift gas, with reinjection of associated gas to maintain reservoir pressures and reinjection of produced water.

The existing Central Production Facility provides ample crude oil stabilisation capacity for current operations but has limited gas compression and does not have gas treatment facilities. This plant will remain in operation without significant changes after the PNG Gas Project commences operation.

2.3.2.4 Kutubu Central Gas Conditioning Plant

A new gas treatment plant (the Central Gas Conditioning Plant) to handle raw gas will be installed at Kutubu to provide sales-quality gas, stable condensate and an LPG side stream.

Site and General Description

Land in the vicinity of the existing Kutubu Central Production Facility area has been identified for the Central Gas Conditioning Plant. Figure 2.10 shows the layout of the new facilities.

The Central Gas Conditioning Plant will handle the gas and liquids from the Hides field, as well as gas from existing oil fields, and will condition the gas to meet relevant Australian sales gas quality standards. The plant will include:

- Separation, slug handling, dehydration, gas conditioning and compression equipment.
- Liquid treatment to produce a stable condensate product to be mixed with the Central Production Facility's crude oil product and an LPG stream for reinjection into wells in the Kutubu fields.
- Services and utilities required to complement the new process facilities.

Figure 2.8 provides a simplified process flow diagram of the Central Production Facility and the new Central Gas Conditioning Plant.

The new gas treatment facilities will comprise dehydration, gas conditioning using turbo-expander plant, and liquids treatment involving a debutaniser and a de-ethaniser. In the event that the liquids treatment part of the plant, condensate export, or LPG reinjection is unavailable, sales gas production must continue. To allow this, there will be suitable backup facilities for liquids handling (as shown in Figure 2.8), which will include:

- Central Gas Conditioning Plant liquids can be diverted to the Central Production Facility for processing.
- Condensate may be reinjected.

The feed from the Hides field will be provided by two pipelines. The Hides rich gas pipeline will provide the bulk of the gas, and the Hides liquids pipeline will provide the bulk of the liquids. A single multiphase pipeline to carry all the Hides fluids was ruled out by flow assurance studies, which showed that such an option would be impractical because of severe terrain-induced slugging. Performing separation at Hides will substantially reduce the volume of liquids in the gas and make the slugging problems in the Hides rich gas pipeline manageable.

The interconnections between the Central Gas Conditioning Plant and the Central Production Facility, under normal operation, are expected to be in the following areas:

- Condensate from the new gas plant will be blended directly into the crude oil storage tanks.
- Vapour from the Central Production Facility compressors may be reduced in pressure and routed to the front of the new gas treatment facilities.
- Storm water, after treatment, will be fed to the existing Central Production Facility retention pond.

Normal fuel for the plant will be sales gas, but some pieces of equipment will be designed to use diesel or kerosene as a backup. A hot oil circuit will be used to provide heat for reboilers and molecular sieve regeneration. An economic assessment will be undertaken to determine whether the use of gas turbine waste heat, with a fired heater as backup, should be considered as the prime heat source for the circuit.

Gas Separation, Dehydration, Conditioning and Compression

Hides gas will enter the Central Gas Conditioning Plant via an eight-fingered slug catcher into two high-pressure inlet separators. The gas from these separators will be combined with gas from the de-ethaniser overheads (see 'Liquids Handling' below) and pass through filter coalescers, mercury removal beds, molecular sieve beds (for dehydration) and dust filters to provide a dry clean gas for feeding to the gas dewpoint control unit.

In addition, some gas will be directed to the plant's fuel gas system, which will provide fuel gas at high pressure (3 MPa) for the gas-turbine engines and at low pressure (0.5 MPag) for the hot oil heaters, flare purges and pilots, and blanket gas.

The mercury removal beds will use a proprietary non-regenerable adsorbent. When the adsorbent is exhausted, the beds will be emptied and the adsorbent will be removed for disposal. The mercury in the adsorbent will be disposed of appropriately or recovered. Two 50% beds are provided. Bed change-out is expected to occur at about 5-year intervals.

The molecular sieve gas dehydration package comprises six vessels, four of which will be on line while two will be regenerating. They will operate on a cycle of 16 hours adsorption, four hours heating and four hours cooling. After 16 hours of adsorption, a sieve vessel becomes moisture laden and it must be regenerated. A small gas stream from the dry outlet gas stream first passes through the 'cooling' bed, and then the regeneration gas is heated by a hot oil system and is fed through the 'heating' bed where it desorbs all the water from the sieve. The moisture-laden gas is cooled, and the condensed water is collected in the plant drains. The cool gas is then compressed and recycled back to the inlet of the mercury removal bed.

Once dehydrated, the gas is fed to the gas dewpoint control unit, which achieves the required gas specification by reducing the pressure and temperature to about -30°C at 4.5 MPag.

Each train of the gas dewpoint control unit consists of a gas-gas exchanger (which uses heat from the inlet gas to warm the cold processed gas) followed by a separator, then an expander followed by a low-temperature separator. The gas from the low-temperature separator provides cooling to the inlet gas in the gas-gas exchanger and then is compressed by the compressor end of the turbo-expander unit. The gases from the three trains are combined in the sales gas compressor manifold. Four turbo-compressor sets, complete with air-cooled aftercoolers, increase the pressure to the sales gas pipeline operating conditions of 15.56 MPa and 55°C. Part of this gas can be directed to the gas reinjection system if required.

Liquids from the separators in the gas dewpoint control unit trains are collected in the de-ethaniser feed surge drum.

The slug catcher is designed for a slug of 500 m^3, dictated by the size of the slug expected from pigging. However, there is also a post-pigging ramp-up slug, and the design allows for diversion of Hides liquids from the slug catcher to the Central Production Facility during a pigging operation.

In the future, gas from the Agogo Production Facility will be mixed with the Hides gas in the inlet separators as shown in Figure 2.8.

Gas from Kutubu that is to be processed through the Central Gas Conditioning Plant will be taken from the discharge of the existing Central Production Facility reinjection compressors. This Central Production Facility 'off gas' will be fed into the raw gas stream just upstream of the mercury removal beds along with the gas from the de-ethaniser.

Treated Gas Disposition

The project is intended to provide sales-quality gas at the outlet of the new export compressors at Kutubu. Concurrently, it is intended to provide reinjection gas and gas-lift gas to the Kutubu reservoirs.

Surplus treated sales-quality gas will be directed to reinjection and gas lift.

Liquids Handling

The extracted natural gas liquids, predominantly condensate, will be mixed and sold with the stabilised crude oil from the current Central Production Facility production. The lighter components, predominantly propane and butane, will be recovered as an LPG stream, which will be reinjected for later recovery.

The hydrocarbon liquids are separated from the gas in the Central Gas Conditioning Plant at four main points: the slug catchers, the inlet separators, the cold separators and the low-temperature separator. These liquids are all commingled in the de-ethaniser feed surge drum. The separated liquid is heated in the two heat exchangers and fed to the top of the de-ethaniser, which is a reboiled absorber. Methane and ethane are stripped out along with some propane and small quantities of butanes. These overhead vapours are compressed and fed back into the raw gas upstream of the mercury removal beds.

De-ethaniser bottoms are cooled and fed to one of the middle trays in the debutaniser, which is a full distillation column. Debutaniser overheads are condensed for reflux with a draw taken as the LPG stream. Bottoms are cooled and flow to the Central Production Facility crude oil storage tanks. Debutaniser control is based on the Reid vapour pressure of the Central Production Facility crude oil and the condensate mix.

Pumps and flowlines will be installed to allow for reinjection of LPG and condensate separately into selected existing wells.

The water/glycol mixture from the incoming fluids will be recovered from the slug catcher and inlet separators for glycol recovery. Glycol regeneration for the PNG Gas Project will occur at the Central Gas Conditioning Plant. The regeneration process will remove water from the glycol, recondense the water for injection into an existing produced water injection well at Kutubu, and then return the regenerated glycol to the Hides Production Facility storage tanks via the glycol return line, which will be a DN 80 pipeline buried in the same trench as the Hides rich gas and liquids pipelines. The glycol regeneration packages will use a proprietary process to condense the vapours from the process, thereby directing almost all volatile organic compounds to the produced water system for subsequent disposal via an injection well.

Water from the glycol regeneration packages will be recovered and directed to the existing produced water system at the Central Production Facility. It will then be pumped to an existing produced water injection well. Existing water-handling equipment at the Central Production Facility is expected to meet project requirements, since Hides production will add only condensed water to the Kutubu water stream.

Pipeline and Process Control

All the project pipelines will be controlled from the existing Central Production Facility control room. Pipeline operating data from Australia, including sales flow rates and pressures, will also be displayed at the existing control room as part of the supervisory control and data acquisition (SCADA) system.

Both the Central Production Facility and the Central Gas Conditioning Plant will be controlled from the existing Central Production Facility control room. A new human–machine interface for the Central Gas Conditioning Plant will be installed in the existing control room. A fault-tolerant Ethernet system will link the existing process and fire and gas modules that control the Central Production Facility to the new safety instrument system, process control system, and fire and gas modules to be installed for the Central Gas Conditioning Plant (for further information, see Chapter 8, Operations).

PNG Gas Project operations will be monitored 24 hours a day. The facilities will be designed to allow control and monitoring (data surveillance) of the wells, process facilities and pipelines from the Kutubu control room. An auxiliary control room at the Hides Production Facility will be able to take control of the Hides Production Facility and the Hides wells as required.

The design of the integrated control and safety system will provide safe and reliable monitoring, control, and protection for PNG Gas Project facilities. Pressure, temperature, level, flow-rate and position instrumentation and control systems will be set for safety and reliability. The control systems (process and safety) will provide sufficient surveillance to safely shut down the process in the event of a major failure.

Utilities

The existing Central Production Facility utilities will continue to operate. New utility systems for the Central Gas Conditioning Plant include:

- Hot oil system for reboilers and molecular sieve regeneration.
- Instrument air at 1.0 MPag.
- Fire water (fed from the existing Central Production Facility firewater tanks and pumps).
- An essential-services diesel-fired generator.

The kerosene backup fuel system for the gas-turbine generators and produced water handling system at the Central Production Facility will also be used by the Central Gas Conditioning Plant.

One additional 3.5-MW gas-turbine generator will be added to the existing bank of three 3.5-MW generators at Kutubu to provide the main power source for the Central Gas Conditioning Plant.

Flare System

The existing Central Production Facility flare will remain dedicated to the Central Production Facility, and a new elevated flare will be installed for the Central Gas Conditioning Plant.

The new flare system will feature a free-standing stack that will possess both high pressure and low-pressure flares. A constant pilot will be required. Some flaring during commissioning and startup of the new facilities will likely be necessary until the plant comes to equilibrium. Thereafter, flaring will be an infrequent and short-duration event that will only occur during emergencies, process upsets or blowdown.

The new flare will be located some 600 m northwest of the Central Gas Conditioning Plant to provide adequate separation from other facilities.

2.3.3 Gobe

Figure 2.11 shows an overview of the Gobe Production Facility locality.

2.3.3.1 Wells

No new wells associated with the PNG Gas Project are currently planned at the Gobe fields.

2.3.3.2 Gathering System

No changes associated with the PNG Gas Project are anticipated to the gathering system that feeds the Gobe Production Facility.

2.3.3.3 Existing Gobe Production Facility

The Gobe fields (Gobe Main and SE Gobe) were developed as part of the Gobe Petroleum Development Project and have been producing crude oil for export since 1998. The field is located approximately 92 km southeast of the Kutubu Central Production Facility. The Gobe Production Facility (Plate 2.2) has been modified over time to meet operational requirements.

2.3.3.4 Modifications to the Gobe Production Facility

Future processing plant modifications at the Gobe Production Facility will be required to process gas from Gobe. A pipeline will connect this facility to the sales gas pipeline where provisions will be made for the future tie-in. Subject to the participants making a decision to proceed, this development is expected to occur by 2015.

2.3.4 Agogo

Oil from the Agogo and Moran fields flows via the Agogo Production Facility for further processing at the Kutubu Central Production Facility. This section describes the new and existing facilities at Agogo and Moran. Figure 2.9 provides an overview of their locations.

2.3.4.1 Wells

No new wells associated with the PNG Gas Project are currently planned at the Agogo or Moran fields.

2.3.4.2 Gathering System

No change associated with the PNG Gas Project is anticipated to the gathering systems that feed the Agogo Production Facility.

2.3.4.3 Existing Agogo Production Facility

The Agogo field was developed in 1990 as part of the Kutubu Petroleum Development Project and commenced oil production in 1992. The Agogo Production Facility (Plate 2.3) is located 23 km north west of the Kutubu Central Production Facility and is connected by a road network to that facility and the Ridge Camp. The Agogo Production Facility was installed as a satellite facility to the Central Production Facility, separating oil and water (from gas) for transport to and processing at the Central Production Facility.

The Agogo Production Facility has been modified to process fluids for the Moran Project and has been expanded to accommodate additional Moran needs. The current Agogo Production Facility:

- Receives oil, water and gas from the Moran and Agogo fields.
- Separates gas from liquids using test separators and inlet separators.
- Dehydrates the gas prior to compression for gas lift and reinjection.
- Pumps unstabilised crude oil and water to the Central Production Facility for further processing.

The SE Mananda oil project, which is not part of the PNG Gas Project, is currently being developed, and its production will also be processed at the Agogo Production Facility.

2.3.4.4 Modifications to the Agogo Production Facility

Agogo gas will continue to be used to provide pressure maintenance to the Moran Petroleum Development Project until the oil at Moran is depleted. Agogo and Moran gas is expected to be available to the PNG Gas Project in year 13 after first gas.

A meter, pig launcher and tie-ins to the compressor discharge lines will be installed at Agogo to tie the gas into the new Agogo rich gas pipeline (Section 2.4.4). Agogo liquids will continue to be processed through the Kutubu Central Production Facility.

2.3.5 Kopi Support Base

Figure 2.12 shows an overview of the Kopi Support Base locality.

2.3.5.1 Existing Situation

The Kopi Support Base was used as a construction camp during the installation of the crude oil export pipeline from Kutubu to the Kumul Marine Terminal and serves today as a logistical centre for materials arriving by barge that require transport to Gobe or Kumul.

The base is located on the Kikori River, approximately 30 km from its mouth at the Gulf of Papua. The site is generally swampy but has limestone ‘pinnacles’ that can be made suitable for supporting heavy equipment and rotating machinery without the need for piles.

The existing wharf facilities on the Kikori River provide three arrangements for berthing vessels:

- The main wharf, used for normal operations at Kopi for the supply of materials, consisting of a straight jetty approximately 15 m long and 8 m wide, perpendicular to the river.
- The disused, small upstream wharf.
- The downstream wharf, occasionally used for berthing of island trader vessels.

2.3.5.2 Kopi Modifications

Proposed modifications at the Kopi Support Base are shown in Figure 2.13 and described below.

Wharf Facilities

The existing wharf facilities at Kopi will be upgraded to allow the unloading of materials and equipment required for the construction of the PNG Gas Project. The proposed upgraded wharf facilities will include:

- The construction of a new 30-m-long, steel and concrete barge wharf upstream of the existing main wharf. This new wharf will be centrally located along the base's river frontage and will become the main wharf at Kopi. It will have the capacity to accommodate a travelling crawler crane on a caterpillar track with a maximum safe working load capacity of 200 t.

- The retention and refurbishment of the existing main wharf, which will become the secondary wharf. This refurbishment will be undertaken after the new wharf is constructed and becomes operational.

- Extensive modifications to the existing downstream wharf to provide a new roll-on, roll-off barge ramp at the downstream end of the laydown area.

The construction of the new wharf facilities will provide:

- Berthing of vessels at the new main wharf in all weather, seasonal, tide and water conditions in a safe and controlled manner.

- Safe access to berthed vessels on the new main wharf for 200-t mobile cranes, operating on tracks.

- Roll-on, roll-off operations in all weather, seasonal, tide and water conditions.

- Berthing of two vessels and one roll-on, roll-off vessel at any one time.

Receiving Warehouse, Laydown Area and Main Fuel Depot

During the early works stage of the project, a receiving warehouse, laydown area and main fuel depot will be constructed at the Kopi Support Base (see Figure 2.13). The main fuel depot will receive fuel from barges via a pipeline from the wharf.

The laydown area will occupy approximately 14 ha to accommodate wharf operations and materials storage. The proposed site is at the northern end of the existing laydown area and would have a river frontage of approximately 260 m.

Scraper Station

Scraper stations, or pig launchers and receivers, are installed in a pipeline to enable pigs to be inserted into and retrieved from the pipeline. Pigs are used for such purposes as cleaning the internal pipe wall, separating product batches and checking for pipeline integrity. Intelligent pigs are used to provide a record of pipe wall thickness, to detect dents or gouges that may have occurred, to detect pits caused by corrosion, and to monitor the overall physical integrity of the pipeline.

Modifications at Kopi will include the addition of a scraper station (Figure 2.14) to service the sales gas pipeline segment between Kutubu and Kopi and the segment between Kopi and the Cape York, Australia, landfall.

Future Compressor Station

A compressor station may be required during the later development of the PNG Gas Project. The future gas flowrate case considered potential ways to accommodate future increases in dry sales gas deliveries. That case would require the construction of an intermediate compression station at or near Kopi.

2.4 Pipelines and Access Ways

Pipelines are used to transport intermediate stages of processed products for additional processing or to transport saleable products to market. Rights of way (RoWs) accommodate the pipeline (usually within a trench) and any associated trench spoil. They usually incorporate or are paralleled by an access way to provide site access during construction and operations.

This section describes the proposed PNG Gas Project's onshore and offshore pipelines and their RoWs, the existing roads that will be upgraded, and the access ways that will be constructed or upgraded during pipeline construction.

In addition to the freshwater line, the glycol injection line, and the flowlines from the wells at the Hides gas field and the new LPG reinjection pipeline, new gas-lift and gas reinjection pipelines, and new condensate reinjection pipeline at Kutubu discussed above, the onshore pipeline sections comprise:

- Hides gas field to Hides Production Facility: the Hides spine line (Section 2.3.1.2 above).
- Hides Production Facility to Central Gas Conditioning Plant: the Hides rich gas pipeline, Hides liquids pipeline and glycol return line in a new RoW with new or upgraded access ways (Section 2.4.2).
- Gobe Production Facility to the sales gas pipeline (Section 2.4.3).
- Agogo Production Facility to Central Gas Conditioning Plant: the Agogo rich gas pipeline (Section 2.4.4).
- Central Gas Conditioning Plant to Omati landfall: the sales gas pipeline, part of which will require a new RoW, and new access ways or upgraded roads (Section 2.4.5.1).

The offshore section comprises a continuation of the sales gas pipeline from the Omati River landfall to Cape York, Queensland, landfall (Sections 2.4.5.2 and 2.4.5.3).

2.4.1 Pipeline and Access Way Design Parameters

2.4.1.1 Pipeline Design Parameters

The PNG Gas Project onshore pipelines will be buried for their entire length, emerging from the ground at processing facilities and at the Kopi scraper station. The onshore pipelines will be designed in accordance with the prevailing Australian Standards for gas and liquid petroleum pipelines (AS 2885.1, 2885.2, 2885.3, 2885.4 and 2885.5).

Design specifications may be subject to variation based on finalisation of commercial negotiations and detailed design. Table 2.3 summarises the proposed design parameters for each section of the pipeline.

2.4.1.2 Road and Access Way Design Parameters

The standard to be adopted for the access way from Kopi to the Hides Production Facility that will become a public road is PNG Rural Medium – Rural Class 2, designed as a two-lane unsealed road but one lane on bridges.

Road drainage structures (culverts) will be designed to accommodate design flows, with allowance for the possibility of bed load and debris restricting their flow. Scouring will be controlled at anticipated erosion-prone culvert outlets using energy dissipaters, such as rock riprap, weirs or gabions.

Buffer strips of undisturbed land or vegetation will be retained between roads and streams.

Road surfaces will be graded and shaped to conserve existing surface materials to the extent practicable without compromising the design drainage.

Where practicable and in view of conventional civil engineering considerations, for the RoW/access way engineering design:

- Roads will not be built in highly erosion-prone areas.
- Ridge-top roads will avoid the headwalls at the source of tributary drainages, as these areas are prone to erosion.
- Roads will not be located within inner valley gorges (the over-steepened slopes adjacent to streams), as these areas have a high landsliding incidence.

Suitable speed limits will be established along the RoW and access ways during construction.

The design criteria that will be used for other roads or access ways, which will not be used as public roads, are similar. These design parameters are summarised in Table 2.4. Figure 2.15 provides an overview of construction and operations access ways.

Table 2.5 summarises the work to be done on roads, bridges and culverts.

Table 2.3 Indicative pipeline design parameters

Parameter	Hides Rich Gas	Hides Liquids	Agogo Rich Gas	Sales Gas Onshore	Sales Gas Offshore to Border	Hides Spine Line	Glycol Return Line
Design life (years)	30	30	30	30	30	30	30
Length (km)	118	118	24	192	273	19	118
Diameter (DN)	550	200	250	700	700	550	50
Capacity kSm^3/h (Mscfd)	826 (700)	25 kbd	124 (105)	708* (600)	708 (600)	826 (700)	0.20 kbd
Wall thickness (mm)	18	7.8 and 8.5	6.1	17.7	16.3	19.4	4.2 and 7.5
External coating	3-layer polyethylene (3LPE)				3-layer polypropylene (3LPP)		
Mechanical protection	Rockjacket (25 mm)				Concrete weight-coating	Rockjacket (25 mm)	None
Pipe joint length (m)	12 or 18					12	12
Pipe weight (t)	27,633	5,011	961	61,368	124,088	6,355	1,624
Coating weight (t)	9,305	3,927	1,232	20,584	300,000	2,006	0
Total weight (t)	36,938	8,938	2,193	81,952	424,088	8,361	1,624

* Nominal capacity. Additional gas demand within Papua New Guinea will be met by additional compression or by looping the pipeline.

Table 2.4 Summary of access way design parameters

Parameter	Details
Design speed	70 kph (desirable) in flat and rolling terrain with less than 10-degree cross slope 50 kph in hilly terrain with 10- to 30-degree cross slope 25 kph in mountainous terrain with greater than 30-degree cross slope
Curve Radius: Preferred minimum Absolute minimum	 40 m 27 m
Curve widening (6.5-m pavement width road)	R27 to R60 - 1.2 m R61 to R90 - 0.9 m R91 to R120 - 0.6 m Greater than R121 – 0.0 m
Vertical Grades: General maximum Absolute maximum* Minimum grades in box cut	 14% 18% 3% (for drainage)
Road Width: Pavement minimum Formation minimum Bench minimum	 6.5 m 8 m (Road only) 10 m (Road Only); wider bench required where pipeline and road run together.
Cross-fall on Pavement and Shoulders	4%
Batter slopes (Indicative only): *Cut slopes* Limestone Volcanic rocks Volcanic clays *Fill slopes* Heights 0.5m or less Heights greater than 0.5m	 0.25H:1V to 0.5H:1V 0.5H:1V 1H:1V Bench height 15 m max. 4H:1V 1.5H:1V
Pavement Depth (indicative only): Rock subgrade Clay subgrade	 300 mm thick 500 mm thick
Design Loading: SM 1600 Loads Standard vehicle loading	 AS 5100.2 (2004) T44
Maximum Equipment Dimensions: Length Width Height Equipment Weight	 18.0 m 3.8 m No set height, but preferably less than 4.5 m. Maximum overall weight is 73 tonnes nett, which includes equipment, packaging, cradles, etc. The low loader is in addition to this weight.

*May reach 20% in steeper sections of the RoW/access way, e.g., between the Hides 4 well and the Hides Production Facility.

Table 2.4 Summary of access way design parameters (cont'd)

Parameter	Details
Drainage: Culverts min size Floodways Bridges	 600 dia. Protected for major flood Locate above maximum flood
Guard Rails	Generally excluded except in locations of high risk.
Bridges: Width Loading	 4.2 metres, kerb to kerb (extra wide single) T44 or abnormal trucks: as detailed in standard; SM 1600 loads as per AS 5100.2 (2004).
Design Life: New bridges Existing bridges	 30 years To be determined

Table 2.5 Summary of proposed new and upgraded access ways or roads, bridges, and culverts

Access Way or Road Section	Access Way or Road length (km)		Truss Bridges		Beam Bridges		Culverts		Nature of Construction
	Exist	New	Exist	New	Exist	New	Exist	New	
Kopi - Samberigi turnoff	46.3	3.0	2	1	14		31	62	Minor upgrade of existing road
Samberigi turnoff - Gobe	27.4		1		2		4	2	Minor upgrade of existing road
Gobe to Mubi River	18.0			2		6	2	20	Major upgrade of existing track
Mubi River to KP 55		14.6						28	New road on new route
KP 55 to Kutubu	55.0						38	34	Major upgrade of existing track
Kutubu Central Production Facility bypass		1.5						4	New road on new route
Kutubu to Ridge Camp	0.0						0		Minor upgrade of existing road
Ridge Camp bypass		2.0						4	New road on new route
Ridge Camp to Moro	12.0						70	2	Minor upgrade of existing road
Moro to Homa	45.7		5				98		Minor upgrade of existing road
Homa to Idauwi		54.3		6				107	New road on new route
Idauwi to Hides Production Facility	18.3		3				25		Minor upgrade of existing road
Hides Production Facility to Hides 4 well	6.0						7		Minor upgrade of existing road
Hides 4 well to Hides 1 well		20.0						10	New access way on new route
Totals	228.7	95.4	11	9	16	6	275	273	

2.4.2 Hides Production Facility to Kutubu Central Gas Conditioning Plant

Separate gas and liquids pipelines are proposed between the Hides Production Facility and the Kutubu Central Gas Conditioning Plant to transport produced rich gas and liquids. The DN 550 rich gas pipeline and the DN 200 liquids pipeline will be constructed of API 5L X-70 carbon steel. The two pipelines will generally be buried in a common trench with the glycol return line (discussed in Section 2.3.1.4 above) to reduce land clearing requirements.

These pipelines will require a new RoW and construction access way for approximately 13.1 km between kilometer post (KP) 0 (the proposed Hides Production Facility) and KP 13.1 (a point some 10 km south of Idauwi). At KP 13.1, the proposed route for these pipelines turns south, and a further new RoW and access way will be constructed, generally parallel with one another, but with occasional deviations, to join an existing road approximately 2 km south of Homa. From that point, the pipelines' RoW generally follows the existing road, which will be upgraded to allow construction access between Homa and Moro.

The new access ways will be 8 m wide and will generally be located within the 21-m wide RoW to support construction of the pipelines, as well as project logistics and continuing operations.

The sections of the pipelines that will be buried within some parts of the Moro to Ridge Camp road will require special construction techniques to traverse existing buried or above ground pipelines and to allow the passage of traffic during the installation of the pipelines (see Section 6.4.3.5). Currently, two water crossings are proposed for horizontal directional drilling in this area (see Section 6.4.3.3), one at the Tagari River and one at the Bakari River.

2.4.3 Gobe Production Facility to Sales Gas Pipeline

Future processing plant modifications at the Gobe Production Facility will be required to process gas from Gobe. A pipeline will connect this facility to the sales gas pipeline where provisions will be made for the future tie-in. Subject to the participants making a decision to proceed, this development is expected to occur by 2015.

2.4.4 Agogo Production Facility to Kutubu Central Gas Conditioning Plant

A further development planned is a rich gas pipeline, constructed of API 5L X-70 carbon steel, which is anticipated to be installed from the Agogo Production Facility to the Kutubu Central Gas Conditioning Plant. It will be buried at a nominal depth of 750 mm and will have the capacity to transport gas from the Agogo and Moran fields.

The buried gas pipeline is anticipated to generally follow the existing above-ground Agogo crude oil pipeline RoW and road and then the Moro road and will be laid in a trench within the two roadways. Thus, no additional clearing of vegetation will be required. All water crossings for this pipeline are minor.

Agogo gas will continue to be used to provide pressure maintenance to the Moran Petroleum Development Project for some years, and construction of this pipeline is planned 11 years after first gas.

2.4.5 Central Gas Conditioning Plant to Australia

A 625-km, DN 700 sales gas pipeline, constructed of API 5L X-70 carbon steel, will be installed from the Kutubu Central Gas Conditioning Plant to Australia. It will be buried at a nominal depth of 750 mm (1,200 mm if within or crossed by an access way) onshore and will transport sales gas from Kutubu to Australia. Scraper stations will be installed at the Kutubu end of the pipeline and at the Kopi Support Base for cleaning and inspection of the pipeline. The three sections of this pipeline are discussed below.

With the current configuration of compression at the Central Gas Conditioning Plant, the onshore and offshore sales gas pipeline system is expected to operate in a range of 708 to 760 kSm^3/h, dependent upon downstream pressures and sales gas offtake rates. The onshore section from the Central Gas Conditioning Plant to Kopi has a maximum capacity of approximately 1,500 kSm^3/h (assuming additional compression and expansion at the Central Gas Conditioning Plant and a low-pressure offtake for PNG sales at Kopi). The maximum flow rate for the offshore section, following the addition of booster compression at Kopi, is calculated to be approximately 895 kSm^3/h.

2.4.5.1 Central Gas Conditioning Plant to Omati River Landfall

This approximately 192-km section of the sales gas pipeline commences at the Kutubu Central Gas Conditioning Plant and will generally follow the existing RoW of the crude oil export pipeline and, south of Gobe, the existing road between Gobe and Kopi (which parallels the existing RoW) to near Kopi where the proposed pipeline turns south through a new 34-km-long RoW to the Omati River landfall. Some existing roads will be upgraded, and some new sections of access way will be constructed.

The existing crude oil export pipeline government easement has a 40-m width (20 m either side of the oil pipeline centreline) and incorporates the existing RoW and has an access way along the majority of its length. From Kutubu to Gobe, the gas pipeline will generally be to the east of the existing access way, on the other side of the access way from the existing crude oil export pipeline. In some areas, the pipelines will both be located on the same side of the access way, with the sales gas pipeline either between the access way and the crude oil export pipeline or between the oil pipeline and the edge of the easement.

Deviations from the existing RoW or easement will be needed in certain sections either to accommodate the greater turning radius of the larger-diameter gas pipeline or where terrain difficulties prevent the use of the existing RoW or easement for the new pipeline. For example, there may be deviations in the Mubi River area to avoid the swamp area to the east of the Mubi River and the steep area to the west. As another example, approximately 10 to 20 km of the existing RoW has a restricted working width due to local topographic and environmental conditions. These ‘pinch spots’ will require side cuts and through cuts and the removal of considerable volumes of soil to widen the existing RoW. These deviations will involve vegetation clearing, but they will be adjacent to the existing RoW or will follow the new sections of access way to be constructed.

The Central Gas Conditioning Plant to Omati River section has several significant waterway, road and pipeline crossings that will require special construction methods (see Sections 6.4.3.3 and 6.4.3.5). The significant waterway crossings of the pipeline that are currently proposed for horizontal directional drilling in this area (see Section 6.4.3.3) are:

- Mubi River.
- Wah River.
- Kikori River.
- Utitu Creek.

From Kopi, the last 34 km will require a new construction RoW and a temporary construction access way. In this section, the pipeline will run in a southerly direction to the Omati River landfall, traversing limestone ridge and swamp terrain of the Kikori-Omati delta. The final 12 km of this section will require special swamp construction techniques (see Section 6.4.3.4).

2.4.5.2 Omati River Landfall to PNG–Australian Border

This 273-km section of the sales gas pipeline will be installed offshore by a pipelaying vessel, as described in Chapter 7 (Project Construction (Offshore)). Construction at the Omati River landfall will require the special techniques described in Section 7.3.5. Provision for the installation of an offtake valve for potential PNG petrochemical development may be included (Section 3.4.3).

2.4.5.3 PNG–Australian Border to Australian Landfall

A further 160 km of pipeline will be installed across Torres Strait to a landfall on Cape York Peninsula in Queensland; however, this section of the sales gas pipeline is beyond the scope of the PNG Gas Project and is not covered by this EIS. It will be owned and operated by the AGL Petronas Consortium.

2.4.6 Common Pipeline Permanent Infrastructure

The pipelines will require the following permanent infrastructure, which will be located either within or adjacent to the RoWs:

- Mainline valves.
- Check valves.
- Vents.
- Cathodic protection impressed current facilities and test points.
- Communications facilities.
- Pipeline route marker signs.

2.4.6.1 Mainline Valves

Mainline valves enable sections of a pipeline to be isolated for maintenance or, in the event of a serious leak or rupture, to limit the amount of gas or liquid released.

The Hides liquids pipeline will have four mainline valves spaced approximately equidistantly along the pipeline. The Central Gas Conditioning Plant to Omati portion of the sales gas pipeline will have one mainline valve at the Kopi scraper station. No other pipelines will have mainline valves installed.

The mainline valves will be buried adjacent to the RoWs, with only the actuator and its associated equipment visible above ground. Mainline valve sites will be security fenced.

Because of the remoteness of the pipelines, the mainline valves will be capable of operation by remote control in case of a pipeline leak or rupture.

2.4.6.2 Check Valves

Check valves prevent the medium being carried in a pipeline from flowing backwards.

The Hides liquids pipeline will have one check valve located upstream of Moro to prevent the backflow of liquids from the Central Gas Conditioning Plant. This valve will be buried with no above-ground appurtenances and will not be security fenced.

2.4.6.3 Vents

Vents are used to evacuate the pipeline contents and allow piping to be depressurised prior to maintenance or in an emergency situation.

A manual vent system will be installed at the Hides Production Facility for the spine line. The Hides liquids pipeline will only have a vent installed at the Kutubu end, as the Hides Production Facility will not have sufficient liquids-handling capacity to allow venting there. Vents will be installed at the start and end of all other pipelines and at Kopi on the sales gas pipeline. Rich gas pipelines and gathering systems will be vented to facility flares. The vents on the sales gas pipeline will vent to atmosphere.

2.4.6.4 Cathodic Protection Impressed Current Facilities and Test Points

Cathodic protection impressed current facilities prevent corrosion of the pipe by maintaining a pipeline at a negative electrical potential (less than 1 volt). Cathodic protection test points allow monitoring of the effectiveness of the corrosion protection system.

Cathodic protection impressed current facilities will be installed at the ends of each pipeline and along the pipeline at above-ground facilities. The test points will be installed at 2- to 3-km intervals on all pipelines.

Where the sales gas pipeline is close to the existing crude oil export pipeline, it is probable that both lines will share the existing cathodic protection facilities. The impressed current for this pipeline will come from facilities at the Central Gas Conditioning Plant and the Kopi Support Base. Solar-powered units with diesel-generator backup will be used at other sites.

During construction, sacrificial magnesium anodes will provide temporary cathodic protection of the pipelines via electrolysis.

2.4.6.5 Communications Facilities

Additional control and communications facilities to activate valves will be located with the mainline valves. The existing communications towers of the crude oil export pipeline will be used by the PNG Gas Project.

2.4.6.6 Pipeline Marker Signs

Pipeline marker signs will be installed so that the community will be aware of the pipeline location and to help avoid possible interference from third-party excavation. The signs will be installed to be inter-visible. This translates into an expected separation of between several hundred metres to several tens of metres between markers. Pipeline marker signs will not be able to be used in swamp conditions. (Plate 2.4 shows a typical sign.)

2.5 Design of Production Facilities and Pipelines

2.5.1 Project Development Principles

Proven engineering design and management principles underlie the project development: these include an understanding of site conditions, adherence to codes and standards, and implementation of quality assurance procedures.

This section describes these principles, which constitute the minimum requirements for engineering design, construction and management aspects of the project. Adherence to these principles will ensure that the range of environmental constraints identified is properly considered and that the environmental effects of project construction are limited.

The design, construction and operation of the project will be conducted in a manner that:

- Protects the safety, health and security of project construction and operations workers, customers, the public and other involved parties.
- Maintains environmental integrity.
- Complies with applicable laws and regulations.
- Applies sound engineering and applicable best practices.
- Focuses on correct execution with minimum rework.
- Maximises the PNG content consistent with the project objectives.

Inspection, assessment and reporting will ensure that the project team adheres to these general principles.

The project objectives and the strategies to achieve them are listed in Table 2.6 below, in order of priority.

Table 2.6 Project objectives and strategies

Objective	Strategy
Safety	Give the highest priority to personal safety.
Physical and Social Environment	Perform project design and construction work in a manner that meets the appropriate environmental and socio-economic performance expectations in Papua New Guinea.
Quality	Provide installed facilities that meet specified project requirements.
Reliability	Provide installed facilities capable of safe, environmentally sound, cost-effective, lifecycle operations.
Cost	Deliver a reliable product at or below the appropriated cost.
Schedule	Produce gas as early as possible commensurate with construction of reliable facilities at a competitive cost.
PNG Content	Foster development of PNG-based industry without unduly impacting schedule.
Co-venture Relations	Foster an effective, productive relationship with the PNG Gas Project sponsors.

2.5.2 Site Investigations

Initial and ongoing site investigations and data analyses are being or have been undertaken to further detail environmental constraints on project design, construction and security.

Subjects investigated for the onshore segment of the project included:

- Meteorological conditions, including storms and climatic extremes.
- Geotechnical investigations for soil and terrain conditions, particularly in areas where trenching and road building will be difficult, such as on steep or unstable slopes and in swamps.
- Geotechnical investigations to determine the presence of geohazards due to seismic disturbance or vulnerability.
- Resistivity testing as input to the design of the cathodic protection systems for the pipelines.
- Surface water flows and flooding, particularly as they relate to bridge and culvert design.
- Groundwater, to the extent that it was readily apparent and could be reported on.

Subjects investigated for the offshore segment of the project included geotechnical and geophysical investigations of seabed conditions, including sediments. Video images and grab samples of the seabed were also taken to provide information about the seabed environment.

2.5.3 Design Standards

The design of the PNG Gas Project and its associated facilities and infrastructure can be categorised as conforming to the following design standards:

- The standards and constraints placed on design by local conditions, including environmental, economic and engineering considerations. These constraints have been factored into the design of the project.
- The standards associated with the design, manufacture and installation of the individual components of the production facilities, pipelines and infrastructure. The suppliers of the individual components will be required to meet these standards.
- The standards imposed by regulatory authorities. These standards represent best practice for the industry, and may include international standards.

A list of the almost 800 design codes and standards that will be applied to the project is provided in Attachment 1.

The PNG Gas Project will adhere to these or comparable design standards through front-end engineering and design (FEED), detailed design, construction, and operations and will comply with the project's safety, health and environment systems. The design, construction and operation of the PNG Gas Project, as outlined in this project description, incorporate these considerations and standards.

2.5.4 Safety and Security

All of the PNG Gas Project facilities and pipelines will incorporate appropriate safety and security measures. The following aspects of safety and security are described in this section: site layout, site security, fire detection and fire fighting, gas detection, plant emergency shutdown systems and alarms, and pipeline leak detection.

2.5.4.1 Site Layout

The sites of the PNG Gas Project facilities, such as the Hides Production Facility and the Kutubu Central Gas Conditioning Plant, will be laid out based on inherent safety considerations and for optimal land consumption economy, with appropriate loss prevention systems and the provision of adequate space for:

- Normal operation and maintenance.
- Separation of plant and support (administration) areas.
- Emergency response actions.
- Evacuation.

2.5.4.2 Site Security Systems

A contracted landowner security company currently provides 24-hour security coverage of the major facilities at Kutubu. This comprises entry and exit control at facility gates (Moro Airfield and Ridge camps, Central Production Facility and Agogo Production Facility), as well as the access points to the in-field roads. In addition, dog patrols guard aircraft and warehouse facilities at night. The Kutubu control room provides radio and telephone monitoring 24 hours per day.

The Kopi Support Base has similar security systems.

Similar arrangements are envisaged for the PNG Gas Project to protect mobile plant, construction materials and other equipment during pipeline construction and to protect the new facilities during operations.

2.5.4.3 Fire-Detection and Fire-Fighting Systems

The Central Gas Conditioning Plant at Kutubu and the Hides Production Facility will have appropriate fire-detection and fire-fighting systems as dictated by a hazard evaluation and relevant industry standards. The primary strategy for the facilities is for an inherent safety approach that reduces the potential for accident events to occur; this applies to layout, separation, segregation, isolation and blowdown, and prevention of ignition. This is achieved by applying prudent plant layout and safety design principles and maintaining sensible operations practices.

Hazard evaluations identify the need for mitigation measures, including fire and gas detection systems and active/passive fire protection systems. Fire-detection systems may include flame detectors, smoke detectors, heat detectors, fusible plug loops or a combination of these where appropriate.

The fire-fighting system for the Central Gas Conditioning Plant will include the following active elements:

- Fire water storage systems.
- Fire pumps (2 x 100%).
- Fire monitors (fixed and oscillating).
- Fire hydrants and hoses.
- Deluge and foam systems.
- Automatic gaseous extinguishing systems for electrical areas.
- Water-mist extinguishing systems for turbines and generators.
- Manual (hand-carried) extinguishers.

The fire-fighting system for the Hides Production Facility will include:

- Automatic gaseous extinguishing systems for electrical areas.
- Water-mist extinguishing systems for turbines and generators.
- Manual (hand-carried) extinguishers.

There is no active plantwide fire-fighting system at the Hides Production Facility. Escalation of a fire event is controlled through blowdown or shutdown and equipment segregation.

Well sites will include fire detectors at the wellheads and fire detection equipment in the wellpad local equipment rooms.

2.5.4.4 Gas Detection

The Kutubu Central Gas Conditioning Plant, the Hides Production Facility, and all wellheads will have appropriate gas detection systems as dictated by the hazard assessment and relevant industry standards. The gas detectors will be monitored continuously.

Gas-detection systems may include point detectors, line of sight detectors, ultrasonic detectors or a combination of these where appropriate.

2.5.4.5 Plant Emergency Shutdown Systems and Alarms

The Kutubu Central Gas Conditioning Plant, the Hides Production Facility, and all wellheads will have process and emergency shutdown systems activated either automatically or manually.

Automatic systems include:

- Centrally controlled, computer-based systems.
- Local controllers.

Manual systems include:

- Manual call points activated by operators.
- Manual emergency shutdown pushbuttons.

Process and emergency shutdowns for pipelines will be completely manual, activated from the Kutubu control room.

The Central Gas Conditioning Plant, Hides Production Facility, and wellheads will have fire- and gas-detection systems (see Sections 2.5.4.3 and 2.5.4.4). The executive actions for a confirmed fire or confirmed gas leak will be different depending on whether the site is manned (Central Gas Conditioning Plant) or unmanned (Hides Production Facility and wellheads).

- A confirmed fire at Hides will cause a facility shutdown and blowdown.
- A confirmed gas leak at Hides will cause a facility shutdown and blowdown after a defined time delay.
- A confirmed fire at the Kutubu Central Gas Conditioning Plant will cause a facility shutdown.
- A confirmed gas leak at the Kutubu Central Gas Conditioning Plant will cause a facility shutdown.
- A fire at a wellhead will cause a well shutdown.
- Gas detection at a wellhead will cause an alarm only.

Confirmed fire or gas detection means that at least two detectors in an associated area detect either a fire or gas leak.

For potentially hazardous process excursions, there will be at least one level of pre-alarm prior to shutdown of the system or initiation of the response system.

A cause-and-effect matrix will be prepared to ensure that all inputs to, outputs from and actions by the shutdown system are formally recorded, evaluated and implemented.

2.5.4.6 Pipeline Leak Detection

Hides Gathering System

The gathering system flowlines and spine line upstream of the Hides Production Facility will be fitted with safety shutdown valves that will be activated on:

- Low pressure in the event of flowline or spine line failure.
- High pressure in the event of a downstream shut-in or blockage.

Rich Gas Pipelines, Hides Liquids Pipeline and Sales Gas Pipeline

The rich gas pipelines, the Hides liquids pipeline and the sales gas pipeline will have pipeline integrity monitoring systems installed that monitor inlet and outlet pressures and pipeline operating pressures. Possible leaks can be identified from this data and investigated.

2.6 Supporting Facilities

Construction and operation of the PNG Gas Project production facilities and pipelines will require the use of a variety of new and existing supporting facilities, such as transport and accommodation facilities, storage areas, and water, power, and telecommunications facilities.

Preconstruction activities will make limited demands upon existing accommodation, vehicle hire, fuel supply and airport facilities.

The demands on supporting facilities will be greatest during the initial pipeline construction phase, although landfall construction activities will be essentially self-sufficient with only fuel supply for vehicles and airport facilities for transport of construction workers required. Offshore construction crew changes will be via small vessels or helicopter, and the crew members will be accommodated on the vessels.

In the operations phase, demands are significantly reduced, being restricted primarily to the provision of accommodation and fuel during routine maintenance, monitoring or remedial work in and around the RoW. Operations personnel will usually be accommodated at the Kutubu Ridge Camp, Kopi Support Base, Moro Airfield Camp, or Nogoli Camp near the Hides Gas Plant.

2.6.1 Construction

2.6.1.1 Transport Facilities

The tonnage of pipe, equipment and materials to be transported during construction is approximately:

- Onshore: just over 500,000 t.
- Offshore pipeline: 510,000 t.

In addition, personnel, supplies and equipment will be transported from a number of points of origin to the project area by sea, road and air (Figure 2.16), as follows.

Roads, Access Ways and Bridges

Roads and access ways will be required for the heavy haulage of pipe, materials, fuel, equipment and supplies. In addition, onshore construction workers will be transported to and from the workplace each day by buses or four-wheel-drive vehicles.

The two main overland routes within the project area are the Highlands Highway and the crude oil export pipeline access way.

The Highlands Highway provides good vehicle access from Lae and Madang to Poroma. The Poroma-to-Moro access road was opened after the Kutubu Project was completed and currently supports all operations in the Kutubu and Hides areas.

Cargo arriving at Kopi (including fuel) will be consolidated and moved by road along the crude oil export pipeline access way. The access way has been upgraded from Kopi to the Gobe Project turnoff at KP 82, but the limitations to this route include:

- Barge access to Kopi is limited by water depths in the delta and by constraints on traversing river sections where the crude oil export pipeline has been installed.
- Numerous log bridges and a small number of steel-truss bridges beyond KP 82 were installed during oil pipeline construction and are now in poor condition. Many of these have been replaced or upgraded and further upgrades are planned or expected.
- The Kaiam crossing was furnished with a ferry to support the Gobe Petroleum Development Project, but the ferry that served the Mubi River crossing while the oil pipeline was being constructed has been demobilised. New bridges will be constructed for these two major river crossings.
- The portion of the oil pipeline access way between the Gobe Project turnoff and the Mubi River has not been used or serviced since the oil pipeline was completed. This portion will be upgraded.
- Two sections of the oil pipeline access way are very steep. The first is just north of the Mubi River and extends for about 5 km north of the Mubi valve station. The second runs up the Iwa Range from the Ai'io valve station near Hedinia Village (oil pipeline KP 10). A new access way for the gas pipeline will be constructed to avoid the steep section near the Mubi River. However, this does not appear to be an option in the steep section from Hedinia to the Kutubu Central Production Facility. Tow tractors may have to be used for heavy haulage up this section.

Ports

Cargo for the Kopi area (including fuel and local purchases) will be transported by sea-going, self-propelled barges from Port Moresby to the Gulf of Papua, and then through the Kikori River delta to Kopi.

In addition to the wharf facilities at Kopi (see 'Wharf Facilities' in Section 2.3.5.2), the following ports may be used during construction.

The primary PNG port of entry for ocean shipments will be in the Port Moresby area with some freight coming in at Lae. Ports will be used to receive or transport line pipe, equipment and materials for both offshore and onshore construction. International commercial freight services currently operate at Port Moresby and Lae. Ships also call with reasonable frequency from Australia, New Zealand, Japan and Singapore. European shipping services also call, although less frequently.

Madang is another small PNG port that could serve the project area, with the potential to handle occasional small cargo shipments.

Stevedoring in PNG ports is handled by private companies licensed by the PNG Harbours Board and generally is associated with the major shipping companies.

Cargo destined for the offshore pipelaying vessel will consist mainly of line pipe and consumables. Consumables for offshore pipelaying will be sent by general supply vessels to the offshore spread on a regular basis. It is currently anticipated that these will operate out of Port Moresby, Thursday Island or Cairns, depending on the location of the offshore spread. Daru is also well-located to support the offshore work. Corrosion- and weight-coated line pipe for offshore pipeline construction will be transported from stockpiles located at the ports where the pipe has been coated, then will be loaded onto barges and delivered to the pipelaying vessel for welding and laying.

Other ports local to the pipelaying vessel's area of operation will be used for the offloading and storage of supplies, such as food, fuel and water, and for maintenance and technical support of the pipelaying vessel.

Airports, Airfields and Heliports

International air freight services operate to Port Moresby and Mt Hagen. The primary PNG port of entry for air shipments will be Port Moresby. Onward transport will be by local charter aircraft or a combination of sea and land transport.

While it is not planned as a regular route, as a contingency, some cargo from the port at Lae will be road-hauled to the airport at Nadzab for onward air freight to Moro Airfield.

Most expatriate project workers will enter Papua New Guinea at Port Moresby's Jacksons International Airport, which receives regularly scheduled commercial flights. Expatriate project workers may also fly directly from Cairns to Moro Airfield via chartered flights.

When required, PNG-based skilled workers will be flown from Port Moresby or Mt Hagen to Moro Airfield on company chartered aircraft.

In-country air travel into the project area will be by chartered aircraft to Moro Airfield, with further air travel via helicopter to Kopi, Gobe or Hides.

Light helicopters will be used for emergencies and urgent transit of onshore personnel under unforeseen circumstances, such as medical evacuations or access track or airstrip closure due to flooding.

Heliports for offshore construction crew changes, for medical emergencies or to courier light cargo will be required to handle helicopters. Suitable locations exist at Daru, Kikori and Thursday Island, and their use will depend on where the offshore spread is operating. Transiting offshore personnel will be transferred at these locations.

2.6.1.2 Accommodation Facilities

Drilling Camps

An accommodation camp for the rig crew is proposed to be established at the site of the disused Hides 3 wellpad. The camp will be designed to limit the overall impact of drilling operations on Hides Ridge while ensuring a safe and efficient operation. The camp will include such facilities as sleeping quarters, a kitchen and dining area, recreation room, first aid room, ablutions (toilets and showers), an electricity generator, a water tank, fuel tank, sewage treatment plant (for sewage and grey water), lighting and car parking. The camp will be constructed to house between 75 and 100 people and will be present during the three drilling programs. Use of the existing Hides 3 wellpad site will reduce the additional land clearing required for the camp. Alternatively, the camp could be located at the Hides 4 wellpad for work at that end of the field.

For the first drilling program activities, the camp will be in place from the last quarter of 2007 until the second quarter of 2009.

Onshore Construction Camps

During onshore construction, construction camps will be established to accommodate the workforce. Some of the camps will use the sites of previous construction camps established for the Kutubu and Gobe projects. All camps will be self-contained, with full catering services, sleeping quarters, ablution facilities, first-aid facilities, maintenance workshops, fuel and equipment storage, offices, water supply and sewerage systems (Figure 2.17 shows an example camp layout). Accommodation for the construction management staff will most likely be at the existing Moro Airfield Camp, which has its own water source, sewerage and wastewater disposal facilities. The existing camps (Ridge, Nogoli, Moro Airfield and Kopi camps) will be expanded in a fashion that is similar to that shown for the Ridge Camp in Figure 2.18.

New moveable line camps will be established at suitable locations along the RoWs. They will be occupied sequentially by first the road and bridge construction crews and then the pipeline crews. These camps will be sited to limit driving time to the workface. Forest loss and edge effects will be limited to the extent possible when clearing land for these camps.

Line camps are expected to be located at the Hides Production Facility site (Hides Camp), at Idauwi (Idauwi Camp), east of Angore (Angore Camp), at Homa (Homa Camp), northeast of the existing Moro Airfield Camp (Moro 2 Camp), southeast of the Kutubu Central Production Facility (Kutubu Camp), at the KP 41 laydown area (Mubi River North Camp), at the Gobe laydown area (Gobe Camp), and near the existing Kopi Camp (Kopi Camp). The Kopi, Moro 2, Homa and Hides camps are unlikely to be relocated. The Gobe and Mubi River North camps can be relocated to Angore and Idauwi.

Figure 2.19 shows the locations of the existing and proposed construction camps, and Table 2.7 shows the estimated number of occupants.

Offshore Construction Crew Accommodation

During offshore pipeline construction, the support vessel crews and the pipelaying crew will be accommodated entirely on the vessels.

Table 2.7 Construction camps and their estimated number of occupants during initial development

Camp	Expansion	Early Works	Roads and Bridges Construction	Pipeline Construction	Facilities Construction
Existing					
Nogoli	30				
Moro Airfield	50				
Ridge Camp	72				
Kopi	30				
New					
Hides					400
Idauwi			500		
Angore				750	
Homa			500	750	
Moro 2			500	750	
Kutubu					700
Mubi River North		500	500	750	
Gobe		300	500	750	
Kopi		300	500	750	150

2.6.1.3 Water Supply and Treatment Facilities

During construction, water will be required for potable and domestic water at the construction camps and sites, for construction activities (such as making concrete), and for hydrotesting.

This water will be sourced, in the main, from nearby watercourses. If the capacity of the proposed water source to continue to provide adequate flows to support village water use requirements and to sustain aquatic life would be threatened, then an alternative water source will be sought.

Potable and Domestic Water

At previously used construction camps, the previous water supply and treatment facilities will be reinstated. Sewage and grey water will be directed to the camps' sewage treatment plant. Water for line camps will be sourced from nearby watercourses. Where water is not potable, it will be treated and stored for reticulation within the camp using automatic pressure pumps.

Pipelaying vessels have large water-storage capacities and high-volume distillation units. These will provide all fresh water requirements of the crew during pipelaying operations.

Construction Water

In addition to water at the accommodation sites, the construction of the Central Gas Conditioning Plant at Kutubu and the Hides Production Facility will require small amounts of fresh water for concrete foundation work and other construction activities. This will be sourced from local water sources. A dust-control contractor will be employed as required during construction; water for this activity will come from the water storage tanks at the construction camps.

Hydrotesting

Water for hydrotesting of the onshore pipelines will generally be drawn from convenient rivers. The following have been provisionally identified: Kikori River at KP 118, Wah River at KP 96, Mubi River at KP 65, and Ai'io River at KP 20 and the Tagari River for the Hides pipelines. The Kutubu Central Production Facility will also provide water for hydrotesting. Estimated hydrotest water volumes are shown in Table 6.2 in Section 6.4.4.2.

See Section 7.4.2 for information on hydrotesting of the offshore pipeline.

2.6.1.4 Quarries

Suitable rock and borrow material will be required to upgrade or construct the access ways. This material will generally be available from existing quarries used for oil pipeline construction, but some potential new quarry sites have been identified. Any new quarries excavated outside the RoW are not likely to be larger than 1.5 ha in area and will be approved by the landowners prior to their use by the project.

Grade rock will also be required to be crushed and screened for use as concrete aggregate. An existing quarry near Kutubu will provide these requirements in this locale. A new quarry site will be required in the Hides area as the existing Hides quarry cannot provide material of the required grade. No quarries are anticipated to be located above the Hides 4 well.

2.6.1.5 Power

All local construction power at camp sites, field workshops and construction sites will be provided by portable diesel-driven generator sets, as follows:

- 10 x 500-kW generators.
- 14 x 200-kW generators.
- 24 x smaller generators of various capacities.

2.6.1.6 Offices

The main project construction office will be located at Kutubu. Site offices will be incorporated into the construction camps.

2.6.1.7 Waste Management

Wastes generated during construction will be managed as set out in Chapter 17, Waste Management.

2.6.1.8 Telecommunications

The telecommunications system that will be installed for the PNG Gas Project will utilise the existing oil project telecommunications towers.

2.6.1.9 Laydown Areas

Laydown areas are sites at which pipe and other equipment and supplies will be stored prior to delivery to the pipelaying vessel, RoW or construction camps.

The main laydown and storage facility will be located at the Kopi Support Base, which requires reinstatement and expansion of the barge unloading facilities, laydown areas, warehousing, and bulk fuel storage used during the Kutubu Petroleum Development Project, as described in Section 2.3.5.2.

In addition to Kopi, suitable open space is available at Hides, the Agogo Production Facility, and near the Kutubu Central Production Facility to cater for most of the project's laydown and storage requirements. In addition, laydown areas associated with the Gobe Petroleum Development Project will be available. Laydown areas will also be established at Moro and Port Moresby.

Figure 2.16 shows the proposed laydown areas in relation to ports and supply routes.

2.6.1.10 Fuel Depots

Major fuel depots will be situated at Kopi, Gobe, KP 41 and Hides. Smaller ones will be at Moro, Homa and Idauwi. Fuel will be supplied from either Kutubu or from offshore sources via the main fuel depot at Kopi Support Base.

Bowsers will be set up at each of the fuel depots as well as at the camps that are storing fuel.

Fuel will be transferred from the storage tanks at Kopi Support Base to tanker trucks of 20,000-litre capacity, which will deliver the fuel to the fuel depots at each of the camp sites.

At the start of the project, fuel will be coming in from the north route because there is no bridge to get from Kopi Support Base to Hides. Once the bridges are constructed, all fuel may go overland from the southern route.

Fuel consumption is expected to be in the order of 130,000 litres per day, which equates to seven 20,000-litre tanker deliveries per day. A 21-day supply reserve will require 3.78 ML of storage capacity shared across the project sites.

Appropriate environmental safeguards, such as impervious berms and bunds to contain the largest expected spill and liners to avoid ground contamination, will be installed at each fuel depot and fuelling station. Fuel depots and fuelling stations will be located as far away as practical from watercourses.

All fuel tanker trucks will carry a spill kit, and those carrying A1 jet fuel will carry a fuel spill response kit and carry and initiate ~~the~~ oil spill response ~~plan~~ procedures when required.

2.6.1.11 Equipment Maintenance Facilities

Service trucks will provide daily and routine fleet maintenance at the workface. Small service facilities at each camp will provide intermediate service for the fleet and light vehicles. Major service and repair work will be carried out in a new dedicated facility to be constructed in the vicinity of Moro Airfield.

2.6.1.12 Warehouses

In addition to the warehousing at Kopi and Kutubu, warehousing during construction will be provided at the various laydown areas.

2.6.1.13 Construction Support Facilities

Pipe-Coating Plants

A coating will be applied to the external surface of all pipe to protect the steel from corrosion when it is buried or submerged. In addition, concrete weight-coating will be applied to pipe intended for swamp and underwater installation, and rockjacketing (a flexible, concrete coating) will be applied to pipe intended for installation in rocky terrain.

Corrosion-coating and weight-coating of pipe for offshore installation will either occur prior to delivery or at a pipe-coating plant in Australia.

Pipe for onshore installation is likely to be coated at a pipe-coating plant at Motukea Island, Port Moresby, where the imported bare pipe will be offloaded from barges and stockpiled. The bare pipe will then be corrosion-coated, rockjacketed, concrete weight-coated and restockpiled ready for later loadout to Kopi and then on to stockpile locations along the RoWs.

During the corrosion-coating process at the pipe-coating plant, pipe lengths will be passed through a mild acid solution to clean the steel and then dried, heated and abraded to produce a surface profile for the coating. The corrosion coating will be sprayed, rolled or extruded onto the pipe, and the pipe will be cooled and checked for coating defects prior to stockpiling.

A pipe-coating plant will require up to 10 ha of flat land to accommodate line pipe stockpiles, the coating plant, and administrative facilities.

A typical pipe-coating plant layout is shown in Figure 2.20. The pipe-coating plant will be built and operated to conform to government regulations and legislation concerning occupational health and safety and environmental requirements, including appropriate safeguards to contain spills and avoid ground contamination.

Other Construction Support Facilities

- Batch plants near the Kutubu Central Gas Conditioning Plant and the Hides Production Facility.
- Civil/rebar fabrication shops near Moro and the Kutubu Central Production Facility.
- Pipe fabrication shops near Moro and the Central Production Facility.
- Structural steel fabrication shop for light steel.
- Paint/sandblasting area near the Central Production Facility for paint touch-up only and small bare piping.

2.6.2 Operations

2.6.2.1 Transport Facilities

It is likely that the current daily round-trip flight from Moro Airfield to Port Moresby will continue to be used to transport workers and visitors in and out of the project area. Movement of personnel between project sites will be by helicopter, four-wheel-drive vehicle and minibus. Supplies landed at the Kopi Support Base wharves will be transported by road to their intended destinations.

2.6.2.2 Accommodation Facilities

Operations personnel will usually be accommodated at existing camps, such as the Ridge Camp or Kopi Camp.

2.6.2.3 Offices

The operations of the PNG Gas Project will be carried out from offices located in Port Moresby and the Ridge Camp. In addition, small office modules are or will be established at the production facilities for use by operations staff.

2.6.2.4 Water Supply And Treatment Facilities

Existing water supply and treatment facilities will be used during project operations, although some may be upgraded to accommodate the additional demand.

2.6.2.5 Electricity

Production Facilities

The Hides Production Facility electric power demand will be met with two gas-turbine generators that are capable of generating 2.5 MW each. These gas-turbine generators have been sized for start-up requirements. Power distribution throughout the site will generally be via overhead transmission lines.

The additional electric power demand at Kutubu, Agogo, and Gobe due to the PNG Gas Project will be approximately 6 MW. There are currently three gas-turbine generators at Kutubu, and a fourth will be added to meet the extra load.

2.6.2.6 Waste Management

Wastes generated during operations will be managed as set out in Chapter 17, Waste Management.

2.6.2.7 Communication

The pipeline control systems will operate via microwave links. Personnel telecommunications will build on the existing oil project facilities.

2.6.2.8 Support Services

Support operations will be provided mainly by contractors. These operations will include:

- Camp and canteen operations.

- Regular import of supplies on surface vessels to the Kopi Support Base, and subsequent distribution by road throughout the project area as required. Supplies will include fuel, spare parts, and food and other consumables.
- Regular flights to and from Port Moresby, Mt Hagen and Australia of personnel going on or returning from leave.
- Warehousing activities at Kutubu and Kopi.

3. Project Substantiation (Alternatives Analysis)

3.1 Project Viability

Project viability comprises the technical and commercial case, the legal framework, the environmental and socioeconomic impact assessments, and the negotiated agreement between governments and landowners for sharing the distribution of project benefits.

The PNG Gas Project co-venturers hold primary responsibility for the technical, environmental and commercial parts of this equation.

On the technical and environmental side, the PNG Gas Project is primarily a 'brownfield' development, building on the foundation of existing oil and gas production facilities. The project can be successfully executed using proven engineering technology and construction methods.

Commercial viability of the PNG Gas Project involves two products, crude oil and gas condensate liquids, and natural gas (see Section 1.2).

Crude oil and gas condensate liquids are fungible and are more straightforward commodities than natural gas, being readily saleable into the global marketplace (as is the case for PNG's current oil production). Natural gas, however, is commercially complex, requiring a number of (commonly related) criteria to be fulfilled, including:

- Customers for the gas.
- An adequate price for the gas to justify the costs of development.
- An affordable pipeline transport cost.
- Appropriate funding.

The PNG Gas Project co-venturers are also engaged in planning and managing the project's socioeconomic interface with other parties within the framework of applicable PNG law. The support via negotiated agreements between these other parties—national, provincial and local-level governments and the landowners of the project impact area—defines the political viability of the project.

Table 3.1 summarises the main project viability milestones based on the current schedule.

Table 3.1 Project viability milestones

Milestones Achieved	Date	Author/Parties	Comments
Selection of pipeline company for the Australian portion of the sales gas pipeline	1998	AGL Petronas Consortium (APC)	Will complete the sales gas pipeline to customers in Australia.
Gas Agreement and Fiscal Stability Agreement	2002	Independent State of Papua New Guinea and co-venturers	Main elements: • State equity. • Fiscal stability. • Legal framework.
Indicative terms agreements with gas customers	1997 to 2005	Comalco, QAL, CS Energy, Alcan, AGL	
FEED contract (PNG)	2004	Esso (operator); EOS Joint Venture (WorleyParsons and Kellogg Brown and Root, contractor)	Optimisation of upstream facilities, design and costs; tender documentation for EPC contractors' bidding
APC FEED contract (Australia)	2005	APC (operator): GHD (contractor)	Optimisation of downstream facilities, design and costs; tender documentation for EPC contractors' bidding
Gas Project Co-operation and Sharing Agreement	In prep.	The Independent State of Papua New Guinea, project-area landowners, Southern Highlands and Gulf provincial governments and local-level governments	Coordinated Development Agreement under the *Oil and Gas Act 1998* and the Gas Agreement. Distribution by the Independent State of Papua New Guinea to project-area landowners and provincial and local governments of proceeds from royalties and equity dividends; may also include provisions in relation to special support grants, the development levy, tax credits and other grant
Local business development	In prep.	The Independent State of Papua New Guinea; project-area landowners	
EIS submission	Nov. 2005		Esso as project Operator
EIS assessment and Minister's Decision	Feb. 2006		Minister for Environment and Conservation
Project Sanction	2006		Project co-venturers
Financial Close	2006		Project co-venturers and lenders

3.2 No-Project Option

For stand-alone resource projects, the no-project option is typically the inverse of the benefits and drawbacks of the project case. Moreover, as a feasible development proposition in its own right, a stand-alone resource project that does not proceed can usually stand as a development option for the future.

The situation is more complex for the PNG Gas Project, which sits as a link in a chain of sequential development. In such cases, each stage of the development requires the historic infrastructure of previous stages to be in place and, in turn, creates the foundation for subsequent phases of development. The PNG Gas Project also requires the financial synergies of contemporaneous oil production from established operations.

The implications of the no-project option for the PNG Gas Project fall therefore into two groups: the strategic opportunity costs; and the impacts avoided and benefits foregone.

3.2.1 Strategic Consequences

3.2.1.1 Opportunity Costs

There are two strategic opportunity costs associated with the no-project scenario: first, the failure to take advantage of the synergies presented by the existing oil and gas infrastructure; and second, the loss of opportunities in the future to, in turn, build on the PNG Gas Project's infrastructure to develop new fields.

Synergies

While the PNG Gas Project's resource base depends mainly on the Hides gas field, the feasibility of the project relies on synergies with the existing oil and gas developments and on three factors in particular:

- The opportunity to convert the existing field production infrastructure of the Kutubu, Gobe and Moran petroleum development projects to gas production at an acceptable additional cost.
- The availability of the crude oil export pipeline RoW for the placement of most of the onshore route of the new sales gas pipeline at an acceptable additional cost.
- The opportunity, offered by a market for the gas, to blow down the gas caps of the currently producing oil reservoirs at the appropriate times. This will remove a current constraint on oil recovery[1] and will add to combined oil and gas recovery.

If the PNG Gas Project were not built now, the synergies of combined oil and gas production operations would progressively diminish and finally vanish when oil production stops in approximately 20 years' time. It is difficult to predict at which point in this decline an otherwise commercial PNG Gas Project would become unviable, but the likelihood increases with time.

Future Opportunities

The second major strategic opportunity cost associated with not proceeding with the PNG Gas Project is foreclosure on future development options:

- Potential value-adding, gas-based industries, such as methanol production, liquefied petroleum gas and compressed natural gas, will have no supply source.

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[1] The alternative exists to remove this constraint by the flaring of large quantities of gas. This is contrary to the State's resource conservation policy.

- Undeveloped gas and condensate fields to the northwest of the existing production operations will not have the synergies of following the PNG Gas Project into production. Instead, they will have to face the more difficult commercial hurdles of stand-alone development, with a correspondingly reduced chance of meeting investment criteria.

The PNG Gas Project is a link in the sequential development of PNG's oil and gas resources: it capitalises on developments to date and creates a foundation for the future. Taken in their entirety, the sequential combination of the existing oil and gas developments, then the PNG Gas Project as currently proposed, and finally the possible future new oil or gas field developments could potentially aggregate to a productive life for PNG's oil and/or gas fields into the middle of the century—six decades or more since gas production started at Hides in 1991. The strategic opportunity cost of no PNG Gas Project arises because there are limits to the time in which this opportunity can remain open.

3.2.1.2 Policy Consequences and Expectations

The no-project option runs counter to the principles and policies of successive State governments, in particular:

- Falling short of the full attainment of the nation's economic and social development objectives.

- Disappointing the expectations of the local people, who have generally expressed strong support for the PNG Gas Project to proceed.

- Ending the economic benefits of existing oil production operations earlier than could be the case. In the interim, the oil-only benefits would be lower than would be the case with the realisation of the PNG Gas Project.

- Similarly shortening the period of active oil industry employment, training and contracting opportunities.

- Leaving unbuilt the western road link between the Highlands and Kikori, which will generally follow the proposed new gas pipeline access ways via Kutubu, Moro and Hides to Tari. This leaves only the longer eastern route via Samberigi, Erave, Kagua and Kisenapoi, with links to Mendi and Mt Hagen. Parts of this route are under construction but, without the PNG Gas Project, will have to rely on the Oil Search-operated ferry across the Kikori River near Kaiam rather than the bridge proposed as part of the project. The economic benefits of the more direct road route will be consequently foregone.

3.2.2 Specific Consequences

3.2.2.1 Economic Benefits Foregone

In quantitative terms, these departures from long-standing and widely supported national policies and development objectives will forego the following (ACIL Tasman, 2005):

- Net present value to Papua New Guinea of between US$3 billion and US$4 billion over an approximately 30-year period from first gas (anticipated to be 2009) to approximately 2039.
- Construction direct employment peaking at 1,600 and permanent direct operations employment of approximately 400.[2]
- Net cash flow to the government and project-area landowners of between US$3.2 billion and US$5.6 billion over a 30-year period from first gas in 2009 to 2039—compared to US$1.7 billion from 2009 to the projected end of oil production in 2025.
- A substantial contribution to gross domestic product, peaking at 9% some 12 years after first gas.

ACIL Tasman's (2005) analysis of the economic impacts of the PNG Gas Project concluded:

> The PNG Gas Project offers the opportunity to harness the value of the gas resources of the Southern Highlands region to enhance significantly the welfare of the people of Papua New Guinea. The benefits from the Project would spread throughout the economy as the National Government applies its substantial share of the Project earnings to social and economic programs. These programs have the potential to improve the quality of life of Papua New Guineans by providing essential services and enhancing the country's productivity. Benefits would also flow through the economy as the wages and salaries of Project staff are spent and as suppliers meet the Project's demand for inputs. Landowners in the Project area stand to benefit from direct payments as well as improved social and economic amenities.
>
> Whether the opportunity presented by the Project is fully realised will depend on the ability of the Project proponents to meet business forecasts and on the capacity of the PNG Government to use its revenue from the Project wisely. If these conditions are met, the net benefits for Papua New Guinea are potentially very large – around US$3 billion in net present value terms under conservative development assumptions, and potentially more than US$4 billion.
>
> The potential benefits offered by the PNG Gas Project are expected to flow from the:
>
> - Capital investment in production and support facilities, raw gas and product pipelines and other facilities
> - Employment

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[2] This figure represents the total operations phase workforce for the combined oil and gas operations and excludes contract service providers (see Chapter 8).

- Direct cash flows to government and landowners in the form of taxes, royalty, development levies and other charges, and returns on equity participation, and
- Increased exploration and production (E&P) activity in the country.

3.2.2.2 Local Aspirations Disappointed

Strong and consistent local support for the PNG Gas Project is evident in the household surveys conducted by the project, averaging 83% across the project impact area (see Section 11.14.6.7). Not implementing the project will be a severe disappointment to the populace of the project impact area.

3.2.2.3 Other Benefits Foregone

The loss of economic benefits would have flow-on effects on government services related to health, education and training, albeit from a low base. These benefits have fallen short of the expectations of local people in the project impact area since oil and gas production began, and these social services (together with benefits distribution) are the major issue between people at the grass roots and their representatives in the provincial and national governments. While nearly half the people inhabiting the project impact area think that the current petroleum developments have improved their lives, the remainder either disagrees (5%) or is unsure (50%). This does not diminish their support for the PNG Gas Project but highlights the fact that governance issues, the perceived inequitable distribution of benefits, and shortcomings in social service provision are among the local population’s key issues.

3.2.2.4 Social Impacts Avoided

The main exception to the generally high support for the PNG Gas Project and for the public roads to be completed by the project are reservations amongst the people of Gulf Province about a road linking their area to the highlands. This polarisation of attitudes sees Highlanders’ support for the road link at more than 90%, Gobe at 60% but Kikori at less than 40%. The latter viewpoint in part reflects concerns about squatting and a deterioration in law and order if criminals and other undesirable individuals use the road to migrate to Kikori.

The roads also provide a potential for an increase in prostitution and the incidence of sexually transmitted diseases.

The no-project option will mean that the western of two links between the Highlands and Kikori will not be built. This might diminish the intensity of the social impacts of the road links but will not prevent them from happening altogether.

3.2.2.5 Environmental Impacts Avoided

Similarly, collateral biodiversity impacts (i.e., increased forest clearing and, to a greater extent, hunting) radiating out from the western road link associated with in-migration, poaching expeditions and settlement will also not occur if the PNG Gas Project is not realised (see Chapter 16). Rather, biodiversity impacts will remain localised to the present-day footprint of the existing oil and gas operations.

More directly, the main environmental impact foregone will be that associated with the gas field development on Hides Ridge, where the (post-mitigation) residual direct and indirect biodiversity impacts of the PNG Gas Project are predicted to be as follows (see Chapter 13):

- Of moderate severity, that is, an effect that is ‘not severe [and is] unlikely to lead to major changes to population, community or ecosystem survival or health’ (although the local populations or the areal extent of affected communities may be reduced).
- Over a limited area, that is, in the immediate surrounds of the limited number of impact sites and extending for a radius of from 200 m to 2 km around each site.

Similarly, the cumulative impacts set out in Chapter 16—those effects attributable to future potential scenarios in the project area—would be different. In particular, the western of the two public roads from the Highlands to Kikori would not be completed, depending as it does on the conversion of PNG Gas Project construction access ways into PNG Class 2 roads. Part of the eastern link via Samberigi is currently under construction, but there is no completion date.

3.3 Strategic Alternatives

Strategic alternatives entail radical differences to the project scope.

3.3.1 Liquefied Natural Gas

Natural gas in the form of liquefied natural gas (LNG) can be transported to markets that are too distant to be economically reached by pipeline.

The LNG option requires the natural gas to be cooled to –160ºC, at which point it condenses into a liquid having one six-hundredth the volume of its gaseous phase. The LNG is then transported by specialised tankers to receiving terminals overseas for unloading and regasification. The capital costs of the cryogenic plant and tankers are very large; and some gas is consumed as refrigeration, transport and regasification fuel. LNG becomes a commercial proposition when:

- The gas resource is very large.
- Markets are inaccessible by pipeline.
- A large and stable gas demand supports the long-term contracts needed to underwrite the high capital costs of LNG processing and transport facilities.

LNG projects are therefore complex, with long lead times in competitive markets. An LNG plant in Papua New Guinea would face a number of major hurdles. ACIL Tasman (2005) notes:

> Existing and proposed LNG facilities in the Middle East, Australia (North West Shelf and Timor Sea), Malaysia, Indonesia, Alaska and Russia will meet the forecast LNG requirements until at least 2015. An LNG project in Papua New Guinea could, of course, ‘jump the queue’ if project economics permitted, but the obstacles are formidable:

- Several of the proposed new projects are expansions of existing facilities. Such projects have inherently lower cost structure because of the ability to take advantage of existing facilities.
- Some of the new projects are based on low cost resources for which adequate project returns can be realised at very low gas prices.
- Those projects in areas which, unlike Papua New Guinea, already have established gas production, handling and shipping infrastructure have a distinct advantage.

Establishment of the PNG Gas Project facilities and a track record for Papua New Guinea as a gas exporter would assist in the future marketing of LNG. However, it is ACIL Tasman's view that such a development is unlikely to be cost competitive before the year 2015 at the earliest.

3.3.2 Alternative Sales Gas Pipeline Route

The PNG Gas Project continues the sequential development of the country's oil and gas resources, and the resource base for the project encompasses hydrocarbon reservoirs that are all currently in production. The strategic site selection criterion for the additional PNG Gas Project facilities is therefore the best functional fit with existing production facilities. This means the maximum utilisation of established production and processing facilities, civil works (such as the crude oil export pipeline RoW) and support facilities and, conversely, the fewest possible 'greenfield' excursions from the existing oil and gas facilities' footprints.

In practice, the only major alternative for the route would be to build an entirely new RoW that would allow the sales gas pipeline to travel the shortest distance over land to the shortest sea crossing of Torres Strait. This would involve a corridor generally southwest from the Kutubu Central Production Facility, passing to the south of Mt Bosavi, running across the floodplains of the Strickland, Bamu and Aramaia rivers to cross the Fly River, then tracking south across swamps, savannah and flooded grassland to a landfall on Torres Strait.

A sales gas pipeline running along this general corridor might involve up to 300 km less offshore pipeline and could be some 160 km shorter overall.

However, the engineering and cost disadvantages of this type of alignment become evident on closer examination; in particular:

- It would not allow for the use of the existing crude oil export pipeline RoW to cross some of the rugged Highlands terrain, a valuable asset to any section of new sales gas pipeline that is able to be co-located.

- The difficulty and cost of building a construction RoW across floodplains of wet, unconsolidated sediments are substantial. Fill for the RoW embankment would require long and expensive hauls of material from distant quarries.

- The difficulty and cost of a long crossing of the Fly River of up to several kilometres in width.

These comparatively very unfavourable conditions more than nullify the apparent cost advantages of a shorter overall distance and a reduced length offshore sales gas pipeline section, incurring substantial constructability and schedule risks in the process. In addition, no direct route to Torres Strait could avoid breaking entirely undisturbed ground for its entire length, substantially expanding the spatial scope of the project and its environmental impacts. For these fundamental reasons, this shorter sales gas pipeline route option has not been developed further by the project.

3.3.3 Hides Field Development Strategic Options

Within the area of the PNG Gas Project, the karst in the Hides Ridge area constitutes a noteworthy biodiversity area, featuring little-disturbed montane forest and sinkhole habitat. Hides, the neighbouring Karius Range and the extinct volcano of Mt Sisa are the high-altitude outliers of a much larger expanse of montane forest to the northwest, but they are in and of themselves of high conservation value for their largely or entirely undisturbed condition and suite of endemic plants and animals (see Section 9.3).

The first phase of petroleum development in Papua New Guinea saw seismic lines and pads, exploration wells, and gas production wells and flowlines in the Hides area, with gas production for electricity generation beginning in 1991. The small scale of the Hides Gas to Electricity Project enabled these works to be carried out by low-impact manual methods with helicopter support. Today, the limited impact of this development is evidenced by its light and localised footprint.

The PNG Gas Project is a much larger-scale endeavour (see Table 3.2). The question today is the extent to which it can achieve a level of environmental performance similar to the Gas to Electricity Project.

Table 3.2 Comparison of existing and proposed field production facilities on Hides Ridge

Field Production Facility	Gas to Electricity Project (Existing)	PNG Gas Project (Initial and Further Developments)
Production wells	2	Up to 11 wells, 3 of which could be existing production (2) and exploration (1) wells
Gathering lines – length	10 km of flowlines from wells to the Hides Gas Plant	26-km spine line plus 9 km of flowlines from wells to the Hides Production Facility
Gathering lines – nominal bore	DN 100 flowlines	DN 550 spine line and DN 250 flowlines

3.3.3.1 Strategic Options

Tactical options for the field development at Hides are discussed in Section 3.5 below. The strategic option – to avoid development on Hides Ridge altogether – has been investigated on the basis of the base case and two options for well and gathering systems off the ridge, as follows:

- **Base Case:** Currently planned well arrangement on Hides Ridge.

- **Valley Case 1:** To the northeast in the Tagari River valley within the footprint of existing roads, villages and gardens of the adjacent Tagari River valley.

- **Valley Case 2:** To the southwest in the undisturbed intermontane valley between the Hides and Karius ranges.

3.3.3.2 Design Basis Criteria

Both valley cases require inclined drill holes offset from the bottomhole targets in the producing formation. Wellbore instability is a common feature of the formations of the PNG Highlands and becomes a significantly higher risk at high well inclinations. This progressively and rapidly increases drilling costs, with a correspondingly increasing risk of losing the well altogether. Therefore, the design basis used for the Hides wells is to limit the maximum well-inclination angle to 65 degrees from vertical.

A high level of availability during a well's productive life eliminates the need for backup wells to cover downtime. If a well requires intervention, it must be able to be repaired and brought back on line quickly. Well inclinations below 65 degrees enable straightforward wireline operations and simplify the well maintenance and repair process.

Wells in the Hides field require high drilling fluid densities for two reasons:

- To control the pressure in the overpressured Bawia Formation above the gas-bearing Toro Sandstone.

- To stabilise the wellbore while drilling open hole in highly tectonically stressed rock.

Two factors place technical limits on the density of the drilling fluid that can be used at Hides:

- The maximum amount of solids that can physically be suspended in the drilling fluid.

- The strength of the formations, which, if exceeded, would fracture the wellbore and see a total loss of drilling fluid. These limits have been empirically established by previous drilling experience at Hides.

In the Hides area, the drilling fluid density limit is approximately 19 ppg (pounds per gallon), or a specific gravity of nearly 2.3.

3.3.3.3 Calculations and Conclusions

The inclination and drilling fluid weights for each of the eight proposed new wells at Hides have been calculated for each case:

- **Base Case:** The maximum well inclination is 58 degrees, with four of the wells at Hides being vertical (lowest drilling and operational risk and cost). Maximum drilling fluid densities are below 19 ppg.

- **Valley Case 1:** Wellpads distant from the bottomhole targets require well inclinations between 77 degrees and 82 degrees. Corresponding drilling fluid densities are well above the 19-ppg wellbore fracture limit, with the minimum required drilling fluid density calculated to be 22 ppg. None of these wells is able to meet the design basis criteria (and would far exceed extended-reach wells actually drilled to date for the equivalent mud density and reach).

- **Valley Case 2:** Two wells would be vertical and would meet inclination and drilling fluid density criteria. Two of the six deviated wells would fall within the well-inclination criterion (44 degrees and 66 degrees) and would narrowly meet the drilling fluid density criterion. The other four wells fail on either one or both counts.

The proposed Hides Ridge Base Case wells take advantage of existing and useable wellpads, from which three new wells can be drilled. An additional four wellpads will be required for the remaining five new wells.

Valley Case 2 would need to become a hybrid of ridge and valley wells in order to achieve the required production rates. However, in so doing, it would lose its environmental objective while incurring additional impacts in an otherwise little disturbed area. It would require six new wellpads instead of the four new wellpads in the proposed Base Case, with four of the new wells being drilled from Hides Ridge. The existing wells would also have to be accessed. This option would require access ways to be built both along the valley and on Hides Ridge, the latter in the northwest portion of the field. This would mean that the construction access way along Hides Ridge would be no shorter than for the Base Case.

In addition, it would not be technically feasible to drill wells targeting the backlimb (eastern side) of the reservoir under Valley Case 2. These backlimb wells are not currently in the Base Case, but they are a future option.

Drilling from other than Hides Ridge is therefore not a feasible alternative, and it is the intention of the project to adopt the Base Case, i.e., to drill the wells required to meet gas supply requirements from conventional locations on the top of the ridge.

3.4 Tactical Options—Commercial

3.4.1 Liquefied Petroleum Gas

Liquefied petroleum gas (LPG) is traded globally. The production of LPG from the PNG Gas Project at an export scale has been evaluated, and it was found that the cost of fractionation, storage and offloading facilities make this option uneconomic.

The domestic LPG sales potential is too small for the project to change this conclusion. ACIL Tasman (2005) notes:

> The LPG market in Papua New Guinea is currently very limited, with a total consumption of about 7,000 tonnes per year. Availability of locally produced LPG has the potential to significantly increase demand based on simple price elasticity considerations as the current prices are high. The best opportunity for rapid growth in Papua New Guinea LPG markets would be for a major consumer to emerge, providing genuine economies of scale and incentives to overcome existing distribution constraints. There may be opportunities to encourage existing energy consumers (typically fuel oil consumers) to switch to LPG

and new industrial consumers to establish facilities to take advantage of competitively priced locally produced LPG.

Papua New Guinea is currently a net exporter of LPG from the InterOil refinery in Port Moresby. LPG production is technically feasible, and the design of the PNG Gas Project maintains the option for possible future recovery of the reinjected LPG (see Section 2.3.2.4).

3.4.2 Compressed Natural Gas

Compressed natural gas (CNG) involves pipeline-quality natural gas being compressed to up to 3,600 psi for storage in pressure tanks and transported by tanker to export markets. CNG has become an established alternative to petrol and diesel fuel for buses and trucks in a number of countries.

Oil Search, Itochu and EnerSea Transport LLC are studying the possibility of shipping CNG from Papua New Guinea to New Zealand to replace a declining local gas supply and cover what is expected to be a national shortage of natural gas beginning in 2009. LNG is under evaluation for electricity generation and general distribution, but the low capital cost and ability of CNG to increase supply in much smaller increments versus an LNG approach makes it an attractive option.

As far as the PNG Gas Project is concerned, a feasible CNG development would add to, rather than replace, natural gas export by pipeline.

3.4.3 Petrochemical Plant

Oil Search is investigating the feasibility of constructing a petrochemical plant to produce methanol/ dimethyl ether at Port Moresby. The plant feedstock would be natural gas. If feasible, this project would add to, rather than replace, natural gas export by pipeline.

3.5 Tactical Options—Hides Wells and Gathering System Construction

3.5.1 Context

A gathering system (flowlines and spine line) will convey raw gas and liquids from wellheads on Hides Ridge to the Hides Production Facility. The current design is based on a buried DN 550 spine line and DN 50 glycol injection pipeline, with a DN 100 above-ground water pipeline.

The route for both the pipeline RoW and the construction access way from Hides 4 well will generally follow a ridge line (Hides Ridge) threading a path between sink holes on either side. The construction access way will support pipeline installation and provide ground access for drilling the wells. The RoW/access way will be completed as a narrow, private access way to service the wells, support pipeline inspections and carry out maintenance and monitoring during operations, as well as to provide access for future drilling campaigns.

3.5.1.1 Options

The generally undisturbed condition of the forest habitat on Hides Ridge is broken only by the very light and localised footprint of the existing gas wells and above-ground, small-diameter gathering flowlines. These were able to be built using manual methods with helicopter support, because of the small-diameter nature of the line pipe used to construct the flowlines. This raises the question of whether similar reduced-impact methods could be adapted to the PNG Gas Project's much larger production capacity and a spine line involving 550-mm diameter line pipe with a heavier wall thickness.

A road already exists as far as the Hides 4 well. The following alternatives have been compared for the construction of facilities beyond the Hides 4 well:

- Helicopter construction of wellpads with wells drilled entirely with heli-support.
- Helicopter-supported spine line construction.
- Conventional spine line construction with no permanent access way, a revegetated RoW and support of future operations by helicopter.
- Base Case: Conventional spine line construction and use of the construction RoW as a narrowed, private, in-field access way.
- Helicopter-supported drilling and multiple small-diameter flowlines to replace the large-diameter spine line.

3.5.1.2 Weather Constraints for Helicopter-Based Options

The use of helicopter-based construction techniques has been a common practice in Papua New Guinea for remote exploration wells, including the Hides discovery and exploration wells, two of which were subsequently (and as a separate exercise) completed as producing wells.

For a large, 15-month drilling program at Hides Ridge, however, consistent access becomes hostage to frequent poor flying weather, and considerable and costly schedule delays would be incurred.

The limitations to helicopter utilisation arise mainly because clouds tend to sit on the ridges in this area; the valleys are usually flyable most of the year, with morning fog clearing as the sun rises. Hides Ridge is usually covered by clouds between 6,500 and 8,500 feet (1,850 and 2,600 m), mainly on the north side. In June, July, August and September (the rainy season), the ridge tops are usually in the clouds all day. In the non-rainy season, helicopter flights would usually be possible from 0630 or 0700 to 1000 or 1100. By late morning, wind from the southeast pushes warm air up the ridges, and clouds form that obscure the ridge. There will be limited occasions at any time of the year when flying is possible all day (see Plate 3.1).

Realistic planning for a typical year would assume no flying on the ridges in the four months of the rainy season, with operations for three to four hours per day for the remaining eight months of the year.[3]

3.5.2 Heli-Supported Drilling

For the PNG Gas Project, it is anticipated that helicopter-supported drilling would add several million dollars per well to the cost of each of the currently planned 11 wells. A variation on this alternative would be to interconnect the wellpads with in-field access ways to facilitate movement between them but without constructing a permanent access way from the valley. This would still require all equipment and vehicles to be brought in by helicopter, and therefore helicopter flight reductions would be limited.

3.5.3 Heli-Supported Pipeline Construction

Large helicopters can carry 4.3-t, DN 550 line pipe sections, but the high altitudes of the Hides Ridge affect the performance of aircraft. More than 2,000 helicopter flights will be needed, with a corresponding safety risk and an enormous maintenance effort required to keep the machines in service (approximately seven hours of maintenance are required for each flying hour for a twin-rotor Chinook helicopter). All construction equipment, machinery, supplies and manning will also need to be heli-lifted if this pipeline construction approach were to be utilised. The requirement to trench the pipe into the ground and the weight and size (diameter and wall thickness) of the line pipe, however, mandate the use of heavy ground machinery for its actual installation.

3.5.4 Conventional Pipeline Construction (No Permanent Access Way)

In accommodating terrain, the number and size of co-located pipelines proposed for the Hides Ridge (DN 550 spine line, DN 50 glycol injection line and DN 100 water line) would normally call for a 25-m-wide working easement. However, the terrain in the Hides area makes this impractical. A 12-m-wide cleared strip is considered to be a reasonable nominal easement width for this type of construction, although the rate of progress will be restricted. The cleared RoW would also be used as a construction access way for equipment, personnel and loads of pipe and to prepare wellpads. The pipeline will be installed before all of the wells were completed, and so the road will need to stay in service throughout the subsequent drilling campaigns.

Without a permanently maintained private access way to support operations activities, part of the RoW could be revegetated once drilling activities were completed. Regrowth

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[3] Information on flying conditions courtesy of E. Zeitler, pilot, Columbia Helicopters, Moro, Southern Highlands Province, PNG. Telephone conversation, 26 October 2005.

over the pipelines would need to be controlled to prevent the growth of trees that could damage the coating of the pipe. Required vegetation management could be accomplished on foot.

If the construction access way were not subsequently maintained as a permanent private access way, then all future operations at the wellheads would need to be undertaken by helicopter, and an additional well would be required to ensure gas availability. This additional well would have incremental environmental impacts associated with it.

3.5.5 Conventional Pipeline Construction (Private Access Way)

If the spine line were constructed conventionally with a reduced-width RoW being cleared, then the construction access way could be maintained as a private, single-track, infield access way during operations. This would support the subsequent drilling campaigns, pipeline pigging and inspection and would offer operations access to the wellheads more reliably and safely than by helicopter and in all weather conditions. This access way would be gated at the Hides 4 well, and its usage would be managed so it did not become an avenue for indirect impacts associated with facilitated or increased public access, especially access by vehicles.[4]

3.5.6 Multiple Small Flowlines

The Hides Gas to Electricity Project has been supplying gas from the Hides 1 and Hides 2 wells to the Porgera Power Plant since 1991. These wells feed small-diameter flowlines installed manually with helicopter support. The flowlines run above ground and straight down the fall line of Hides Ridge to the Hides Gas Plant. This raises the question of why a similar method could not be used by the PNG Gas Project.

The principal constraint arises from the vast difference between the gas flows required by the Porgera Power Plant and those required by the PNG Gas Project. By way of comparison, the power plant currently requires 18 kSm^3/h; the proposed Hides Production Facility is designed to process up to 826 kSm^3/h.

Under the base case, therefore, the spine line needs to deliver more than 40 times the amount of gas currently being produced by the existing Hides wells.

There are difficulties in scaling up the use of multiple above-ground flowlines of a diameter similar to that of the existing Hides flowlines to deliver the gas flow rate required by the PNG Gas Project.

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[4] As previously noted, the authority over what activities occur on customary land resides with its landowners. The Operator will seek to strike an agreement with Hides Ridge landowners regarding access controls and the limitation of certain activities on their land.

Modelling indicates that the nominal number of DN-100 flowlines is a range of between 70 and 90.

The above-ground flowlines from each wellhead would be supported on pipe racks along a shared RoW to a manifold at the Hides 4 well.

Construction would require the RoW to be cleared by hand and the pipeline racks to be installed by hand with support from helicopters. Pipe of such small diameter can usually be bent to conform to the natural land surface, and so bulk earthworks are not generally needed.

A number of construction locations would need to be established at which pipe sections could be stockpiled by helicopter, welding stations established, the flowlines continuously welded and the pipestrings pulled out along the racks. Again, all construction equipment, machinery and supplies would also need to be heli-lifted. The total weight of the multiple smaller-diameter pipes would be approximately the same as that of the single large-diameter spine line, and a large number of helicopter flights would be required to ferry the pipe up to the ridge. Above-ground flowlines require insulation to prevent hydrate blockages expected at the low ambient temperatures characteristic of the Hides Ridge climate (compared with a buried pipeline). This would probably require considerably higher injection rates for monoethylene glycol, which in turn would require larger pumps, tanks and glycol injection lines.

The practicalities of helicopter transport and manhandling on the ground require the smaller-diameter pipe to be in short lengths. The 12-m pipe lengths necessitated by this scenario would require considerably more linear metres of welding.

Above-ground multiple flowlines would require a wider RoW to accommodate their pipe racks. The number of individual flowlines using the RoW increases at each well, and the rack arrays become progressively wider, to the point where the RoW would be up to 28 m wide approaching the Hides 4 well. This RoW would need to be kept cleared of vegetation regrowth for the life of the project. Above-ground pipelines are also more accessible to the public and are therefore less secure (note, though, that no problems of tampering have been experienced with the existing above-ground lines to date).

The conventional pipelay crew for the DN 550 base case would number about 100, or 200 if two spreads are utilised. The multiple, above-ground flowline option requires additional labour for clearing, setting pipe support, manhandling pipe lengths and welding and this could lead to a workforce of up to 1,000. A daily helicopter commute for the workers would be impractical in the poor weather on Hides Ridge, and so there would need to be camps of approximately 200 people each at intervals along the ridge to service the multiple pipelay crews.

The environmental objective of this option is to avoid the bulk earthworks that ground access for vehicles require. Consequently, future operations at the wellheads would also need to be supported by helicopter. This would include shutdowns, routine maintenance, interventions, well workovers, inspections and pigging. Poor weather will frequently make the field facilities inaccessible, which creates some chance that a well stays off-line long enough to affect gas supply. A backup production well would be the normal safeguard against this risk, but an additional well would have incremental environmental (footprint) impacts associated with it.

Table 3.3 compares constructability, security and other factors of a single, large-diameter spine line versus multiple, small-diameter flowlines.

Table 3.3 Hides field facilities: base case vs multiple, smaller-diameter flowlines

	DN 550 Buried Pipe	Multiple DN 100 Above-ground Pipe
Safety	• Conventional and proven practices • Road transport – minimum helicopter operations • Rated machinery for pipe handling	• Extensive manual labour raises safety risks • Extensive helicopter operations with associated safety and availability risks • Manual handling of equipment and pipe increases safety risks
Security	• Buried pipeline less accessible	• Above-ground flowlines more accessible
Weight	• ≈ 12,000 t of concrete-coated pipe • Each 12-m section ≈ 4 t • ≈ 3,000 lengths of pipe	• ≈ 13,000 t of pipe • Each 12-m section ≈ 0.18 t • ≈ 60,000 lengths of pipe
Welding	• ≈ 3,000 welds • ≈ 5,000 m weld length • ≈ 1.3 m^3 weld volume	• ≈ 60,000 welds • ≈ 0.57 m^3 weld volume
Workforce and camps	• Two spreads • Approximately 200 workers • One camp, not on Hides Ridge	• Five spreads • Approximately 1,000+ workers • 5 to 6 camps at 1,500-m spacing and moving along the ridge
RoW	• Nominal 12-m width for construction • Construction access way in RoW • Regrowth to 7-m access way above pipe for operations access	• RoW width: up to 28 m • Pipe above ground, all tree regrowth cleared • Foot track for future inspection
Operations	• Future operations, maintenance and inspection via access way • Enables rapid all-weather access when intervention required	• Future operations, maintenance and inspection accessed via helicopter • Access may be weather-constrained when intervention required
Drilling	• Drilling mobilisation and support via access way • Future workovers and new wells via access way	• Drilling mobilisation and support by helicopter • Future workovers and new wells accessed by helicopter
Schedule	• Supports project schedule • Weather risk largely avoided	• Manhandling will increase schedule/costs • Schedule at risk from prolonged weather window closures
Costs	• Weather risk largely avoided	• Manhandling lengthens schedule • Cost risk from prolonged weather window closures
Environ-mental impact	• Nominal 12-m RoW bench + batters = average width of 30 m • 75 ha cleared (bench/batters and sidecast) • 1.4 Mm^3 bulk earthworks: – 0.22 Mm^3 cut to fill – 1.18 Mm^3 cut to spoil • Pipe installed underground • Gated operations access way • Reduced size workforce	• RoW width up to 28 m • 36 ha cleared (for pipe rack and RoW) • Limited bulk earthworks • Above-ground pipe installation • No vehicle access way • Helicopter noise • Large workforce
Helicopter operations	• Occasional	• 6 x B CH-47 Chinook helicopters • 10,000 flights @ 1/2 hr: 5,000 hrs • 35,000 hrs maintenance* • 850 hrs/yr weather window/yr** • Aircraft flying ≈100% of weather window

Hides 1 to Hides 4: 19.2 km (flowlines from third drilling program not included). *Helicopter maintenance @ 7 hrs per flying hr. **Weather window @ 3.5 hrs/day for 8 months, October to May, (see Section 3.6.1.2).

3.5.7 Conclusion

Table 3.4 summarises the attributes of the various methods for constructing the field facilities at Hides. These options fall broadly into two categories:

- Drilling and pipelaying with ground access support and the workforce housed generally off Hides Ridge.
- Drilling and pipelaying using helicopters, with the workforce housed on Hides Ridge.

The functionally optimum size and wall thickness of buried pipe to be installed from the wellheads to the Hides Production Facility mandate traditional ground-access-based pipelaying methods and machinery for reasons of safety, cost and schedule. The nominal 12-m RoW bench is a necessary constraint imposed by the difficult terrain in the area and is much narrower than typical pipeline construction RoW widths in more accommodating country. However, the radial effects of the earthworks needed to establish even this narrow bench will extend tens of metres beyond the RoW, in the form of cut and fill batters and sidecast scree slopes.

During operations, the RoW above the buried pipelines will need to be kept free of tree regrowth, which creates sufficient width for a single-track, private in-field access way, with a good chance of forest canopy reclosure. Lack of ground access to sections of the pipelines during operations may make it necessary to have a back-up well, with the additional earthworks and associated, albeit localised, environmental impacts that this would entail.

The multiple, small-diameter pipeline option does achieve the environmental benefits of reduced earthworks. However, the safety, construction cost and schedule delay costs and risks associated with this option are not trivial. They are compounded by the requirement for a much larger workforce, which brings its own environmental management challenges (for example, sewage treatment and discharge, water use, waste generation and disposal).

It is therefore the intent of the project to construct the field facilities on Hides Ridge using conventional means, but with the RoW reduced to a safe nominal width of 12 m.

Table 3.4 Hides field facilities (Hides 1 to Hides 4 wells only) construction methods summary

	Ground Construction Access (drilling/pipelaying)		Helicopter Construction Access (drilling/pipelaying)	
Design basis	Base case: DN 550 spine line	DN 550 spine line; decommission construction access way*	DN 550 spine line	Multiple DN 100 flowlines
Engineering, constructability	Constructible by standard methods		Manhandling – very heavy work for light tools	Manhandling
Cost (construction)	Lowest cost		Significant helicopter cost, severe weather downtime	Significant helicopter cost, severe weather downtime
Cost (operations)	Lowest cost	Operations cost penalty (helicopters) Backup well in reserve		
Workforce	Reduced size, easy daily commute to the work site from Hides camp via the access way		Drilling workforce at pads. Large pipelaying workforce; housed on Hides Ridge to avoid heli-commute and weather downtime	Large pipelaying workforce; housed on Hides Ridge to avoid heli-commute and weather downtime
Schedule	Standard		Drilling: weather risk during set up Construction: weather risk for heli-lifting machinery and pipe	
Well availability	Standard	Weather risk for well workovers, emergency repairs		
Safety risk—construction	Standard		Flying risk; limited options in an emergency Construction methods dangerous (manhandling)	
Safety risk—operations	Standard	Flying risk; limited options in an emergency		
Earthworks	1.4 million m^3		Minor	Negligible
Area affected	90 ha		Not estimated**	36 ha
Nominal RoW width	12 m	12 m	12 m	28 m

*After third drilling program, ca. 2017. **Likely to be in the range of 36 ha to 50 ha.

3.6 Tactical Options—Pipeline Routes

3.6.1 Routing Criteria

Section 3.3.2 has noted that, because the PNG Gas Project is intended to be a predominately 'brownfield' development, the routing criteria for the sales gas pipeline are dominated by a single overriding directive: to utilise the existing crude oil export pipeline RoW to the maximum extent practicable. The cost and environmental advantages associated with this approach are self-evident; to this end, there has been, for pipeline safety reasons, only one departure from this prime criterion (to avoid compromising the existing crude oil export pipeline in the Kikori River; see Section 3.6.4 below).

The 'greenfield' portion of the project (Hides to Kutubu) is qualified as follows:

- For the high-biodiversity Hides Ridge area, the constraints of the polygonal karst landform are ubiquitous, and so the only development alternative has been to develop the gas field from wells that are off the mountain altogether. Section 3.3.3 addresses this situation.
- For the section of pipeline from the Hides Production Facility to Kutubu, the route was mandated by a decision of the State that the pipeline RoW must follow existing roads at either end and the Idauwi to Homa link road to be built by the project (see Section 3.7).

Therefore, Hides Ridge excepted, the more conventional process of pipeline route selection based on inclusion and avoidance criteria was not adopted by the PNG Gas Project.

For the purposes of discussing pipeline routing in more detail, the project's principal pipeline routes have been divided into the five sections shown in Figure 3.1.

3.6.2 Section A: Hides to Kutubu Central Gas Conditioning Plant

This section comprises segments 1 to 7a (as defined in Section 12.3).

The route for the gas and liquids pipelines from Hides to the Kutubu Central Gas Conditioning Plant was chosen because there were already existing roads over much of the distance and because the PNG and Southern Highlands governments and the local landowners wanted the road link to be completed in this area (see Section 3.7 below). An alternative pipeline route might be found requiring the breaking of entirely new ground, running south from Hides, then east to the north of Mt Sisa to cross the Hegigio River west of the Hegigio Gorge. This option fails to capture synergies with existing roads and was therefore not considered further.

This has the effect of keeping pipelines within the ambit of existing petroleum developments and avoiding incursion into the lands of the Onabalasu people, a small group living south of the Karius Range.

Within the vicinity of this pipeline route section is the proposed Agogo rich gas pipeline. This pipeline will generally follow the existing crude oil export pipeline RoW from Agogo to the Kutubu Central Gas Conditioning Plant (see Section 12.5).

3.6.3 Section B: Kutubu Central Gas Conditioning Plant to Kopi

This section comprises segments 7b to 12 (as defined in Section 12.4) and contains the first onshore portion of the proposed sales gas pipeline route.

This section follows the RoW of the existing crude oil export pipeline. Section 3.4.2 above notes that the cost of a new pipeline construction RoW in the terrain of the project area is substantial, and there are no engineering, cost or environmental advantages in departing from the path of the existing crude oil export pipeline in this area.

3.6.4 Section C: Kopi to the Omati River Landfall

This section comprises Segment 13 (as defined in Section 12.4). The only fundamental alternative to the proposed route from Kopi to the Omati River would be to exit the delta via the Kikori River. However, the Kutubu crude oil export pipeline already occupies this section of the river, and to place a second pipeline in the same river would incur an avoidable operability and safety risk.

Otherwise, the pipeline route overland from Kopi to the Omati River cannot avoid the two main intervening features: the low limestone Veiru Hills to the south of Kopi and the swamp forest in the route down to the landfall location. Alternatives to the most direct route offer no engineering, cost, social, cultural or environmental advantages and have therefore not been examined further.

3.6.5 Section D: Omati River Landfall to Torres Strait Protected Zone

The offshore section of the proposed sales gas pipeline route crosses two entirely different subsea environments: the sediments of the Gulf of Papua prograding offshore from the deltas of the Kikori and Fly rivers (see Sections 12.7.1 and 12.7.2); and the reefs, shoals and high-energy, inter-reefal passages of Torres Strait (discussed under ‘Section E: Torres Strait Protected Zone’ below; see also Sections 12.7.3 and 12.7.4).

For the Gulf environment, alternative alignments have not been established and compared because, regardless of where it runs, the sales gas pipeline must traverse or negotiate the same four features of the seabed: the unstable delta front of the Fly River; the otherwise generally muddy, stable Gulf seabed, interspersed with dead trees; prawn trawl grounds; and the hard carbonate shelf with extensive areas of the calcareous alga *Halimeda* beyond the zone of sedimentation.

The principal routing criterion used to position the sales gas pipeline in this offshore area was to achieve the shortest distance consistent with a safe setback from the delta front of the Fly River. The identified route and its environmental and resource features are described in Chapter 10. As it happens, a route selected in view of this criterion can avoid the *Halimeda* beds (see Figure 10.7 in Section 10.3.1). There is no route in this area that can avoid the almost ubiquitous muddy seabed; but equally, there is no reason to do so.

It is important to note that no route can avoid the Gulf prawn trawling grounds entirely (see Section 10.4.1). However, the line of the shortest route takes the sales gas pipeline to the west, and this has the effect of reducing the overlap with the prawn trawling grounds, which are mainly in the eastern part of the Gulf of Papua (see Figures 10.14 and F10.8 in Section 10.4.1).

Consequently, no formal comparison of options has been carried out by the project in the Gulf of Papua area, there being no point at which the shortest, safe route was not also the least constrained from environmental and resource-use standpoints.

3.6.6 Section E: Torres Strait Protected Zone

The situation in the Torres Strait is less straightforward. The entrance to the Strait through PNG waters is environmentally and economically unconstrained, but crossing the international boundary near Pearce Cay, the pipeline encounters a major obstacle in the form of the platform massif of the Warrior Reefs. This feature and its outliers run north–south for more than 100 km. The pipeline must cross from east to west through one of a number of natural breaks, as the passage around its southern extremity is constrained by shallow sections of shipping channels. Four transits of the Warrior Reefs were assessed under Australian and Queensland environmental assessment processes (Figure 3.2), and one was selected and approved in 1998 (North Central [‘Basilisk’] Passage). However, subsequent consultation revealed that Basilisk Passage was constrained by its cultural heritage and, at the request of its Islander custodians, a route further to the south has been nominated, approved by the Australian Commonwealth and Queensland authorities and adopted for detailed engineering survey and design (South Central Passage [‘Bet Reef’]).

The assessment of Torres Strait alignment options has been updated since 1998, and the results are summarised in Figure 3.3.

3.7 Public Road System

The road requirements of the PNG Gas Project are twofold:

- To service the pipeline RoWs and plant sites during construction.
- To provide access for inspections, maintenance and emergency response during operations.

The PNG Gas Project requires improved road access for construction purposes—to avoid the long (more than 600 km), deteriorated and insecure alternative of the Highlands and Southern Highlands highways from the port of Lae on the north coast of New Guinea to Tari.

Closed, project-only access to valve stations, cathodic protection test points and the pipeline in general has security advantages during operations. This option would have been the PNG Gas Project's preference.

However, strategic roads have long been the national infrastructure policy objective of successive State governments and have been covered at some length by the Gas Agreement, as set out below.

Figure 3.4 shows existing roads and proposed new project-related construction access ways that will become public roads in the Southern Highlands and Gulf provinces.

3.7.1 Independent State of Papua New Guinea Road Commitments

Attachment 3 of the Gas Agreement, 'Joint Road Proposal and Special Tax Credit', defines the State's road construction and maintenance commitments as follows:

- Kagua to Kikori section of the Gulf to Southern Highlands Highway.
- The Kisenapoi to Erave to Kagua section of the Gulf to Southern Highlands Highway.
- The Tari to Komo road upgrade.
- The Kutubu to Homa to Tari road.

The State's intentions have been to create two roads between the Southern Highlands and the Gulf coast, with upgrades to roads connecting other parts of the Southern Highlands to the two primary links. The two roads in question are:

- The western link from Tari via Idauwi, Homa, Moro, Kutubu, Kaiam and Kopi to Kikori. The section between Idauwi and Homa is currently under construction.
- The eastern link from Mendi and Mt Hagen via Kisenapoi, Erave, Kagua, and Samberigi to join the western link at the Samberigi turnoff. The section between the Samberigi turnoff and Samberigi is currently under construction (first 10 km) or is about to be surveyed (remaining 40 km).

The new sections of both roads are being constructed under State funding arrangements in accordance with the requirements of the Gas Agreement.

The PNG Gas Project requires new construction access along short sections of the western link. For the most part, upgrades to the existing crude oil export pipeline RoW would have sufficed. As a practical matter, however, the PNG Gas Project will complete certain construction access ways so that the western link becomes a public road. This will be handed over to the ownership of the State.

3.7.2 PNG Gas Project Road Commitments

The Gas Agreement contemplates that the PNG Gas Project may carry out for its own purposes road works as follows:

- The Samberigi turnoff to Kutubu.
- Maintenance of the road between Nogoli and Kikori up to a maximum expenditure of US$0.5 million per year until 2027.
- Such other construction and maintenance work as may be required.

3.8 Spoil Management

The establishment of construction access and a pipeline RoW in steep terrain yields a surplus of cut material over fill material (spoil) that requires management. The normal and long-standing practice in Papua New Guinea is set down in the Department of Works Road Design Manual, which provides for spoil to be sidecast. This method creates vegetation damage down the slopes, and fugitive sediment falls or is transported by rainfall runoff into nearby streams and rivers. These processes have an analogue in the natural landslides that are a common feature of the PNG Highlands.

3.8.1 Mitigation Options

In more accommodating environments, it would be normal practice to dispose of spoil in stable emplacements and implement measures to reduce erosion, downstream sedimentation and turbidity. Therefore, the bulk earthworks necessitated by the PNG Gas Project raise the question as to the feasibility, affordability and utility of such mitigation measures.

Table 3.5 sets out the factors for the standard base case and three levels of mitigation related to spoil management, with approximate additional costs of applying these mitigation measures to the Homa to Idauwi, Hides Production Facility to Angore, Hides Ridge, and KP 55 to Mubi River access way sections.

The mitigation options fall broadly into two categories:

- Spoil sidecasting (Options 1, 2 and 4).
- No spoil sidecasting (Option 3).

3.8.2 Discussion

Option 1, the base case, reflects the present-day standard practice in PNG and conforms with all stipulated government road building requirements and directives. Sidecasting of spoil is believed to have been adopted for all roads and pipelines built in Papua New Guinea to date except where cut material could be economically and practically salvaged as fill or for land reclamation.

Table 3.5 Spoil management options

Factor	Option 1 (base case) (sidecasting without mitigation)	Score	Option 2 (spaced sidecasting)	Score	Option 3 (no sidecasting; removal to dump)	Score	Option 4 (sidecasting with revegetation)	Score
Slope stability	Unstable until vegetation naturally re-establishes.	3	Unstable where dumping occurs until vegetation naturally re-establishes.	4	Limited downslope stability issues.	1	Unstable until revegetation occurs.	2
Engineering feasibility	Feasible – standard practice for roadworks in Papua New Guinea.	1	Difficult – will require dump plans and haulage procedures for new fleets of large earthmoving plant and trucks on narrow benches. Turnaround and passing areas in steep unstable sections incur an increase in volume of cut for the wider bench.	4	Difficult – will require dump plans and haulage procedures for new fleets of large earthmoving plant and trucks on narrow benches. Turnaround and passing areas in steep unstable sections incur an increase in volume of cut for the wider bench.	4	Feasible – similar to standard practice for roadworks in Papua New Guinea but with progressive active revegetation.	1
Additional cost (A$)	Base case.	1	Approximately $50 million.	3	Approximately $140 million.	4	Approximately $2 million.	1
Construction schedule	Lowest construction schedule risk.	1	Several more months for road and pipeline construction.	4	Several more months for road and pipeline construction.	4	Limited impacts to construction schedule.	1
Biodiversity impacts	Direct loss of vegetation and fauna habitat in path of sidecast material. Natural regeneration of grasses over trees increases fire risk and permanently alters habitat.	3	Similar impacts as for Option 1 with less frequent but thicker deposits of sidecast material. Revegetation rate will be reduced.	3	Limited downslope impacts. However, will require additional area to be cleared for dump site.	2	Direct loss of vegetation and fauna habitat in path of sidecast material. Impacts will be mitigated where slopes are actively revegetated.	3
Time to achieve revegetation	Six months; may be longer on unstable sections and significantly longer on hard limestone substrate.	3	Longer than for Option 1 as slopes will be more unstable and will take longer for vegetation to establish.	4	Limited in any areas of disturbance. Dump will be needed for six months.	1	Involves active revegetation on steep slopes and monitoring and maintenance until vegetation is established.	3

Table 3.5 Spoil management options (cont'd)

Factor	Option 1 (base case) (sidecasting without mitigation)	Score	Option 2 (spaced sidecasting)	Score	Option 3 (no sidecasting; removal to dump)	Score	Option 4 (sidecasting with revegetation)	Score
Riverine impacts	Will increase riverine turbidity and possibly bed aggradation where sidecast spoil enters river system. However, impacts will reduce as vegetation re-establishes, with the affected watercourses recovering in 2 to 3 years.	3	Will increase riverine turbidity and possibly bed aggradation where sidecast spoil enters river system. However, impacts will reduce as vegetation re-establishes, with the affected watercourses recovering in 2 to 3 years.	3	Limited impacts to riverine system.	1	Will increase riverine turbidity and possibly bed aggradation where sidecast spoil enters river system. However, impacts will reduce as vegetation re-establishes, with the affected watercourses recovering in 2 to 3 years.	3
Personal safety	Lowest risk to personal safety as minimum additional work required.	2	Inherent risks in manoeuvring loaded trucks along narrow benches and reversing into designated sidecast areas in generally wet weather.	4	Increased safety risks, as additional work is required to transport materials to dump sites.	4	Depends on method of revegetation (hand planting on steep slopes may be hazardous).	2
Visual amenity	Immediate, widespread visual impacts where bare earth is visible. Changes in vegetation (from trees to grasses) will cause long-term localised visual impacts.	n.a.	Immediate, localised visual impacts where bare earth is visible. Changes in vegetation (from trees to grasses) will cause long-term localised visual impacts.	n.a.	Limited downslope visual impacts; however, spoil dumps will be large and will visually alter the landscape.	n.a.	Temporary widespread visual impacts where bare earth is visible until vegetation re-establishes. Limited long-term impacts.	n.a.

Scoring for engineering, cost and safety impacts

1 Minimal.
2 Low.
3 Moderate.
4 Substantial.
5 Severe.
n.a. Not assessed.

Scoring for biodiversity and riverine impacts

Insignificant (1): No detectable effect.
Low (2): Detectable effect but is small and highly unlikely to have any significance.
Moderate (3): Detectable but not severe effect; populations or the areal extent of communities may be reduced but unlikely to lead to major changes to population, community or ecosystem survival or health.
High (4): Likely severe negative impact on population, community or ecosystem survival or health.
Very High (5): Likely very large impact on population, community or ecosystem survival or health, possibly even leading to local extinctions or widespread system collapse.

The rationale of Option 2 is to break up the continuity of downslope vegetation impacts by concentrating spoil disposal in sacrificial areas spaced according to the:

- Amount of material to be disposed.
- Suitability of site.
- Ability to transport mobile material from the source to the deposition location.

Option 3 seeks to restrict sidecast spoil to natural erosion from active construction areas, with the bulk of cut material being trucked to a dedicated stable deposition area.

Option 4 adds active revegetation to Option 1, the rationale being to accelerate the recovery of a stabilising and more visually attractive plant cover and to prevent the establishment of fire-prone grassland that is such a common impediment to forest regrowth in the PNG Highlands.

From a feasibility standpoint, these options again divide between those that require rehandling, trucking and placement of spoil (Options 2 and 3) and those that do not (Options 1 and 4). The following constraints apply to the double-handling options:

- The trucking operation to move spoil from workfaces to other locations would require a larger fleet of heavy earthmoving equipment and trucks that would not otherwise be needed. Incremental fuel consumption associated with the more numerous trucks and earthmoving equipment would be significant.

- Traffic circulation would require the RoW to be widened from the base case of between the nominal 12 m and 21 m to more than 21 m. The additional volume of cut material requiring management would be very large along some sections, and incremental short-term environmental impacts would be considerable.

- Safety is ‘the’ cornerstone of the PNG Gas Project, and traffic safety is a matter of management. However, the introduction of large numbers of heavy earthmoving equipment and trucks in a steep, narrow, wet and remote environment will add a very challenging and significant safety risk.

- The overall project schedule would require more active workfaces, which in turn would require a larger workforce and more camps; these would give rise to incremental environmental impacts (i.e., water use, sewage treatment and disposal, waste generation and disposal, etc.).

An examination of the locations where the large cuts would be needed reveals the practical difficulties of the two spoil trucking options. For example:

- The section between the Pawgano and Maruba rivers is anticipated to generate about 1.6 million m^3 of cut-to-spoil material.

- The section between the Hides 1 and Hides 4 wells is anticipated to generate 1.2 million m^3 of cut-to-spoil material over 20 km.

- Widening the RoW to accommodate the large number of pieces of heavy earthmoving equipment and trucks to remove the spoil will itself generate large quantities of additional spoil – 300% more on the sections of 45-degree slopes where the RoW width would need to be doubled to enable truck traffic to safely circulate.

It is not straightforward to trade off the feasibility disadvantages and the potential environmental benefits of the trucking options. What is clear is that, at most locations, the cost and schedule penalties of trucking will be substantial. At the same time, however, the additional earthworks that double-handling of spoil requires will make the environmental benefits of trucking less than might be first thought. This holds particularly true when temporarily conspicuous short-term impacts of spoil sidecasting are viewed in their time context: Sections 13.4, 13.5 and 13.6 reveal that impacts on rivers related to spoil sidecasting are predicted to be negligible after one year as natural vegetation regrowth will be rapid in the volcanic soils between Homa and Idauwi (ensured by the active revegetation measures proposed; see Section 13.3.3.1). Further, generally rapid and unaided regrowth on limestone is evident from the analogue of the earthworks associated with the Kutubu Petroleum Development Project (where all cuts were established by spoil sidecasting).

The overall volume of cut material associated with the PNG Gas Project is currently estimated to be approximately 7.9 million m^3.

The assessment in Table 3.5 above summarises the difficulties of spoil handling in steep terrain and the substantial environmental costs of multiple handling of material, constructing stable dump sites and widening access ways to allow the additional truck traffic to safely operate.

For these reasons, the PNG Gas Project intends to follow standard practice in Papua New Guinea with regard to the management of spoil—i.e., spoil will be sidecast in situ. The impacts of spoil sidecasting on vegetation and water quality are fully assessed in Chapter 13.

3.9 Basis for Selecting the Proposed Project

The basis for selecting the nature of the project as proposed in this EIS is implicit in the review of the strategic and tactical options set out in Sections 3.3 to 3.8 above.

Of these factors, the most important have been the following:

- Product: The exclusion of LPG product from the project scope in order to maintain overall project viability.
- Arrangement of facilities: The maximum use of existing facilities and RoWs.
- Hides Ridge field facilities: Infeasibility of drilling production wells from the Tagari River valley.

4. Policy, Legal and Administrative Framework

The Independent State of Papua New Guinea promotes the development of its petroleum resources by policies to encourage investment. This is supported by a regulatory framework that ensures that developments manage social and environmental impacts. It is a priority of the government that the people of Papua New Guinea benefit from the development of their resources. The *Oil and Gas Act 1998* provides that petroleum resources belong to the State and that licences are required to explore, recover or sell these resources.

In particular, the Fourth National Goal and Directive Principle of the Constitution states the following:

> We declare our Fourth Goal to be for Papua New Guinea's natural resources and environment to be conserved and used for the collective benefit of us all, and be replenished for the benefit of future generations.

4.1 PNG Legislation and Agreements

The two principal pieces of PNG legislation regulating the environmental and socioeconomic aspects of the PNG Gas Project are the *Oil and Gas Act 1998* and the *Environment Act 2000*.

4.1.1 *Oil and Gas Act 1998*

The principal legislation governing the exploration, development, processing and transportation of petroleum in Papua New Guinea is the Oil and Gas Act. This act stipulates five types of petroleum licence for the petroleum industry:

- Petroleum prospecting licence (PPL).
- Petroleum retention licence (PRL).
- Petroleum development licence (PDL).
- Petroleum processing facility licence (PPFL).
- Pipeline licence (PL).

The PNG Gas Project will require variations and extensions to be made to a number of existing petroleum development licences and will require five new licences (Table 4.1). While the licensing strategy and proposed applications have been identified, the formal application for any licence required will not be made until the relevant participants have taken a decision to do so.

Applications for all the new licences and variations and extensions to existing development licences will be based on a single master development plan. Applications for these licences will be accompanied by detailed information about the development proposal, including its social and environmental implications. When granting a petroleum development licence, the Minister must be satisfied that the project provides adequately for the protection of the environment and the welfare of the people of the area (s57). Pipeline and petroleum processing facility licence applications also require environmental management particulars, including the results of environmental studies.

Table 4.1 Petroleum licences scenarios for the Papua New Guinea Gas Project under the *Oil and Gas Act 1998*

Licence		New	Variation	Extension
PDL-1			√	√
PDL-2			√	√
PDL-4			√	√
PDL-5			√	√
PRL-12	New PDL to succeed PRL-12	√		
PL-1	Transports gas from Hides1 & 2 to the Hides Gas Plant		Minor	
PL- 2	Transports oil and liquids from Kutubu to the Kumul offshore loading terminal		√	√
PL	Gas, liquids and glycol return pipelines between Hides Production Facility and Kutubu.	√		
PL	Rich gas pipeline between Gobe and Kutubu	√		
PL	Sales gas pipeline from Kutubu to the PNG–Australian border	√		
PPFL	Central Gas Conditioning Plant at Kutubu	The Central Gas Conditioning Plant may be licensed separately as a PPFL or included within the PDL-2 variation.		

This EIS will assist in fulfilling the environmental and social requirements of the Oil and Gas Act and support the licence applications.

4.1.2 *Environment Act 2000*

4.1.2.1 Environmental Impact Statement

The legal framework for regulating the environmental effects of the PNG Gas Project is administered by the Department of Environment and Conservation (DEC) under the *Environment Act 2000*

On 10 February 2005, Esso submitted a Notification of Preparatory Work on Level 2 and Level 3 Activities to the DEC under the provisions of the Environment Act.

The notification reported that the PNG Gas Project would involve:

> recovery, processing, storage or transportation of petroleum products requiring the issue of a Petroleum Development Licence and a Pipeline Licence under the *Oil and Gas Act 1998*.

The PNG Gas Project is a Level 3 activity under the Environment Act (Category 18.1), for which an environmental impact statement (EIS) is required. Accordingly, on 21

February 2005, DEC issued a Notice To Undertake Environmental Impact Assessment under Section 50 in the following manner:

- Submit an Environmental Inception Report (EIR) under Section 52. The objectives of the EIR were to:
  - Identify the potential environmental and social issues of developing the project.
  - Set out the scope of the EIS to address these issues.
  - Initiate the process of stakeholder consultation.
  - Enable DEC to review the proposed EIS scope and redress any shortcomings.

  Esso submitted the EIR in March 2005. DEC approved the EIR in April 2005 as listing 'all the relevant issues relating to the project's impacts on the environment' (DEC, 2005).

- Submit an EIS under Section 53 (this document).

The requirements of the EIS are described in the DEC (2004) publication GL-Env/02/2004, *Guideline for Conduct of Environmental Impact Assessment and Preparation of Environmental Impact Statement.* This guideline requires the EIS to assess potential environmental and social impacts of the PNG Gas Project and to describe how the proponent intends to avoid, manage or mitigate these impacts.

4.1.2.2 Approval Process

Figure 4.1 shows the EIS approval process stipulated by Section 51 of the Environment Act. The EIS is submitted to the Director who has 30 days to inform the proponent how long the assessment period will be. The Director, while assessing the EIS, may refer the EIS to a number of bodies, such as an environment consultative group or a public enquiry committee. If a provincial environment committee has been established, the Director must refer the EIS to the committee for its comments.

After this preliminary assessment period, the Director will make the EIS available for public review; and during this time, the proponent may be required to make public presentations or submit a program of public review.

Following the public review, the Director must make a decision to accept or reject the EIS. If the EIS is rejected, the decision can be appealed under Section 68 of the Environment Act. If the EIS is accepted, the Director must refer the decision to the Environment Council together with an assessment report and any public submissions. The Environment Council then has 90 days to decide whether it is satisfied with the EIS. If the Council is not satisfied with the EIS, it is returned to the proponent for revision and resubmission. If the Council is satisfied with the EIS, it advises the Minister to approve the proposed activity in principle. The proponent can then apply for a permit to carry out its project.

4.1.2.3 Environmental Permit and Management

An application for a permit for a Level 3 activity must be accompanied by an EIS (e.g., this document). Sections 65 and 66 of the Environment Act provide criteria for granting and setting conditions of permits respectively. Under Section 66, these conditions may include installation of monitoring equipment (s.66(1)(c)), preparation and carrying out an environmental management program (s.66(1)(d)), audits (s.66(1)(g)), emergency response (s.66(1)(h)), baseline studies (s.66(1)(k)) and rehabilitation (s.66(1)(l)). Part VII of the Environment Act provides for permits for the use of water resources in Papua New Guinea, including dams, diversions, discharges of wastes and/or contaminants and the taking of water resources via water use and investigation permits. The Environmental (Water Quality Guidelines) Regulation 2002 prescribes water quality guidelines to be met beyond a mixing zone by discharges to the natural water environment.

Chapter 18 describes the proposed environmental management framework for the PNG Gas Project.

4.1.3 Other Legislation and Regulations

The legislation of Papua New Guinea has been reviewed to identify those acts and regulations that are applicable to the preparation of the EIS and the implementation of the project. Table 4.2 provides a summary of the applicable legislation.

Table 4.2 Other environmental legislation and regulations

Statutory Instrument	Implications for PNG Gas Project
National Parks Act (Chapter 157)	None involved
Conservation Areas Act 1978 (Chapter 362)	Locations of conservation areas and potential impacts to be assessed (Kutubu, formerly Digimu, Aird Hills)
The Fauna (Protection and Control Amendment) Act (Chapter 154)	Needs measures to prevent workforce poaching
The International Trade (Fauna and Flora) Act (Chapter 391)	Needs measures to prevent workforce poaching
Dumping of Wastes at Sea Act 1979	Does not apply
Prevention of Pollution at Sea Act (Chapter 369)	Standard offshore operating requirements for contractors
Oil and Gas Regulation 2002	Manuals: • Safety Instructions for Operations • Emergency Response Approvals: • To interfere with any existing pipeline or with any road, airstrip, telephone or power transmission line or cable, radio mast or other public utility or facility • To conduct geophysical, geological and/or their related operations in the search for petroleum • To fire shot inside mandated distances • To drill a well or deepen, sidetrack, complete, recomplete, workover, plug back or materially alter an existing approved well program or suspend or abandon

Table 4.2 Other environmental legislation and regulations (cont'd)

Statutory Instrument	Implications for PNG Gas Project
Oil and Gas Regulation 2002 (cont'd)	• To dispose of liquids from well drilling or workover • To commence construction of a facility • Enhanced recovery, including gas cycling • Disposal of any fluid or other substance to an underground formation through a well • Pipeline safety, operating, commissioning and emergency procedures and start of operations Metering: • Certification • Oil, gas and water production from individual pools
Environment Regulations	
Environment (Procedures) Regulation 2002	Procedures of the Environment Council (who will provide advice to the Minister on this EIS)
Environment (Permits and Transitional) Regulation 2002	Procedures for applications for, processing of, appeals against and compliance with environmental permits
Environment (Prescribed Activities) Regulation 2002	Gas Project is Level 3 activity (Category 18.1) requiring an environmental impact statement (this document)
Environment (Water Quality Guidelines) Regulation 2002	Permit required to set a mixing zone, at whose boundary prescribed water quality criteria are to be met
Environment (Fees and Charges) Regulation 2002	Procedures for permit fees and charges for water use, discharges to water and disturbed area runoff Fees and charges to be set by DEC

World Bank standards will be adopted in the absence of PNG criteria.

In addition, a range of acts and regulations cover commercial, professional and health issues of relevance to the project (Table 4.3).

Table 4.3 General legislation and regulations

• *Industrial Safety, Health and Welfare Act* (Chapter 175) • Industrial Safety, Health and Welfare Regulation (Chapter 175) • Industrial Safety (Explosive-Powered Tools) Order (Chapter 175) • *Explosives Act* (Chapter 308) • *Building Act* (Chapter 301) • Building Regulations 1994 • *Licensing of Heavy Vehicles Act* (Chapter 367) • *National Institute of Standards and Industrial Technology Act 1993* • *Road Maintenance Act* (Chapter 246) • *Customs Act* (Chapter 101) • Customs Regulation (Chapter 101) • Customs (Prohibited Imports) Regulation 11 • *Employment Act* (Chapter 373) • *Employment of Non-Citizens Act* (Chapter 374) • Public Health (Drinking Water) Regulation (Chapter 226) • Public Health (Sanitation and General) Regulation (Chapter 226) • Public Health (Septic Tanks) Regulation (Chapter 226) • *Inflammable Liquid Act* (Chapter 311) • Inflammable Liquid Regulations (Chapter 311) • Motor Traffic Regulation (Chapter 243) • *Radio Spectrum Act 1996* • Radio Spectrum Regulation 1996	• *Telecommunications Act* 1996 • *Trade Licensing Act* (Chapter 96) • *Accountants Act 1995* • *Business Names Act* (Chapter 145) • Business Names Regulation (Chapter 145) • *Civil Aviation Act 2000* • Civil Aviation Regulation (Chapter 239) • *Investment Promotion Act 1992* • Investment Promotion Regulation 1992 • *Medical Registration Act* (Chapter 398) • Medical Registration By-Laws (Chapter 398) • *Medicines and Cosmetics Act 1999* • Nursing Registration By-Laws (Chapter 398) • *Professional Engineers (Registration) Act 1986* • *Central Banking Act 2000* • Central Banking (Foreign Exchange and Gold) Regulation • *Customs Duty (Rebate) Act* (Chapter 390) • *Excise Act* (Chapter 105) • *Goods and Services Tax Act 2003* • *Stamp Duties Act* (Chapter 117) • Stamp Duties Regulation (Chapter 117)

4.1.4 International Environmental Agreements

Table 4.4 summarises the international treaties, conventions and protocols relevant to the PNG Gas Project and to which the Independent State of Papua New Guinea is a signatory.

4.1.5 Torres Strait Protected Zone

The Torres Strait has a unique, transnational regulatory jurisdiction, and this poses some challenges for the PNG Gas Project.

The Torres Strait Treaty, ratified in 1985 between Australia and Papua New Guinea, originated in the need for a legal basis for the border between the two countries (which it has defined). The treaty also recognises the areas of jurisdiction for swimming and sedentary marine species in Torres Strait and establishes an area known as the Torres Strait Protected Zone (TSPZ). The treaty sets outs a framework to guide both countries in the management, conservation and sharing of fisheries resources in and around the TSPZ. The TSPZ operates under a joint ministerial authority of the two countries (the Protected Zone Joint Authority).

In 1985, the PNG and Australian governments ratified the Treaty Between Australia and the Independent State of Papua New Guinea (‘Torres Strait Treaty’), which formalised a complex set of boundaries and regulations relating to the Torres Strait region.

The Australian *Torres Strait Fisheries Act 1984* gives effect to those provisions of the Torres Strait Treaty relating to the control of fisheries within the TSPZ.

The principal purpose in establishing the TSPZ was to acknowledge and protect the traditional way of life and livelihood of the indigenous inhabitants of the area, including their traditional fishing practices and right of free movement.

The treaty creates an unusual situation, in that PNG citizens have use and movement rights in Australia and vice versa. Similarly, the two countries share the task of managing the resources of the TSPZ.

The impact and proposed mitigation measures of the PNG Gas Project relevant to PNG interests in TSPZ are presented in Chapter 14.

The boundaries in Torres Strait are shown in Figure 4.2.

Table 4.4 Applicable international agreements to which PNG is a signatory

Title	Objective	PNG Gas Project Issue
International Plant Protection Convention (1976)	Promotes international cooperation to control pests and diseases of plants and plant products	Construction hygiene
Convention for the Protection of the Natural Resources and Environment of the South Pacific Region (SPREP) (1990)	Protection, development and management of the South Pacific marine and coastal environment	Biodiversity studies and management
Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal Adopted by the Conference of the Plenipotentiaries on 22 March 1989 (Basel Convention) (1995)	A major multilateral agreement, relating to transboundary movement in, and responsible management of, hazardous and other wastes	Hydrotest water disposal between Australia and Papua New Guinea
Vienna Convention for the Protection of the Ozone Layer (the Vienna Convention) (1993)	Protection of the ozone layer	Compliance with standards and protocols
Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention) (1993)	An international regime for the 'conservation and wise use' of wetlands and waterfowl populations	Construction works and operations in the catchment of Ramsar-listed Lake Kutubu
Kyoto Protocol to United Nations Framework Convention on Climate Change (1997)	Has as its objective the reduction of negative changes to the earth's climate, with a particular focus on greenhouse gases. Places onus on industrialised countries (Annex 1 countries) to reduce emissions. Developing countries like PNG are exempt from the reduction requirement.	Greenhouse gas emissions to be reported to the Greenhouse Gas/Ozone Unit, Department of Environment and Conservation
Convention on Biological Diversity (1993)	Preserving and sustaining biological diversity	Biodiversity studies and management
International Convention for the Prevention of Pollution from Ships 1973 (as modified by the London Protocol of 1978) (MARPOL) (1994)	The ICPPS requires member states to minimise the risk of marine pollution from ships, in particular oil tankers	Marine pipelaying vessel operations
United Nations Convention on the Law of the Sea (UNCLOS) (1994)	Multilateral agreement on the law of the sea, in particular the protection and preservation of the marine environment	Marine biodiversity analysis and management
Convention to Ban the Importation into Forum Island Countries of Hazardous Wastes and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes Within the South Pacific (Waigani Convention) (2001)	Proscription of international trade in hazardous waste and notification procedures, monitoring mechanisms and cooperative authorities	Plant and materials selection Hydrotest water disposal between Australia and Papua New Guinea

4.2 Socioeconomic Impact Assessment Requirements

Consideration of social and economic impacts is an integral part of the assessment of the PNG Gas Project under the Environment Act and the Oil and Gas Act.

Section 51 of the Environment Act requires that the likely social impacts of the proposed activity be set out in the EIS in accordance with the issues identified in the approved environmental inception report (s53). Two DEC guidelines apply:

- DEC publication GL-Env/02/2004, *Guideline for Conduct of Environmental Impact Assessment and Preparation of Environmental Impact Statement*, s6.
- DEC publication *Social Impact Assessment Guideline*, pp.1–8.

A socioeconomic and cultural assessment has been conducted as part of this EIS in accordance with these guidelines. In addition, the results of landowner identification and social mapping surveys under the Oil and Gas Act requirements have been summarised to facilitate an understanding of the PNG Gas Project's socioeconomic issues and impacts and how they are to be addressed. (see Chapter 15, Sociocultural Impacts and Mitigation Measures.

Section 47 of the Oil and Gas Act requires landowner identification and social mapping studies for PDLs, PRLs and PPLs. Section 48 stipulates that, before a PDL is granted, a development forum must be convened to gather and consider the views of the stakeholders in the project. Section 49 states that the development forum will not be convened until:

- Full-scale social mapping is complete.
- The Minister is satisfied that correct landowner representatives have been identified.
- The applicant has submitted a socioeconomic impact statement as part of an environmental impact statement.
- The director has prepared and presented a proposal for equitable distribution of equity and royalty benefits to project-area landowners.

The results of the social mapping and landholder identification studies for the PNG Gas Project are to appear in four reports corresponding broadly to the ethnic composition of the project area: Hides to Kutubu, Kutubu, Gobe, and Omati.

Likewise fundamental to the PNG Gas Project's socioeconomic impacts is the Gas Project Co-operation and Sharing Agreement (GPCSA). The GPCSA is intended to govern the sharing of project benefits between the national, provincial and local levels of government and the landowners of the project impact area (see also Chapters 11 and 15).

This EIS addresses the socioeconomic assessment requirements outlined above by way of two additional sets of investigations: social impact assessment, and surveys of archaeological and cultural heritage. The scope of these studies and their findings are detailed in Supporting Study 10 and summarised in Chapters 11 and 15.

5. Public Consultation

This chapter describes the public consultation program that has been undertaken and is ongoing for the PNG Gas Project. This chapter provides an overview of the project's public consultation and disclosure program (Section 5.1), outlines the regulatory requirements related to public consultation (Section 5.2), lists the PNG Gas Project's stakeholders (Section 5.3), describes the public consultation and disclosure program that was implemented for the project (Section 5.4), summarises the project consultation schedule (Section 5.5), documents stakeholder consultation outcomes (Section 5.6), and describes processes for continuing stakeholder consultation into the future (Section 5.7).

5.1 Overview

A key component of the EIS investigations and approval process is an effective, ongoing communications program involving the Operator and the other PNG Gas Project co-venturers, national, provincial and local government, local communities, non-governmental organisations (NGOs) and various other stakeholders.

The project's consultation and disclosure program has involved extensive interactions with stakeholder groups using multiple approaches designed to suit each group. This effort has included a survey of 1,174 households in the project area related to the Social Impact Assessment. Information about the project has been presented to communities throughout the project area as part of a Gas Awareness program. There have been 26 meetings with local landowner companies and ongoing regular consultation with the Independent State of Papua New Guinea ('the State') government departments. Archaeological studies associated with the EIS and SIA have included consultations with over 350 landowners in the project area. Consultation with NGOs has included both formal meetings and presentations and ongoing regular informal involvement of local project area-based NGOs**.**

The PNG Gas Project's public consultation program builds on the consultation foundation established during previous oil and gas exploration activities and operations in the area and the previously proposed PNG-to-Queensland Gas Project.

5.2 Independent State of Papua New Guinea Consultation Requirements

Public consultation is a requirement of the State's environmental impact assessment process under the Environment Act. Guideline notes from the State's Department of Environment and Conservation (DEC, 2004) state that an EIS's Executive Summary should provide 'details of the consultation program undertaken by the applicant, including the degree of public interest'**.**

In addition, as part of the EIS approval process under the *Environment Act 2000* (Section 51), the Director will make the EIS available for public review after a preliminary assessment period. During this time the proponent may be required to make public presentations or submit a program of public review.

Consultation is also required to be undertaken as part of the social mapping, landowner identification and social impact assessment process stipulated by the Oil and Gas Act. These processes are intended to provide information about social and environmental implications of a project.

A process of consultation will be undertaken by the State in a development forum prior to finalisation of the Gas Project Co-operation and Sharing Agreement (GPCSA) (see Chapters 11 and 15 for information concerning the GPCSA.) The GPCSA is an agreement between the state, project area landowners, and affected local-level and provincial governments; it sets out how the parties to the agreement will share royalty, development levies and other cash and non-cash benefits associated with the PNG Gas Project.

5.3 Stakeholders

A comprehensive list of stakeholders has been developed and grouped into broad categories reflecting differing interests in relation to the PNG Gas Project. These categories are shown in Box 5.1.

Box 5.1 PNG Gas Project Stakeholders

- Independent State of Papua New Guinea:
  - PNG Gas Project Ministerial Committee
  - Prime Minister’s Department
  - PNG Gas Project Office
  - State Solicitors Office
  - Department of Petroleum and Energy
  - Department of Environment and Conservation
  - National Fisheries Authority
  - PNG Forest Authority
  - Department of Lands and Physical Planning
  - Department of Finance and Treasury
  - Department of National Planning and Monitoring
  - Department of Foreign Affairs and Immigration
  - Expenditure Implementation Committee
  - Department of Trade and Industry
  - Department of Labour and Industrial Relations
  - Department of Provincial and Local Level Government
- Provincial Governments:
  - Gulf Province
  - Southern Highlands Province
  - Western Province
- Minerals Resources Development Company
- Bank of Papua New Guinea
- Landowners along the proposed onshore and offshore pipeline route and in the vicinity of the proposed project facilities (a list of project area villages is provided in Supporting Study 10, Social Impact Assessment).

Box 5.1 PNG Gas Project Stakeholders (cont'd)

- Landowner companies and associations, including National Energy Company Limited (NECL), the proposed umbrella company for project landowner groups, as well as other existing landowner companies providing services to the petroleum industry (a list of main landowner companies and associations is provided in Supporting Study 10, Social Impact Assessment).
- NGOs, including:
  - WWF South Pacific
  - The Nature Conservancy, Pacific Island Countries Program
  - Conservation International
  - Community Development Initiative
  - PEACE Foundation Melanesia
  - Centre for Environmental Law and Community Rights
  - Environmental Law Centre
  - Faith-based, project-area NGOs (e.g., Evangelical Church of Papua, Catholic, Wesleyan and Seventh Day Adventist).
- Industry groups, including:
  - Forestry industry (PNG Forest Authority, PNG Forest Research Institute, log export monitors, forestry industry groups)
  - Fishing industry (National Fisheries Authority, fishing industry groups, fishing companies)
  - Mining and petroleum groups (PNG Chamber of Mines and Petroleum)
- Research organisations, including:
  - PNG Museum
  - National Research Institute
  - University of Papua New Guinea
- Torres Strait Protection Zone
  - Protected Zone Joint Authority
  - Torres Strait Fisheries Management Advisory Committee
- Others, e.g., co-venturer employees, prospective contractors, financiers, insurers, shareholders associated with co-venturer companies, and other individuals.

5.4 Public Consultation and Disclosure Program

5.4.1 Consultation History and Context

The PNG-to-Queensland Gas Project was first proposed in 1995. During the late 1990s, the project operator at the time, Chevron Niugini (a subsidiary of Chevron Corporation), carried out environmental, social and feasibility studies and public consultations, including social surveys that led to the presentation of the 1998 Environmental Plan (NSR, 1998a) in Mendi, Moro, Gobe, Kikori, Kerema and Port Moresby. The Office of Environment and Conservation (now Department of Environment and Conservation [DEC]) conducted its own public consultation related to the proposed project at these locations to receive feedback from communities in the proposed project area. Although the project has since undergone various design changes, this previous consultation work allowed many people to become broadly familiar with the project. The current public consultation and disclosure program builds on this foundation.

5.4.2 Goals

The goals of the PNG Gas Project's public consultation and disclosure program are to:

- Build an understanding among stakeholders to reduce the potential for stakeholder disaffection resulting from a misunderstanding of the project and to provide a structure for stakeholder inclusion in the environmental impact assessment process.
- Ensure that relevant government departments and local communities are properly informed about the PNG Gas Project and that there is a structure for these stakeholders to provide input to the environmental assessment process.
- Ensure consideration is given to the valid concerns and interests of stakeholders.
- Ensure that the applicable regulatory requirements related to public consultation and disclosure are met.
- Provide the groundwork for:
  - Final presentation of the EIS and its Supporting Studies.
  - Ongoing consultation throughout the life of the project; i.e., construction, operations and decommissioning phases.

5.4.3 Consultation Methods

The project's public consultation and disclosure program uses both formal (e.g., presentations, meetings, surveys and workshops) and informal (e.g., visits to villages in the project area, leaflet and brochure distribution, face-to-face and telephone conversations, emails or facsimiles) methods to disseminate information on and to solicit comments from stakeholders regarding the project.

The methods used in the consultation and disclosure program are listed below:

- Face-to-face discussions, telephone conversations, emails and facsimiles with key individuals (at all levels of stakeholder involvement) to disseminate information about the project and to receive questions, comments, opinions and concerns. This approach has included interviews with local landowners during archaeological surveys to identify sites of archaeological or cultural importance (Plates 5.1 and 5.2).
- Information briefings and workshops with national, provincial and local governments, local landowner organisations and NGOs to provide information about the project, to discuss specific issues, and to solicit questions, comments, opinions and concerns.
- A household survey to gather information for the social impact assessment and the social mapping effort, to provide information about the project, and to record questions, comments, opinions, and concerns regarding the project. The household survey is discussed in Annex 5.4 of Supporting Study 10.
- Presentation of information about the project to local community members, such as the Gas Awareness program, which included presentations to project-area villages (Plates 5.3 and 5.4) and to Western Province villages adjacent to the offshore

pipeline route. Figure 5.1 shows the locations of the villages visited during the Gas Awareness program to date. Prior warning of Gas Awareness program visits enabled landowners from surrounding areas to attend the presentations. The Gas Awareness program sessions held in October 2005 utilised A1 size flipcharts with 3-D projections, maps and GIS data to describe where project components would be located.

- Distribution of written material, such as brochures in English and Tok Pisin at key milestones in the environmental assessment process such as after the submission of the EIR (see Attachment 2.1). Gas Awareness program sessions in April 2005 included the distribution of information leaflets in Tok Pisin and local languages including Fasu, Foe, Huli, Kerewo, Kewa, and Kibiri (see Attachment 2.2 for the English version of the leaflet distributed). The EIS Executive Summary will be produced in English and Tok Pisin for distribution after submission of the EIS to DEC.
- Press releases may be used as needed for project-related information dissemination.

Village liaison officers have been established in key project area communities to facilitate communications between the PNG Gas Project and local landowners (see Section 5.4.4).

Each stakeholder group is unique regarding its interest in and understanding of the project, its access to the project and its literacy level. The public consultation and disclosure program therefore addresses project issues by adopting appropriate approaches for each group as described in Table 5.1.

The EIS will be made available for public review after its submission to the Director of DEC. The Operator has consulted with DEC on the nature of the consultation to be undertaken, the exhibit locations for the EIS and the media in which the public review will be advertised. Presentations of key findings and recommendations of the EIS will be made to stakeholder groups via a 'roadshow'. This will provide an opportunity for DEC and the project to not only outline the EIS but to respond to questions and concerns raised in the household survey and in previous consultation sessions. The 'roadshow' satisfies the requirement under Section 51 of the Environment Act to make public presentations or submit a program of public review after the submission of the EIS.

In addition to the approaches listed in Table 5.1, there are a number of avenues landowners can use to raise any issues or concerns regarding the PNG Gas Project. These are:

- A letter to the PNG Gas Project Community Affairs field staff.
- Orally when PNG Gas Project Community Affairs field staff visit their communities.
- Through various survey mechanisms such as the Household Survey.

Table 5.1 Approach to stakeholder consultation

Stakeholder	Approach
Landowners and villagers	Informal meetings between PNG Gas Project Community Affairs field personnel and village leaders. Regular contact by PNG Gas Project Community Affairs field personnel with villagers to provide project development updates. Engaging and training village liaison officers to provide a two-way information exchange between project-area communities and the PNG Gas Project Community Affairs team. Distribution of leaflets and brochures (in English, local languages and Tok Pisin) and presentations at appropriate stages (e.g., the Gas Awareness programs held in April 2005 and October 2005. The latter presented technical aspects of the project to communities). Household survey for the SIA. Meetings between the Independent Advisory Company (IAC) and landowner companies. (See Plate P5.5). The IAC is tasked with the establishment of a Local Business Development (LBD) program for the project, which is expected to use an umbrella landowner company for all project landowners (National Energy Company Limited (NECL)). Information through training programs to improve awareness about employment opportunities for project-area community members. Interviews conducted by archaeologists with local landowners to locate sites of archaeological or cultural significance. EIS information briefing 'roadshow'.
Non-Governmental Organisations	Initial contact by telephone, letter, email or facsimile by PNG Gas Project representatives to determine level of interest. Information meetings and distribution of the Environmental Inception Report (EIR) brochure, which provides a summary of the PNG Gas Project's EIS approach. PNG Gas Project representatives to conduct follow-up briefings and maintain contact and respond according to level of interest and concerns voiced. Participation of local faith-based NGOs in local community presentations (e.g., Gas Awareness program visits). EIS information briefing 'roadshow'.
Industry-Related Groups (e.g., logging and fishing)	EIS technical team specialist discussion with industry group representatives to identify issues of concern. EIS information briefing 'roadshow'.
Research Organisations	Consult as required. EIS information briefing 'roadshow'.
Department of Environment and Conservation (DEC)	Regular EIS progress meetings with the EIS technical team incorporating workshops later in the process to discuss the results of specialist studies. Regular contact with DEC officers via telephone, letters and facsimile by the Operator and its consultants. EIS information briefing 'roadshow'.
Department of Petroleum and Energy (DPE)	Regular meetings to inform DPE of consultation activities and developments as per requirements of the Oil and Gas Act and the Gas Agreement. Representatives of DPE attend the DEC EIS progress meetings mentioned above. PNG Gas Project representatives maintain contact with relevant personnel via telephone, email, letters and facsimile. EIS information briefing 'roadshow'.
PNG Gas Project Working Group	Meetings of representatives of the various impacted government departments to prepare and progress work plans required by the PNG Gas Project. PNG Gas Project representatives are invited to participate as observers. EIS information briefing 'roadshow'.
PNG Gas Project Ministerial Committee	Meetings to provide project updates and assorted technical meetings.
Provincial governments and other government Departments	Consultation with and input to SIA household survey with provincial government representatives. Meetings to provide information on project progress and to address any queries or concerns. PNG Gas Project representatives maintain contact with relevant personnel via meetings, telephone, email, letters and facsimile. EIS information briefing 'roadshow'.

- Through the village liaison officer whose job it is to listen to landowners and report back to PNG Gas Project Community Affairs field managers.
- Through their landowner association.

5.4.4 Consultation Management Resources

Community relations issues are managed by the PNG Gas Project Community Affairs field team, which is supported by the PNG Gas Project Logistics field team. The PNG Gas Project Community Affairs team is responsible for general project field work, landowner programs and land identification and landowner issues. The team coordinates its activities with Oil Search, the current oil project operator. Oil Search provides its own community affairs support team (such as village liaison officers) as needed for PNG Gas Project-related field activities.

Core common activities conducted by the Oil Search and PNG Gas Project Community Affairs organisations are as follows:

- Land management and compensation.
- Identification of key community representatives.
- Benefits management.
- Local business development.
- Industrial relations.
- Social/community development.
- Training and localisation.
- Management of two-way communication of information.
- Government relations.
- Liaison with the Australian Community Affairs group of Esso and Oil Search.

The PNG Gas Project Community Affairs gas field managers are also participating in the process related to the development of the GPCSA in conjunction with various levels of government and project area landowners.

Village liaison officers play an important role in assisting with communications between PNG Gas Project and Oil Search personnel and the project area communities. Village liaison officers live locally in their communities and are fluent in the local language. Their main role is to disseminate information about petroleum operations, including the PNG Gas Project to the community and to represent the PNG Gas Project Community Affairs team in the field. Village liaison officers are usually the first point of contact for landowners wishing to raise an issue concerning the project or the existing oil operations. Village liaison officer also accompany project-contracted specialists such as archaeologists as they visit project-area communities.

Specialist consultants involved in the environmental impact assessment process provide assistance with stakeholder forums, such as meetings with government departments and information briefings to non-governmental organisations. Consultations were undertaken during the specialist study programs associated with the EIS and the Social Impact Assessment.

5.5 Consultation Schedule

The consultation schedule for the PNG Gas Project has been designed to provide the regular dissemination of up-to-date information and to provide stakeholders with the opportunity to communicate their issues and concerns. In terms of scheduling, care has been taken to avoid over-saturation with information and the sharing of partially completed reports, which can lead to confusion. Instead, activities are typically scheduled to coincide with appropriate project milestones. A broad outline of the project's consultation schedule is provided in Figure F5.2.

Public consultation and disclosure during the environmental assessment process has been undertaken in three main phases:

- **Phase 1: Consultation with stakeholders on the environmental assessment process draft terms of reference.** The Operator has consulted with key stakeholder groups on the scope of the environmental impact assessment process by presenting the Environment Inception Report to DEC and DPE and to NGOs and consulted with provincial government officers and landowner representatives on the scope of the SIA studies and the household survey questionnaires. Some of these consultations were undertaken outside the government's formal environmental assessment screening process (e.g., consultation with NGOs), but within the active phase of specialist studies, thereby allowing stakeholder issues to be considered as part of the impact assessment process.

- **Phase 2: Consultation with stakeholders on the draft EIS documents.** This consultation has been largely with DEC and DPE on the proposed content of the EIS and its supporting studies. The consultation has included nine meetings to present and discuss the results of the specialist technical studies and two workshops to discuss the contents of the draft EIS.

- **Phase 3: Consultation with stakeholders on the EIS during the government's formal assessment process.** This phase of stakeholder consultation will be implemented via an EIS 'roadshow' that will be conducted as soon as possible after the formal submission of the EIS to the DEC. The 'roadshow' will involve approximately two weeks of presentations to and meetings with stakeholder groups, including local communities and NGOs, located in Port Moresby, Mendi, Tari, Moro, Gobe, Kikori and Kerema and other sites yet to be decided. The 'roadshow' allows local landowners, NGOs and other interested groups to comment on the key findings of the EIS and to raise residual issues for consideration by the State in their formal assessment and analysis of the EIS.

5.6 Documentation of Stakeholder Consultation

The information obtained from all forms of public consultation is documented in meeting notes, consultation logs, and survey sheets and as part of various EIS and SIA studies (e.g., archaeological studies). These records are maintained by the project.

Consultation logs established to keep track of consultations undertaken for the project include the April 2005 Gas Project Awareness Program village visits and logs of meetings with government departments, landowner NECL meetings, non-governmental organisations and industry groups (e.g., forestry, fisheries). A summary of the public consultation undertaken in 2005 for the project is provided in Attachment 2.3. The summary lists the stakeholders, meeting dates and locations, number of attendees and organisations represented.

5.7 Consultation Outcomes

Table 5.2 is a summary of issues raised during public consultation sessions and other interactions with stakeholders and illustrates how issues have been and are proposed to be addressed by project design, mitigation measures, and the development and implementation of systems and processes.

Table 5.2 Project response to issues raised during consultation sessions

PNG Issue	Project Response
Potential for landowner issues related to construction impacts as the pipeline enters the Omati River.	Hydrological investigations of the Omati River landfall were initiated and are reported in Section 13.4, Hydrology, and Supporting Study 13.
The Torres Strait Protection Zone (TSPZ) is identified as habitat for several threatened species.	Potential impacts on the TSPZ habitat and fisheries were investigated as part of the EIS marine study (Supporting Study 9) and are addressed in Chapter 14.
The people in coastal villages of the Western Province adjacent to the proposed pipeline need to be considered in the EIS consultation process.	A consultation program for all PNG communities along the coast and on the offshore islands adjacent to the pipeline route was undertaken in October 2005. This consultation effort is reported in the Social Impact Assessment (Supporting Study 10).
Recommendation that pipeline construction occur during prawn fishery closure period.	The fishery closure period does not apply to the section of the prawn trawling grounds traversed by the proposed offshore sales gas pipeline (see Section 14.4).
Sediment build up from the Fly River Delta could pose a threat to pipeline integrity and whether monitoring studies are required.	Based on recent data, a physical risk to the pipeline is not expected. (see Supporting Study 9).
Decommissioning plans for the pipeline.	See Section 8.6
Anchor drag impacts.	Temporary localised scouring of the seabed will occur due to laybarge repositions during pipelaying activities. This issue is addressed in Section 14.2.
Security concerns related to not burying the pipeline offshore.	Globally most offshore pipelines are not buried. No security concerns are envisaged and the offshore pipeline will only be buried where it needs protection (e.g., in shallow water, high current areas, shipping lanes, etc.). See Section 7.3.
Potential for noise or heat impacts from gas moving through the pipeline.	No such impacts are expected.
Several questions have been raised about mitigation options for RoW rehabilitation.	Mitigation measures are addressed in the EIS in Section 13.3, Soils.
Discussion on whether the 1999 cultural heritage survey in the TSPZ (Hitchcock, 2000) will be included with the EIS.	The factual contents of the report have been reviewed and are included in the Social Impact Assessment (Supporting Study 10). The recommendations of the 1999 survey (Hitchcock, 2000) are superseded by the findings and recommendations of the October 2005 report (Hitchcock, 2005).

Table 5.2 Project response to issues raised during consultation sessions (cont'd)

PNG Issue	Project Response
Query regarding the status of the road between Gobe and Kopi.	The road has been gazetted as a public road under the PNG Land Act (Chapter 185, refer PNG National Gazette, No. G73, 5 September, 1996). However, the road essentially functions as a private road at present due to access difficulties, in particular the ferry crossing at Kaiam and the lack of connectivity to other public roads.
Will there be on site monitoring of air quality.	An analysis of the project's air emissions indicates that air quality monitoring is not warranted (see Section 13.8)
In the absence of criteria for PNG, the project needs to determine a value for ambient criteria for NO_2 emissions.	Criteria for NO_2 are included in Section 13.9.
One dwelling is potentially in the noise impact zone.	No adverse noise impacts to residents in the vicinity of the project's facilities are predicted during operations (see Section 13.9)
Query on whether construction will take place on a 24 hours per day, 7 days per week basis.	Work may take place 24 hours per day, 7 days per week.
Query whether the PNG Gas Project awareness and consultation process covered the Torres Strait community regarding concerns about perceived project benefits, which may not be the same comparing sea and land ownership.	A consultation program for all PNG communities along the coast and on the offshore islands adjacent to the pipeline route was undertaken in October 2005. This consultation is reported in the Social Impact Assessment (Supporting Study 10).
Distribution of benefits from the PNG Gas Project or previous projects.	Distribution of benefits from the PNG Gas Project will be specified in the Gas Project Co-operation and Sharing Agreement (see Chapters 11 and 15).
Queries related to the establishment of NECL as the umbrella company for landowner companies.	An Independent Advisory Company (IAC) has been tasked to establish an appropriate landowner business development program. The process has involved extensive and ongoing consultations with landowners and communities in the project area (see NECL meetings below).
Confirmation that the stakeholder consultation process was genuine and concern that landowners should be dealt with directly.	The project's public consultation and disclosure program has featured numerous landowner sessions.
Gas emissions might cause 'pollution rain'.	Gaseous emissions from the Hides and Kutubu facilities during operation are not expected to result in the formation of 'acid rain' since emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) concentrations will be very low. Air quality impacts from the project are covered in Section 13.8.
Concern about potential increases in law and order problems.	This is a government matter.
While the majority of household survey respondents in the project area want the project to proceed (82.8%), 97% to 100% of villagers surveyed from the Gobe, Kikori, Kutubu and Moran areas wanted the project while 68% of villagers surveyed in the Hides area wanted the project. Of those objecting to the project, the main reasons were: • Insufficient services to be provided by the government (40%). • Environmental concerns (26%). • Concerns for future generations (15%). • Lack of forum/cooperation (12%). • Huli landowners' desire for a Hela Province (7%).	Environmental concerns are addressed by the EIS in general. Concerns for future generations are discussed in Supporting Study 10. Concerns regarding a lack of forum/cooperation are addressed by ongoing landowner consultations and by the GPCSA forum process. The Huli landowners' desire for a Hela Province is discussed in Supporting Study 10. This issue lies outside the project's realm of responsibility. Issues related to the provision of services by the government are documented in the Social Impact Assessment (Supporting Study 10).

Table 5.2 Project response to issues raised during consultation sessions (cont'd)

PNG Issue	Project Response
The majority of villagers from Gobe, Hides, Kutubu and Moran want the road link from Tari to Kikori. However, only 33% of the household survey respondents from Kikori want the road link. The main concerns raised include: ethnic tension, increase in criminal activity and the potential for land takeover. Other issues raised related to the Tari-Kikori road included: the road surface and maintenance, security, links to other centres and the urgency to build the road.	Impacts related to the Tari to Kikori road link are addressed in Chapter 16. Concerns raised in relation to the road link are addressed in the Social Impact Assessment (Supporting Study 10).
Promises made by government may not be upheld.	Past problems were often linked with written agreements failing to reflect verbal promises; these problems may be able to be avoided by implementing the GPCSA, which is a Landowner - Government agreement.
Risk of gas pipeline exploding.	Hazard evaluation and adherence to regulatory requirements and standards will be incorporated into the design of the project's facilities and pipelines to maximise safety and security (see Section 2.5.3).
Road/pipeline RoW issues including: • People making gardens on the RoW. • Availability of roads to logging vehicles. • Grass fires lit by locals invading the forest. • Spread of weeds during construction.	These issues are addressed in Chapters 13 and 16.
Sabotage risks regarding the pipelines	The pipelines safety and security measures described in Section 2.5.4 will detect any damage caused by sabotage. In addition, most of the new pipelines will be buried.
Benefits of active versus passive rehabilitation.	The project will reclaim construction-disturbed land surfaces so as to facilitate natural revegetation. In those areas where revegetation needs to be accelerated, active revegetation options will be evaluated
Impacts on ecosystem services such as construction impacts on village water supplies.	No adverse impacts on village water supplies are predicted. See Section 13.4, Water Resources and Hydrology.
Benefits reaching their intended beneficiaries.	The main vehicles for the distribution of benefits associated with the PNG Gas Project are the GPCSA and NECL (see Chapters 11 and 15).
Landowner representation.	Addressed through landowner consultations undertaken by the project and the GPCSA forum process.
Pipeline crossing existing logging roads and potential interference with logging barge traffic.	The project does not anticipate any adverse impacts related to commercial forestry. Potential cumulative effects related to timber harvesting are discussed in Chapter 16.
Availability of roads to logging vehicles.	See Chapter 16.
Conversion of forest to oil palm plantation.	This matter lies outside the project's area of responsibility.

Table 5.2 Project response to issues raised during consultation sessions (cont'd)

PNG Issue	Project Response
Potential increases in migration leading to ethnic tension and potential increases in criminal activities.	See Chapter 16.
Distribution of project benefits to the wider community and region.	Addressed in Section 15 and Social Impact Assessment (Supporting Study 10) and will be determined in the consultation process leading to the GPCSA.
Requests for funding assistance by the Operator to monitor forestry activities in the project area and promote landholder awareness of forestry issues and to refund the ecoforestry advisor position at WWF Kopi.	During the construction phase, the project will provide support to WWF initiatives related to biodiversity conservation in the project area.
Previous lack of consultation regarding archaeology and cultural heritage during past construction activities.	Surveys for archaeological and cultural heritage sites have been and will be undertaken prior to construction of project facilities, roads, pipelines and supporting infrastructure. This will include consultation with local communities.
Consultations undertaken during the archaeological survey in the Kopi area suggested further study was needed to fully determine potential impacts.	Additional studies were undertaken in October 2005 around Kopi and between Kopi and the Omati River landfall location, which was not previously surveyed. Follow-up survey work is tentatively planned for November and December 2005 to resolve residual constraints.
Consultations undertaken during the archaeological survey in the section of the pipeline RoW/access way between the Hides Production Facility and Homa indicated the potential for impacts to archaeological and cultural heritage sites.	Additional studies will be undertaken in November and December 2005 to resolve any routing constraints. This survey will involve consultation with local inhabitants. It is the project's policy to avoid identified archaeological and cultural heritage sites to the extent practicable.

Examples where additional studies have been undertaken in response to comments received via the project's public consultation and information provision program include:

- A hydrological study at the Omati River sales gas pipeline landfall location.
- A consultation program for PNG communities along the coast and on the offshore islands adjacent to the pipeline route.
- Additional archaeological surveys along the pipeline route in the vicinity of Kopi and in the section of the RoW/access way between the Hides Production Facility and Homa, particularly in the vicinity of Angore.

Consultations with local community members undertaken during the follow-up archaeological studies have helped to identify sites of archaeological and cultural importance. This has resulted in the development of the following proposed mitigation and management measures:

- Site locations of quarries determined to be sacred sites have been directly reported to PNG Gas Project engineers, so that these sites can be avoided by the project.
- Consultations have identified an area north of Kopi that is of archaeological and cultural significance. Sites in this area have been mapped and suggested re-routes of the pipeline in these areas will be reviewed during the project's detailed design phase.

Many landowner and landowner company queries relate to the distribution of benefits. Mitigation measures to address these concerns include:

- Establishment of the GPCSA by the government.
- Extensive stakeholder consultation between the government and landholders as part of the GPCSA forum process.
- Commitment of the PNG Gas Project to employ PNG nationals to the maximum extent practicable. All things being equal, hiring preference will be given to appropriately skilled individuals from communities in the project area and then to other suitably skilled and qualified PNG nationals.
- Establishment of the umbrella landowner company NECL as a mechanism through which qualified PNG national workers will be provided to the project.

5.8 Continuing Consultation

Consultation with stakeholders will continue during the remainder of the environmental impact assessment and approvals process associated with the PNG Gas Project and will include:

- Ongoing consultations with communities to identify sites of archaeological significance in the vicinity of the proposed pipeline route and project facilities.
- An EIS information briefing 'roadshow' by PNG Gas Project representatives with assistance from DEC officers (see Section 5.4.3 above),
- A program for consultation and disclosure during construction and operations to be included in the Environmental Management Plan (see Chapter 18).

Queries and concerns raised during the EIS 'roadshow' will be documented and reviewed by the PNG Gas Project team in conjunction with other submissions made to DEC during the EIS assessment and public review period. Responses to the queries and concerns will be provided to DEC including information on any design modifications or mitigating measures the project may institute in response to voiced issues, concerns, and comments. Any new or modified mitigation measures or changes to systems and processes will be captured in the EMP.

Consultation will continue during the construction and operations of the project. This will include the regular preparation and distribution of printed materials, the placement of informational material on websites, formal and informal discussions with communities in affected areas, the development and implementation of mechanisms for the receipt and handling of stakeholder concerns and comments, and the communication of relevant project milestones via various media announcements. Procedures for recording and responding to issues raised during such consultations will be detailed in the EMP. A grievance procedure will also be established that will set out, for people affected by the project, how to bring their grievances forward so that they may be considered in a culturally appropriate and expeditious manner.

6. Project Construction–Onshore

This chapter describes how the PNG Gas Project's civil works (Section 6.1), production facilities and camps (6.2), gas wells (Section 6.3), and onshore pipeline system (Section 6.4) will be constructed. It also discusses construction safeguards for the environment (Section 6.5) and safety (Section 6.6).

6.1 Civil Works

Civil works include preparing access ways and upgrading existing roads, preparing rights of way (RoWs) for the pipelaying work, and preparing production facility sites for the erection of new facilities or the modification of existing facilities (Section 6.1.1). Drilling sites also require civil works (Section 6.1.2). Civil works must be done in a logical sequence (Section 6.1.3) to avoid delaying the facilities construction crews and pipelaying spreads.

6.1.1 Preparation of Access Ways, Existing Roads, RoWs and Facility Sites

The contractor for these works will utilise a number of major equipment spreads, consisting of rock excavation crews, general earthworks crews and drainage crews.

Rock crushing and screening plants will be strategically located at existing and new quarries near the workface, and they will be relocated to reduce dump truck travel time as the spreads move forward. Existing quarries will be utilised to the maximum extent practicable.

Crews will follow clearing and grading activities to install sufficient drainage to protect the roadbed and follow-on work.

Table 6.1 lists the 42 bridges to be constructed by the project, and Figure 6.1 shows the location of these bridges. There are 22 existing bridges to be rebuilt or modified. There will be five existing bridges replaced by new bridges, and 15 new bridges at new locations.

The work may be divided into the following regions (from north to south).

Table 6.1 Bridge construction summary

Km from Kopi	River Name*	Description of Bridge	Proposed Construction
1.0		9-m beam	Rebuild
1.7		9-m beam	Rebuild
2.3	Utitu	76-m 3-span truss	Rebuild
2.6		9-m beam	Rebuild
5.3		9-m girder	Rebuild
7.7	Utitu	30-m truss	Rebuild
14.2		9-m beam	Rebuild
27.0		8-m beam	Rebuild
27.2		9-m beam	Rebuild
28.7		9-m beam	Rebuild
28.9		8-m beam	Rebuild
33.4		8-m beam	Rebuild
34.3		9-m beam	Rebuild
38.6		8-m beam	Rebuild
39.2		9-m beam	Rebuild
39.4		8-m beam	Rebuild
41.6	Kikori	120-m 2-span truss	New major bridge
63.1	Wah	46-m truss	Rebuild
71.8		8-m beam	Replace with new bridge
74.7		9-m beam	Replace with new bridge
Km from Gobe	**River Name***	**Description of Bridge**	**Proposed Construction**
0		15-m truss	New bridges proposed for Gobe to Mubi River section
2.1		15-m truss	
8.9		15-m truss	
9.5		15-m truss	
9.9		15-m truss	
11.9	Kwill	30-m truss	
14.0		15-m truss	
18.0	Mubi	140-m 3-span truss	New major bridge
Km from Ridge Camp	**River Name***	**Description of Bridge**	**Proposed Construction**
17.0	Kaimari	30-m truss	Rebuild
21.0	Tigumu	24-m truss	Rebuild
26.0	Tubage	18-m truss	Modify
53.1	Pau'a	40-m truss	Modify
58.4	Madali	34-m truss	Modify

Table 6.1 Bridge construction summary (cont'd)

Km from Idauwi	River Name*	Description of Bridge	Proposed Construction
0	Maruba	36-m truss	New bridges proposed for the Homa to Idauwi section
36.2	Bakari	27-m truss	
24.3	Benaria	40-m truss	
17.2	Wada	32-m truss	
12.8		27-m truss	
11.2	Dagia	45-m truss	
Km from Hides Production Facility	**River Name***	**Description of Bridge**	**Proposed Construction**
6.0	Nogolitogo	18-m truss	Replace with new bridge
4.5	Tuku	18-m truss	Replace with new bridge
2.7	Tumbi	18-m truss	Replace with new bridge

*If no river name is given, the bridge is over a small creek or gully.

6.1.1.1 Hides Spine Line RoW

This will involve construction of a RoW (incorporating an access way) along Hides Ridge. Because of the narrow ridge and numerous sinkholes on top of the ridge, this section may present the greatest challenge and safety risk. It will require extensive rock ripping and potential blasting, with the resulting material used to widen the access bench.

6.1.1.2 Hides Production Facility Site Preparation

At present, preparation of the Hides Production Facility site is not expected to require much rock excavation but will require cut and fill earthworks.

A new camp will be constructed within the existing Hides Camp area.

6.1.1.3 Hides Production Facility to Idauwi Road RoW and Access Way

This section will involve a 13-km length of greenfield pipeline RoW construction across the Tagari River valley via the Angore rest hut. The existing access way between Hides and Idauwi via Nogoli will be upgraded, including the replacement of three bridges.

6.1.1.4 Idauwi to Homa

This section will require major construction activity, involving some 42 km of new RoW and access way through heavily folded terrain. Approximately 6 new bridges and a large number of pipe culverts will be required. An example of a medium bridge is shown in Figure 6.2. An example of a short bridge, of the type to be used in this section, is shown in Figure 6.3. The bridges will be constructed using prefabricated steel.

This RoW section will involve heavy rock ripping, some blasting may be required, and progress is expected to be slow.

6.1.1.5 Homa to Kutubu

This is mainly a road upgrade section and is therefore expected to require a less intensive effort. To reduce the pipeline length, the RoW will depart from the existing road near the Moro airfield, requiring greenfield construction over a length of about 500 m. Two bridges will be replaced, and three will be modified. Localised traffic control measures will be employed as needed during construction, as reportedly there is significant local traffic in some sections.

6.1.1.6 Kutubu to Gobe

The new sales gas pipeline in this section will generally follow the existing crude oil export pipeline alignment. Some heavy equipment will be required to upgrade the existing pavement, particularly the existing access way between the Mubi River and Gobe airfield, which will be reconstructed as part of the early civil works. The work will mostly consist of widening the existing roadbed and establishing the drainage networks. Some cut and fill earthwork is expected.

The site for a new construction camp will be prepared at the former quarry south of the existing Ridge Camp near Kutubu.

The permanent facilities site at Kutubu will be prepared, and a Kutubu bypass road will be constructed.

During early civil works, a 140-m-long, three-span panel bridge on piled foundations will be constructed over the Mubi River (Figure 6.4 shows the type of bridge), as well as a new access way deviation for vehicles to the west of the bridge to replace a steep 10-km section of RoW below Kantobo village, and seven smaller bridges.

6.1.1.7 Gobe to Kopi

This section involves mainly upgrading the existing gazetted road. A number of existing minor bridges along the Gobe to Kopi section will be replaced, and some new ones will be added. There will be one section of new access way construction about 3 km in length where the access way will divert from the existing gazetted road at the Kikori River crossing, where a new bridge will be constructed during early civil works over the Kikori River near Kaiam about 1 km upstream of the existing ferry. The bridge will be a 120-m-long, two-span steel truss structure. A new 2-km section of access way will be constructed leading to and from the bridge.

The Gobe to Kopi section requires the least amount of work and is expected to require only road graders, dump trucks and some fill material. Work activities will include clearing and grubbing, backfill and grading.

6.1.1.8 Kopi to Omati

This section involves clearing for a new 34-km-long RoW. The first 22 km will cross similar limestone terrain to that of the existing RoW north of Kopi and is expected to involve relatively conventional RoW preparation.

The final 12 km will run through low-lying, poorly drained swamp forest with unconsolidated sediments of low bearing strength, which precludes the use of normal construction methods and equipment. There are two options under consideration for pipelaying in this section, one of which does not involve construction of an access way (see Section 6.4.3.4).

In the option involving an access way, the vegetation will be cleared by swamp-tracked excavators and bulldozers and also manually. The trees and scrub will be laid crossways to provide additional support where required (e.g., corduroy construction), and swamp mats, rip rap and/or geotextile fabric will be placed on top of the resulting track. Limestone excavated and transported by dump trucks from adjacent areas will then be placed and compacted by bulldozers and self-propelled compactors to form the working access way.

Material imported from outside swamp forest areas will remain after construction. Culverts will be placed as necessary to allow the normal cross-flow of water.

Culverts may be installed in minor creeks and streams. No major bridges will be required in this area. Construction of the Omati River landfall is described in Section 7.3.5.

6.1.2 Preparation of Drilling Sites

The existing wellpads for the Hides wells will be reconstructed as shared pads, with the current plan being to add one well to each pad. The existing wells on each pad will be recompleted. Four new wellpads will be constructed for the remaining five new wells during later development.

In constructing a new well, the wellpad is prepared prior to the drill rig arriving. This wellpad construction work is generally performed by construction crews, with a drilling representative present to ensure that the site preparation is within the specifications required for the drill rig. This aims to avoid additional adjustments being required when the drill rig arrives. Preparation of the drill site involves:

- Completion of an access road to the site.
- Compaction and preparation of the wellpad. A portion of the pad may be boarded, depending on the soil condition. Trees felled during the clearing of the drill site are a potential source for the rig boards.
- Erection of a gated security fence.
- Provision of water supplies for drilling via a water line adjacent to the Hides field access way. The water source will potentially will be the existing Girebo water source, the Tagari River or a water well at the Hides 3 well.

Some additional cut and fill areas will be required at the existing Hides 1 and 2 wellpads. Figures 6.5 and 6.6 show typical layouts for a single-well site and a double-well site respectively. Plate 6.1 shows a typical drill site (at Kutubu).

6.1.3 Sequence of Civil Works Construction

6.1.3.1 Early Civil Works

One of the first project activities will be to improve wharf facilities and to erect a receiving warehouse, laydown area and main fuel depot for the project at Kopi Support Base. Works will include upgrading the existing wharf, and constructing a new barge wharf and new roll-on, roll-off barge ramp.

The other early civil works will involve preparing the access ways to the extent necessary to allow vehicle access from Kopi to Kutubu, so that the main project contractors have a means of landing and transporting materials and equipment at least as far as Kutubu as soon as construction commences. The access ways and bridges to be constructed during early civil works are described in Sections 6.1.1.6 and 6.1.1.7.

6.1.3.2 Remaining Civil Work

The sequence of events in regards to the remaining civil works will be as follows:

- Upgrade the existing access way and widen the RoW from Kutubu to Gobe (Section 6.1.1.6).
- Prepare the site for the new camp at the former quarry south of the existing Ridge Camp near Kutubu (Section 6.1.1.6).
- Prepare the permanent facilities site at Kutubu and construct the bypass road (Section 6.1.1.6).
- Construct the spine line access way (Section 6.1.1.1) and wellpads (Section 6.1.2) on Hides Ridge ahead of drilling.
- Upgrade the existing access way and prepare the RoW from Homa to Kutubu (Section 6.1.1.5).
- Prepare the Hides permanent and temporary (camp) facilities site (6.1.1.2).
- Construct a new access way and RoW from just south of Idauwi to Homa (6.1.1.4).
- Clear a new RoW from just south of Idauwi past Angore rest hut to the Hides Production Facility (Section 6.1.1.3).
- Upgrade the existing access way from Idauwi to Hides via Nogoli (6.1.1.3).
- Based on the current construction plan, the RoW bench, road pavement/pipeline construction access way and drainage culverts will be installed prior to pipeline construction. Following pipeline construction, the RoW will be restored to its pre-pipeline construction state except areas of sidecast material.

6.2 Construction of Facilities and Erection of Camps

Contractors will be mobilised to Kutubu and Hides to start the erection of camps, offices and fuel depots. During the pioneer stages of building the new camp at Kutubu, accommodation will be provided at the existing Ridge Camp. Camp erection will first focus on food service, water, electricity generation, sewerage, and then living quarters, in that order.

The new Kutubu Camp will have 150 beds completed prior to the mobilisation of the civil group for site preparation. Offices and fuel depots will be constructed simultaneously with camps, as they will be required by the groups erecting the camps. New water supply, where needed, will come from local sources with appropriate agency permits. The Hides Camp will follow the same sequence as the Kutubu Camp but will only require 75 beds prior to civil group mobilisation.

Construction of the production facilities (Hides Production Facility and Central Gas Conditioning Plant) will generally follow access way construction, camp expansion and site preparation at each location.

A prefabrication strategy may be followed where:

- 50-mm and above process pipe spools will be fabricated at a fabrication yard outside Papua New Guinea. Pipe will be coated and shipped in containers, to match the construction sequence.
- 25-mm and smaller process pipe spools will be field fabricated at Kutubu, including the spools for the Hide Production Facility. Spools will then be shipped to Hides by truck.
- Structural steel will be fabricated at a fabrication yard outside Papua New Guinea.
- Fire proofing of process equipment will be yard installed prior to shipment.
- Equipment skids will be modularised with testing completed and all coating and insulation installed.
- Electrical substations will be modular and shipped in sections and reassembled at site as required.

Initial Kutubu Central Gas Conditioning Plant activities include:

- Establishment of the concrete batch plant and aggregate crushing facilities.
- Erection and commissioning of the new firewater tanks and new potable water tanks.
- Provision of an area to the civil works contractor for site preparation.

Once the replacement and demolition work is completed, further preliminary activities include:

- Construction of the Kutubu fuel depot.
- Construction of the Kutubu civil/rebar fabrication yard for both Kutubu and Hides.
- Construction of the Kutubu warehouse and receiving laydown areas.
- Construction of the pipe fabrication yard, miscellaneous steel fabrication yard, paint and sandblast areas.
- Establishment of the quarry and batch plant operations.
- Set-up of jobsite power and water supplies.
- Repeat the process at Hides for warehouse, laydown area and fuel depot.

Two crawler-mounted, 150-tonne cranes will be used in the early stages of construction at Kutubu. One of these will later be dismantled and transported to Hides. Two tower cranes will then be erected at Kutubu to service the erection of the various facility items, particularly the pipe work and electrical installation. Smaller cranes will be also used throughout the construction area to move construction-related materials and equipment.

The plan is for the Kutubu Central Gas Conditioning Plant construction to work from the congested areas west to the open areas on the east end of the site in the following sequence:

- Foundations will start and be worked in the west to east path along the path of construction.
- Structural steel will follow foundations. The structural steel contractor will set up a yard to pre-assemble pipe rack sections then truck them to site to stand on anchor bolts.
- Fireproofing of process pipe will follow after structural steel to fireproof joints prior to starting pipe installation in the pipe racks.
- The mechanical contractor will then start setting equipment from west to east.
- Piping erection will follow equipment setting and steel erection to complete the major installations.
- Electrical and instrumentation will be the last activities. The strategy assumes piping activities will be sufficiently ahead to minimise the interferences.
- Testing and commissioning will then proceed leading to production start-up.

The Hides Production Facility construction plan is for construction activities to work south to north:

- Foundations will work from south to north on each elevation or by equipment delivery dates.
- Electrical and instrumentation will start after pipe installation is far enough ahead to reduce interferences.

Three fuel depots will be established overall to enable adequate supplies of fuel for the construction plant and transport vehicles. The largest of these will be at Kopi Support Base, which will receive fuel supplies by barge. Smaller depots (minimum capacity 76,000 L) will be established at Kutubu and Hides.

When project construction is completed, the camp sites will be demobilised and rehabilitated as required by government agencies and described in the EMPs. Some construction camps will be retained for use during operations.

6.3 Drilling of Wells

6.3.1 Equipment

The type of drilling rig that is to be used by the project will consist of a main derrick, power system (generators), hoisting system (draw works, travelling block), circulating system (pumps, drilling fluid tanks, shale shakers), rotary system (top drive, rotary table), well control system (blowout preventer) and well-monitoring system. Water-based or foam drilling fluids rather than oil-based drilling fluids will be used to drill the wells in the Hides gas field.

6.3.2 Drilling Method

Initial drill site construction involves the selection, clearing, grading and preparation of the wellpad and associated facilities. The drill rig and its associated equipment are then moved onto the site and assembled.

Typically, the drilling process in Papua New Guinea involves the following steps (Figure 6.7 shows the Hides well designs):

- A conductor hole is drilled to the casing setting depth of approximately 100 m through the fractured/vugular Darai Limestone using air or a foam drilling fluid. The conductor casing is then cemented in the hole, with the wellhead A section being welded to the casing and the diverter installed above the A section.
- A surface hole is drilled using air and foam through further fractured/vugular Darai Limestone to the setting depth in the Ubea Formation below the Darai Limestone. (A normal water-based drilling fluid is not used to drill the surface hole because partial or severe loss of fluids downhole is commonly experienced due to the fractured, vugular nature of the Darai Limestone. Excessively high rates of water resupply would be required from the surface to make up for these losses if a normal water-based fluid were used.) The surface casing is then run and cemented in place, and the wellhead B section and blowout preventer are installed. The surface casing covers the vugular Darai Limestone and the weak, permeable Haito/Upper Ubea formations, which cannot tolerate the heavier drilling fluids required to control downhole pressures lower in the well.
- A bit-and-hole opener is run to drill the intermediate hole into the Giero B Formation. These siltstone and shale strata are overpressured, which means that the in-situ pressure exceeds that which would be normal at that depth. In addition, these

formations are folded and highly tectonically stressed. An inhibitive water-based drilling fluid is used to limit the hydration, swelling and disintegration of the shales and thereby maintain wellbore integrity. Rapidly increasing drilling fluid weights are required to both control increasing overpressure and prevent the stressed formations from collapsing into the wellbore. A liner may be run at this point to provide sufficient hole integrity to allow drilling the next hole section to the top of the Toro Sandstone.

- The production hole is then drilled to the top of the Toro Sandstone reservoir. The production casing is run and cemented in place to isolate the overpressured and unstable sections above the reservoir from the less pressurised reservoir sandstone. The wellhead C section is then installed.
- The reservoir section is then drilled to total depth, with a lower-weight drilling fluid designed to protect the porous reservoir from damage, and a liner is run, cemented in place and perforated.
- The tubing is run, and the tubing hanger and tree are installed.
- In the case of a deviated well, the well is drilled vertically to the kick-off point below the depth of the surface casing, at or near 1,500 m total vertical depth. (The kick-off point is the depth at which the well begins to be drilled directionally.) From the kick-off point, the well angle is built at approximately 3 degrees per 30 m, until the tangent angle required to intersect the downhole target at a value that meets reservoir engineering requirements is achieved at the end-of-build.

The well is then ready for flowing. Approximately 2,000 to 3,000 kSm^3/d (70 to 100 Mscf/d) of gas from the well will be flared during testing. A high-efficiency burner will be used for testing and well cleanup.

6.4 Construction of the Onshore Pipeline System

This section describes how the proposed PNG Gas Project's onshore pipeline system will be constructed from the Hides field facilities in the Southern Highlands to the landfall at the Omati River.

6.4.1 Pipeline Construction Program and Labour Requirements

The construction of the onshore pipelines is scheduled to begin in the first quarter of 2007 and is expected to take 18 to 24 months. The construction schedule allows for completion of the roadworks and new RoW construction prior to the commencement of construction of the mainline pipelines (all the new pipelines between the Hides Production Facility and the landfall at the Omati River). This will enable the mainline pipelines construction spread to be transported to and marshalled at Hides.

Due to the varying ground conditions, it is likely that the onshore pipeline contractor will divide the installation into four separate types:

- Spine line and gathering lines at Hides.

- Mainline pipelines (normal construction).
- Mainline pipelines (special construction): i.e., steep or narrow areas, access way crossings, and water crossings.
- Mainline pipeline (swamp construction): i.e., the 12 km to the Omati River landfall.

Each of these types will require different equipment, different labour mixes and different pipelaying rates, as well as presenting distinctly different challenges.

The expected rates of construction using the 12- or 18-m mainline pipelines joints under normal construction conditions are as follows:

- 840 m per day of trench excavation.
- 100 joints laid per day for general ground conditions.
- 6 joints laid per day for restricted conditions.
- 6 joints laid per day for swamp conditions.

Construction of the onshore pipeline system will provide approximately 2,500 jobs. Approximately 70% of the workers to fill these jobs are expected to be PNG nationals, subject to appropriately qualified and skilled individuals being available.

6.4.2 Sequence of Pipeline Construction

The work at Hides will commence with the construction of the spine line, thus enabling the construction contractor to begin work on a section that will probably involve a slower rate of progress than other phases due to the difficult terrain and thus will enable a progressive build-up of personnel and resources. The spine line will be constructed by a dedicated crew with an average lay rate of 250 m per day.

The mainline pipelines will be constructed by one mainline spread with twin construction capacity. Construction in special sections—areas with steep terrain, access way crossings, watercourse crossings and swamp terrain—are discussed in Section 6.4.3.

Construction of the spine line and pipelines will typically involve:

- Detailed location of the route and ground survey.
- RoW clearing, grading and track formation.
- Trench excavation.
- Pipe stringing and bending.
- Pipestring welding, weld inspection and joint coating.
- Trench preparation and coating inspection.
- Lowering-in, tie-in and cathodic protection.
- As built survey.
- Backfilling, clean up and rehabilitation.

These construction activities are illustrated in Figure 6.8 and are discussed below. Testing and commissioning of the pipelines are discussed in Section 6.4.4.

6.4.2.1 Detailed Location of the Route and Ground Survey

The RoW for each pipeline will be surveyed on the ground to confirm that it avoids, to the extent practicable, significant cultural and biodiversity areas and to reconcile construction constraints encountered. Survey pegs will mark the pipeline centreline, RoW boundaries and intersection points. The location of the existing crude oil export pipeline will be identified and marked to ensure that the construction activity avoids it and maintains a safe working distance.

Information on the location of rock obtained from construction of the previous oil pipeline, combined with geotechnical engineering reports and test excavations along the route, will be used to classify the rock encountered so that excavation methods can be planned to suit existing conditions.

6.4.2.2 RoW Clearing, Grading and Track Formation

A construction RoW nominally 21 m in width will be required for the mainline pipelines, incorporating an 8-m-wide access way. The RoW accommodates construction equipment and vehicle traffic, along with the storage of trench spoil (Figure 6.9). The width of the RoW involves balancing a number of considerations, including safety, timing, and environmental and cost criteria, to ensure that construction activities can be performed safely with minimum risk of accident or injury to personnel.

The existing Kutubu crude oil export pipeline RoW will be used, where possible, to install the sales gas pipeline between Kutubu and Kopi. The existing easement containing the RoW is 40 m in width (20 m either side of the oil pipeline centreline). New RoWs will be constructed between Hides and Kutubu and from Kopi to the Omati River landfall.

For the section between Kutubu and Kopi, the grading crew will clear the existing RoW of vegetation (mainly regrowth since the completion of the oil pipeline) (Plate 6.2) and prepare a working surface within the RoW for the passage of construction equipment (Plate 6.3). This may involve the profiling of watercourse crossings and the benching of side cuts.

The construction of the new RoW between Hides and Kutubu will include:

- Clearing of vegetation and grubbing of stumps across the width of the RoW.
- Stockpiling of remaining woody vegetation not used for construction purposes in piles along the side of the RoW.
- Installation of erosion control structures as required near streams and rivers.
- Placement of crushed limestone over the cleared ground, underlain by geotextile fabric if necessary.

Where practicable, timber cleared during RoW construction in this section and elsewhere along the length of the sales gas pipeline will be utilised during construction. This may include supporting the access way in swampy areas, providing material for bridge construction, and marking the existing pipeline. The woody vegetation piles will assist with erosion control and provide a temporary habitat for fauna. Landowners will be permitted to use the timber for construction material and firewood as they desire.

The nominal 12-m to 21-m RoW for the Hides to Kutubu section is less than ideal from a construction efficiency perspective; however, terrain constraints make a wider RoW difficult and, in many cases, impossible to construct. The narrow width, local traffic on some portions of the RoW, and the proximity of villages to the RoW mean that modified construction methods need to be used in many sections of the pipeline. Modified construction methods include:

- Use of excavators to reduce disruption.
- Reduce design width of RoW.
- Install fencing or bunting to restrict movement.
- Enforce traffic management procedures, which takes into account all requirements by all parties and includes wardens.
- Provide safety inspectors to ensure minimum risk.
- Minimise length of open trench (reinstate immediately; after construction, install trench barriers to restrict animals, such as pigs, falling into trenches and install temporary pedestrian paths).
- Prefabricate pipeline sections as much as possible.
- Increase depth of pipeline cover in high-risk areas.

6.4.2.3 Trench Excavation

The mainline pipelines trenches will be excavated using a range of specialised equipment, including wheel ditchers, excavators and rock saws, to a depth that provides an appropriate depth of cover over the pipe commensurate with the terrain and land-use characteristics. In softer soils, the trench will generally be excavated using hydraulic excavators. Rock saws will be used in limestone or other hard material, as drilling and blasting may not be permitted close to the existing crude oil export pipeline.

Where drilling and blasting is proposed in the vicinity of the crude oil export pipeline (or any other pipeline, utility or infrastructure) the construction contractor shall obtain approval to drill or blast from the Operator and from the owner of the oil pipeline (or other pipeline, utility or infrastructure).

The depth of soil cover over the pipeline will be increased at access way and river crossings as appropriate. The trench will be excavated to a sufficient depth to give a minimum soil cover above the pipe of 750 mm, in accordance with AS 2885.

Access across the open trench will be provided to allow for the safe crossing of people and animals, and there will be safety ramps in open trenches to assist exit from the trench.

6.4.2.4 Pipe Stringing and Bending

When the trench has been excavated, the line pipe will be delivered and placed end to end alongside the trench on timber skids. The skids protect the line pipe from damage and enable it to be welded into continuous lengths, or 'strings'. It is estimated that approximately 20,000 timber skids will be required during the project.

Bending will be undertaken to enable the pipe to conform to land contours or to facilitate changes in pipeline route direction. Pipe may be 'cold bent' or roped (using the natural flexibility of the pipe) in the field, or factory induction bends may be used. Pipe diameter, length and wall thickness are variables that may limit the radius of curvature of a cold field bend (reducing the angle that may be pulled from a pipe length). Factory induction bends can achieve much tighter radii and will be used where cold bends are not appropriate.

6.4.2.5 Pipestring Welding, Weld Inspection and Joint Coating

Welding crews join individual lengths of line pipe into sections of pipeline (called strings) up to 1 km long prior to lowering-in of the pipe. The welding crews clean and align the pipe ends and complete a number of welding passes.

Pipe ends are buffed prior to welding. The pipes are clamped using a pneumatic internal line up clamp and welded into the maximum number in the string as conditions permit. Each weld is wire-brushed to remove weld spatter prior to visual inspection. All pipeline joints will be 100% x-rayed, and the x-ray images will be inspected for faults. Each non-complying weld will be repaired or cut out and rewelded by a repair welding crew and radiographed again until an acceptable weld is achieved.

The weld joint area will be cleaned, grit-blasted and corrosion coated. The joint coating process uses sprayed liquid urethane or urethane epoxy for field joint coatings, with the coating applied after the joint is preheated. There is a curing time for the joints, which may require protection from rain and humidity. After curing, the joints will be wrapped in 'Netlon' rockshield or equivalent plastic protective mesh for additional protection.

6.4.2.6 Trench Preparation and Coating Inspection

Prior to lowering-in the pipe, it may be necessary to dewater the trench (e.g., in areas of high watertable or after rain). Any such water will be pumped out of the trench and discharged to land through a filter medium and energy dissipaters in order to prevent erosion and sediment discharge, and only in accordance with regulatory requirements. In some cases where the trench fills with water, the pipe will be weighted and sunk prior to backfilling.

Immediately prior to lowering-in, all coatings will be inspected visually and using a high-voltage holiday detector to detect any coating defects, which will then be repaired.

6.4.2.7 Lowering-In, Tie-In and Cathodic Protection

Lowering-in refers to the placement of the pipestrings into the trench by side-boom tractors as they gradually move along the RoW. The side booms require enough distance from the trench line to place the pipeline into the trench without touching the trench wall.

Specialised tie-in crews will join the pipeline strings together after the pipeline has been lowered into the trench. Tie-ins mostly will be carried out in the trench by lifting each end of the strings.

Where pipelines are located within a road easement, the pipe will be covered with marker tape denoting ‘Buried High Pressure Gas Pipeline’.

Cathodic protection test point leads will be installed after the lowering-in of the pipestring. Sacrificial anodes will be placed at strategic locations to ensure temporary protection of the buried pipeline until the impressed current cathodic protection units are operating. Impressed current cathodic protection units will be installed, generally at compressor or scraper stations, to provide long-term corrosion protection of the buried pipeline.

6.4.2.8 As-Built Survey

An as-built survey will be undertaken before backfilling of the trench to provide GPS coordinates for the buried pipeline.

6.4.2.9 Backfilling, Clean Up and Rehabilitation

Spoil excavated during trenching will be backfilled to the trench and compacted; there will be no compaction of backfill spoil in swampy areas.

RoW clean up and rehabilitation will be undertaken progressively so as not to lag behind the backfilling crew.

Following compaction of the backfill, clean up will be undertaken by removing all temporary infrastructure and machinery. The construction sites and equipment laydown areas will be ripped to relieve compaction if necessary. Erosion and sediment control measures, such as diversion berms and sediment traps, will be put in place as appropriate to protect water quality and divert runoff away from potentially unstable rehabilitation areas.

The success of rehabilitation will be monitored until a stable vegetation cover has been established.

6.4.3 Special Construction Circumstances

6.4.3.1 Construction in Steep Sections along the Existing Oil Pipeline Easement

During the construction of the existing crude oil export pipeline in sections of steep terrain, benches were formed in order to create a level RoW. The pipe was placed in a trench, generally against a ‘cut’ wall (Figure 6.10) to avoid placing the pipe either under the access way surface or in the soft, unstable shoulder formed from uncompacted material. In some of these sections, where the sales gas pipeline cannot be laid safely in the outside shoulder of the access way or where the existing RoW is too steep or tortuous for heavy haulage, a new RoW or access way will be constructed.

6.4.3.2 Access Way or Road Crossings

Where the existing crude oil export pipeline crosses an access way or road, the sales gas pipeline will cross the access way or road at the same location. Here, the sales gas pipeline will be placed below the existing crude oil export pipeline, with a minimum of 500 mm separation.

All backfill material under the access way or road pavement and shoulder will be suitably graded crushed rock. Concrete slabs will be installed over the pipe where it crosses table drains in situations where the cover over the pipe at the drain bottom is less than 1,200 mm.

6.4.3.3 Watercourse Crossings

Trenched Watercourse Construction. Where circumstances permit, conventional trenching with culverts will be used as a first preference for watercourse crossings. Watercourse crossings constructed using conventional trenching and pipelaying methods are shown in Figure 6.11. Trenched watercourse construction, as shown in Figure 6.11, will be carried out in the following way:

- Watercourse crossings construction activities will be carried out, to the extent practicable, when water levels are low.
- Pipe will be strung, welded, coated and tested ready for installation prior to watercourse trenching.
- Temporary vehicle crossing will be constructed for construction traffic across the river, with flume pipe to allow continued watercourse flow.
- The trench through the watercourse will retain hard plugs at each bank until just prior to pipe installation.
- Bank, bed and trench spoil material will be stockpiled separately on the banks.
- Pipe will be lowered-in and backfilled immediately, and the original riverbed material will be replaced on the river bed to a depth equivalent to the original conditions.
- River bed and banks will be rehabilitated as discussed below.
- Erosion and sediment controls will be installed as required (Figure 6.11 shows graded easement drains to prevent erosion into the watercourse and silt fences to prevent sediment runoff into the watercourse).

Bank rehabilitation will be carried out by recompacting the excavated material and assisting native vegetation regrowth. On steep banks, matting may be used to assist with bank stabilisation until sufficient regrowth occurs. Where necessary, additional methods of bank stabilisation may be required (e.g., rock rip-rap).

Figure 6.12 shows the watercourse rehabilitation process:

- Watercourse banks will be rehabilitated immediately after backfill (and prior to dismantling any flow diversion measures), banks will generally be rehabilitated by grading and revegetating, the grade of rehabilitated banks will generally be 1:3, rehabilitated banks will merge smoothly with adjoining undisturbed banks, and the width of bank disturbance will be minimised.
- Watercourse beds will be rehabilitated to the pre-construction profile to the extent practicable to ensure smooth transitions to adjoining undisturbed beds upstream and downstream.
- Trench barriers and cross berms will be installed to divert surface water from new construction.
- Preconstruction fencing will be reconstructed to follow the rehabilitated bank profile.
- Additional fencing can be constructed to exclude livestock from the area under rehabilitation.
- On steep banks, matting may be used to assist with bank stabilisation until sufficient regrowth occurs. Where necessary, additional methods of bank stabilisation may be required (e.g., rock rip-rap).
- Scour protection will be installed where required.

Horizontal Directional Drilling (HDD). HDD methods will be used for watercourse crossings where the watercourse is considered too large and fast-flowing for conventional trenched methods. Pipestrings installed by HDD will be pretested (hydrotested) prior to pulling.

At each of the six locations where the use of HDD is being considered (Tagari, Bakari, Mubi, Wah and Kikori rivers and Utitu Creek), areas of approximately 45 m by 30 m will be cleared and graded on each side of the watercourse (Figure 6.13). Figure 6.14 shows the stages of HDD construction, and Plate 6.4 shows a typical HDD rig. The first stage is to drill a pilot hole where the drill is steered on a planned route using computerised in-head guidance. Above-ground tracking provides the position of the drill bit along its planned course. After the pilot hole is drilled, the pilot hole is reamed out to the required size. A number of different sized reamers are used to enlarged the pilot hole up to its final diameter. Where a casing is required, the prewelded casing is pulled into the hole. The prewelded and tested pipe is then pulled into the casing or hole. The duration of disturbance will depend on the number of holes to be drilled, with a possible duration for three holes being six weeks. Management procedures will be developed for the disposal of the cuttings and water-based drilling fluids, including the minimisation of drilling fluid loss to the river.

6.4.3.4 Delta Swamp Construction

As described previously, the final 12 km of sales gas pipeline section from Kopi to the Omati River landfall, which runs through low-lying swamp forest, will require the use of special construction methods. The Omati River swamp section will require the clearing of a 21-m-wide RoW. Cut vegetation will be placed in a 12-m-wide timber corduroy strip over which will be placed a geotextile base. A 1-m-high by 8-m-wide temporary access track will be constructed of limestone on the geotextile base.

The concrete-coated pipe will be strung out on the access track and welded into strings up to 1 km long. On completion of the welding and joint coating processes, a V-trench 4 m wide at the surface and 1.5 m deep will be excavated 2 m from the access way. The trench may be excavated using excavators working from the track or pontoon-mounted excavators. The trench will be left full of water to improve the stability of the trench walls. The pipe will be lowered into the trench using sidebooms with tie-ins completed outside the trench. The trench will then be backfilled.

Alternative methods may be used, such as the push/pull method (where the pipeline is constructed at the edge of the swamp and the pipe strings are launched into a prepared trench) or a floating dredge and lay barge.

6.4.3.5 Existing Pipelines and Traffic Management

The sections of pipelines that will be buried within some parts of the Moro to Ridge Camp road will require special construction techniques and processes to allow traversing buried and above-ground pipelines at the end of the Agogo road and possibly near the Ridge Camp. These techniques and processes include:

- Written approval and advice from the owner of the existing pipeline regarding the proposed crossing.
- Application of safeguards to eliminate damage to the existing coated pipeline, e.g., hand (in lieu of mechanical) excavation within 1 m of the existing pipeline.
- Application, where necessary, such as the installation of temporary supports, of safeguards to eliminate additional stresses on the existing pipeline caused by increasing span length.
- Utilisation of tie-in crews to facilitate below pipeline crossings.

Where the pipeline is to be installed in a road, road traffic will be managed by:

- Formation and implementation of approved traffic management procedures.
- Liaison and coordination with local traffic management service provider.
- Unhindered and safe vehicle access at nominated and approved periods.
- Use of barricades, road plates, lights, traffic controllers etc. to facilitate the unhindered and safe passage of vehicles.

6.4.4 Testing and Commissioning

6.4.4.1 Pipeline Cleaning

Sections (up to 20 km long) of the pipeline will be cleaned after construction using pigs propelled by compressed air. A temporary launcher and receiver will be welded onto each end of the section to be cleaned. Cleaning pigs will be of the following types: bristle, abrasive coated foam, or conventional disc-type with attached stiff wire brush. Generally, a minimum of five cleaning pig runs will be carried out, with the pipe becoming progressively cleaner after each run.

Gauging pigs will be the conventional disc-type with an attached aluminium plate. Should the preliminary gauging plate show any signs of damage following the gauging run, obstructions and debris will be removed, any dents or buckles will be repaired, and further gauging pigs will be run until an acceptable gauging run is completed prior to filling the section with hydrotest water. Dents and buckles can be located by using a calliper pig, which will detect and locate the fault.

After cleaning and gauging, adjacent sections may be joined together to form a continuous pipeline section for hydrotesting.

6.4.4.2 Hydrostatic Testing

Each onshore pipeline section will be tested hydrostatically using water typically sourced from local waterways. The water will be treated with small quantities of oxygen scavengers (removes dissolved oxygen from the hydrotest water to reduce corrosion potential) and biocides. The use of corrosion inhibitors is normally not required.

Estimated hydrotest volumes required are shown in Table 6.2.

Table 6.2 Onshore hydrotest water volumes

Pipeline	Pipeline Diameter (mm)	Pipeline Wall Thickness (mm)	Length (km)	Volume (ML)
Hides 1 to Hides Production Facility DN 550 spine line	559	19.4	26	5.9
Hides 1 to Hides Production Facility DN 50 chemical injection line	60.3	6.3	26	0.1
Hides Production Facility to Central Gas Conditioning Plant DN 550 rich gas pipeline	559	18	118	27.1
Hides Production Facility to Central Gas Conditioning Plant DN 200 liquids pipeline	219.1	7.9	118	4.1
Hides Production Facility to Central Gas Conditioning Plant DN 80 glycol return line	88.9	4.2	118	0.7

Table 6.2 Onshore hydrotest water volumes (cont'd)

Pipeline	Pipeline Diameter (mm)	Pipeline Wall Thickness (mm)	Length (km)	Volume (ML)
Central Gas Conditioning Plant to Kopi Scraper Station DN 700 sales gas pipeline	711	17.7	159	60.0
Central Gas Conditioning Plant to IDD-1 DN 150 LPG injection line	168.3	6.2	7.4	0.2
Kopi Scraper Station to Omati landfall DN 700 sales gas pipeline	711	17.7	33	12.5

Biocides are used to treat hydrotest water for the following reasons:

- To avoid the translocation of fauna (e.g., native and exotic fish, pathogens) from one river system to another.
- To remove biological organisms from the hydrotest water that may lead to corrosion of the pipe.

Water to be used for hydrotesting will be tested for its suitability prior to use. Where testing reveals the absence of problem species, biocides may not be necessary.

Test water will be reused in each successive section where it is practicable to do so and will be disposed of in accordance to government requirements. Where a biocide is used, the test water may be treated to neutralise the biocide prior to discharge.

Pipeline failure under test is a rare event, because of the stringent procedures in manufacture and pipelaying.

6.4.4.3 Dewatering, Swabbing and Drying

After a pipeline section is tested, it will be dewatered using dewatering pigs, the water generally being pushed into the next hydrotest section. The test heads are removed, and the test section is then tied-in. Temporary heads will be installed, and drying operations will start with a series of pigs being run in the pipeline using dry compressed air. This process will continue 24 hours a day until the pipeline interior is determined to be dry (measured dew point). Open-cell foam pigs will be used to swab any remaining water and remove residual pipeline dust.

6.4.4.4 Introduction of Hydrocarbons

Product will be introduced into the pipeline once all testing has been completed and all equipment is operational. When product is introduced at one end, the other end of the pipeline will be vented to atmosphere and monitored for gas concentration until all the air has been displaced.

6.5 Construction Safeguards

6.5.1 Sediment Control and Management

Where necessary fabric silt fences will be constructed in downstream flow paths and channels to intercept generated sediment. These fences will be formed from commercial silt fence fabric supported on star pickets. The silt fences will be inspected regularly and cleaned out or repaired as required.

Where pipeline construction is carried out along steep slopes, the sidecast spoil areas will form major sources of sediment generation. These areas will usually be allowed to revegetate naturally and will be monitored.

Where spoil is stored during construction, the spoil storage areas will be surrounded by a silt fence to prevent sediment loss.

Rockfilled mattresses may be required at the inlets and outlets of culverts to reduce scour and consequent sediment generation. Stone-filled gabions and Reno mattresses may be required to armour bridge abutments and other vulnerable areas against scour (see Figures 6.2, 6.3 and 6.4).

6.5.2 Management of Drilling Discharges and Solid Wastes

6.5.2.1 Liquid Waste Management

Discharges from typical drilling operations can be categorised as follows:

- Drainage water from the rig, either rainwater or hose-down water used for cleaning equipment. A drainage ditch with an oil trap will be constructed around the well cellar to collect this water, and any overflow will be discharged to the surface water system in accordance with government requirements or permits.
- Water, drilling or completion fluids and residual drilling fluid adhering to wet drill cuttings. Occasional low-volume discharges can occur at the solids control processing points of the circulating drilling fluid system. Higher-volume discharges can occur either at the end of a well section (if the drilling fluid system needs replacement) or at the end of the well before a rig move (where fluid recycling is not practical).

There will be no wastewater discharge from the wellpads other than rainwater runoff once the drilling rigs have been demobilised.

6.5.2.2 Solid Waste Management

Drilling fluid is used to bring the drill cuttings to the surface. A typical Hides well of 3,600 m total depth is expected to generate approximately 600 m^3 of drill cuttings plus at least an equal amount of adhering drilling fluid. (Following separation of the bulk of the drilling fluid from the wet cuttings using a vibrating screen, some residual drilling fluid will still adhere to the cuttings.) The cuttings reflect the geological formation being drilled and so, from an environmental management standpoint, the cuttings simply constitute natural rock fragments of limestone, shale, siltstone or sandstone.

The plan is to dry and dispose of the cuttings off the wellpad in accordance with government requirements or permits.

The recompletion of the disused Hides 3 well and the reuse of the upper annuli of the Hides 4 well and/or the new wells for cuttings injection is also being evaluated. The main issues associated with these cuttings disposal options are:

- Deep reinjection (below the Darai Limestone) of cuttings into the Hides 3 well would first require recompletion and perforation to access a zone remote and capped from the water table.
- Only the relatively clean cuttings generated while air and foam drilling can potentially be discharged into the upper section of a well where the annulus is open to voids in the surrounding limestone.

Cuttings must be slurried with water prior to injection. The total volume of injected slurry for a typical well would likely be well in excess of 10,000 m^3. Much of the waste water produced during well drilling would be consumed to prepare this slurry.

6.5.2.3 Drilling Fluid Management

Approximately 15,000 barrels (2,350 m^3) of drilling fluid are estimated to be required to drill each well in the Hides gas field. The drilling fluid will be recycled in the drilling process to the extent practicable. Once a well has been completed, the drilling fluid that cannot be recycled will be either processed or otherwise disposed of in accordance with the conditions of the applicable discharge permit. The specific physical and chemical properties of the drilling fluid will depend on the fluid type to be used, the current plan being to use a water-based drilling fluid for all hole sections below the upper foam sections through the Darai Limestone (see Section 6.3.2). Typically, a water-based drilling fluid consists of a mixture of solids, liquids and chemicals, with water being the continuous phase. Potentially, the drilling fluid could include water with a range of salt concentrations, low specific-gravity active solids (bentonite), low specific-gravity inactive solids (the drilled solids), specialist chemicals and high specific-gravity solids (barite). These materials are of low toxicity.

6.5.3 Management of Other Construction Wastes

Construction wastes will include:

- Workshop wastes, including waste lubricating oil, filters, lead-acid batteries and used tyres.
- Camp and catering wastes, including wet and dry food wastes, paper, plastics and glass.
- Scrap wood and lumber.

- Waste metals.
- Paint and aerosol cans.

The proposed management strategy for these types of wastes is described in Chapter 17.

6.5.4 Management of Soil Contamination

The following areas or activities are potential sources of soil contaminants:

- Pipe-coating plants: possible contaminants at pipe-coating plants include paint, polyethylene beads, fuel, solvents, acids, epoxies and mastic.
- Refuelling operations and equipment servicing: possible contaminants at refuelling operations include diesel fuel used in construction equipment and generators and jet A1 helicopter fuel. Refuelling will only be undertaken by trained personnel. Possible contaminants produced in mobile workshops for plant and equipment maintenance include waste lubricating oil and engine coolant.
- Field joint-coating operations: possible contaminants include paint, solvents, epoxies and mastic.
- Hydrotesting: possible contaminants include oxygen scavengers and biocides.

Construction crews will carry spill kits and will be trained in their use. Spill response procedures will be developed for construction activities and will be documented in the construction environmental management plan (see Chapter 18).

6.6 Safety, Health and Environmental Systems

The Operator's Operations Integrity Management System (OIMS) or an equivalent system will be the framework that will be used to ensure a systematic approach to safety, health and environmental management for the PNG Gas Project.

6.6.1 Safety, Health and Environmental Issues

The health needs of the project will be met by teams of medical professionals located at each site. First-aid stations will be located at each work site and at the camps. Patients requiring professional medical care will be transported by ambulance or helicopter to the nearest clinic or to a major hospital as appropriate.

Safety issues that will be addressed during construction and commissioning include:

- Noise levels.
- Alcohol and drug consumption.
- Extreme weather conditions.
- Sunburn.
- Emergency response training.
- Fire precautions and bushfire response.

- Road safety.
- Lifting operations.
- Guarding of machinery.
- Excavations.

The safety measures that will be implemented by the project include:

- Use of suitably trained personnel.
- Employee site-safety inductions.
- Regular health and safety meetings.
- Induction procedures for visitors to site.
- Communications systems when working in remote locations.
- Use of personal protective equipment appropriate to each workplace activity.
- Operation of heavy machinery and tools by trained personnel only.
- Use of first-aid and injury-response equipment, such as safety showers.
- Equipment maintenance.
- Location and use of fire-fighting systems and equipment.
- Incident reporting and investigation.

The following management practices will be implemented in accordance with applicable laws and regulations relating to occupational health and safety:

- The development of written occupational health and safety policies, which will be clearly communicated to all workers and contract personnel.

- Appropriate job training and skills matching to ensure all personnel are adequately trained for their assigned tasks and responsibilities.

- Implementation of incident reporting procedures to identify and eliminate problems with procedures.

- Implementation of procedures to ensure that contract personnel are adequately trained, understand and comply with all site safety requirements, and are familiar with the scope of their tasks and the associated safety issues.

- Development of a selection process for prospective site health and safety personnel to ensure that adequately trained and experienced individuals are responsible for managing site occupational health and safety issues.

6.6.2 Management of Hazardous and Dangerous Goods

Hazardous and dangerous goods that will be used during construction, including diesel fuel, jet A1 fuel (for helicopters), oxy-acetylene gas (for welding), explosives (for blasting hard rock in the RoW), solvents (for repair of corrosion coating), oxygen-reducing agents and corrosion inhibitors (additives to hydrotesting water), x-ray sources (for radiography of pipeline welds), drilling chemicals, and domestic cleaning fluids, will be transported to site in accordance with legislation governing the transport and handling of hazardous and dangerous goods.

At the site, all hazardous chemicals and materials will be stored, managed, transported and used in accordance with legislative requirements and local regulations. This will include:

- The development of a hazardous materials register of all hazardous chemicals and materials to be used during construction and drilling.
- The use of vehicles and drivers approved for the transport of hazardous materials.
- Bunding and impervious liners around fuel and other chemical storage vessels to contain spills.
- Storage of paints and other flammable materials away from other areas.
- Storage of corrosive or toxic chemicals in a separate toxic materials store and in suitable containers marked with warnings and precautionary measures.
- Storage of radioactive materials for weld inspection in suitable, adequately marked, purpose-built containers, to be handled by qualified personnel only.
- Appropriate handling of hazardous materials, including the use of protective clothing and reference to material safety data sheets.

7. Project Construction–Offshore

This chapter describes the stages in the construction of the offshore, subsea section of the sales gas export pipeline between Papua New Guinea and Australia. Offshore construction consists of route preparation (Section 7.2), pipelaying (construction) (Section 7.3), and culminates in commissioning of the sales gas pipeline (Section 7.4).

7.1 Introduction

As described in Chapter 2, proven engineering design standards and management principles underlie the project development and include an understanding of offshore site conditions, adherence to codes and standards, and the implementation of quality assurance procedures. The offshore construction work will adopt DNV OS-F101, Code for Submarine Pipeline Systems, as the basis for the safety design of the pipeline.

Offshore site investigations and data analyses are being undertaken to supplement pre-existing information on the physical and biological environment of the seabed in order to define further any environmental considerations related to pipeline construction. A geophysical survey of the entire offshore route was completed in November 2005, covering sections of the sales gas pipeline route that bypass the Kumul Marine Terminal, which were not surveyed during the previous environmental impact assessment (NSR, 1998a), and some overlap sections. This survey included geophysical characterisation, seabed sampling and underwater photography. Findings were available to provide descriptions of the environmental conditions along the proposed offshore route (see Chapter 10).

Construction of the offshore pipeline is expected to progress at a rate of 2 to 4 km per day. The pipelaying direction is envisaged to be from the Omati River to the PNG–Australia border in the Torres Strait.[1]

The offshore pipeline will be installed within a 600-m-wide surveyed corridor, within which a pipeline centreline will be specified with an installation tolerance of ±10 m. Catenary calculations have not yet been performed, and therefore the area of direct disturbance is that of the pipeline centreline and anchor points (if an anchored laybarge is used).

The offshore pipeline will be laid onto the seabed along the majority of the proposed route, where a combination of its inherent weight, provided by a concrete coating, and self-burial in areas of softer sediment will provide the necessary stability. In some

[1] It is anticipated that the pipelaying vessel will continue to lay the pipeline from the border crossing to the Australian landfall location on Cape York.

localised areas, such as in the shipping channels and in the Omati river bed, active burial will probably be required.

7.2 Route Preparation (Preconstruction)

The offshore pipeline must be laid on terrain that is clear of geohazards, debris and boulders. The seabed must be sufficiently flat and in water that is deep enough for construction and construction vessels to operate. If these conditions do not occur naturally, then seabed preparation by methods such as presweeping or dredging may be required. The extent and location of any route preparation activities will be determined following interpretation of the findings of the geophysical survey, completed in November 2005.

Seabed preparation may involve localised presweeping in areas where there are sand waves or natural depressions on the sea floor. Presweeping, which creates a more even surface on which to lay the pipe, is expected to be necessary in the more mobile bedform (sand-wave) areas of Torres Strait. Presweeping is often performed immediately prior to pipelaying, because sand-wave environments are typically dynamic and the preswept seabed surface may quickly resume its naturally uneven profile. Sand-wave presweeping is typically performed by ploughing or jetting. Volumes of sand mobilised when using these techniques are small and tend to settle locally.

Dredging may also be required as a possible alternative to presweeping in shallow water and the landfall approach. If dredging is necessary, one or more of the following dredging techniques would be used:

- Suction dredging works like a vacuum cleaner and is best suited to very fine muds and silts. The suction head operates close to the seabed, and disturbed sediments tend to remain close to the suction head, with minimal amounts becoming suspended in the water. There are two types of suction dredging:
  - *Cutter Suction:* this method can effectively dredge most seabed types, including rocky bottoms in water depths of up to 30 m.
  - *Trailing Suction:* trailing suction is most effective for softer seabeds and water depths approaching 80 m.
- The dipper/backhoe dredging method uses an excavator attached to a barge. This method is slow and is suitable for excavating short trenches in shallow water up to 15 m in depth.

7.3 Pipelaying (Construction)

7.3.1 Pipeline Characteristics

The offshore sales gas pipeline will be constructed of DN 700, concrete-coated, API 5 L X-70 carbon steel line pipe sections12 m long, which will be welded together on the pipelaying vessel. The design life for the pipeline is 40 years. Details such as operating pressure and the need for internal coating are yet to be determined. No internal coating is the base case, as the seawater proposed to be used in hydrotesting may impair the coating.

7.3.2 Offshore Construction

Pipelaying vessels are expected to be employed to install the offshore gas pipeline. Vessels of this type typically operate as follows:

- Sections of line pipe are stacked on the pipelaying vessel.
- Pipe ends are prepared for welding.
- Successive joints of line pipe are lined up and welded together.
- Welds are radiographically inspected and repaired or replaced as necessary.
- Anti-corrosion material (fusion-bonded epoxy) and a weight-coating are applied to the welded joints.
- The pipeline is lowered to the seafloor.

A constant tension is applied to the pipeline as it is lowered from the vessel to the seabed using a pipelaying arm (called a stinger). The stinger extends from the stern of the pipelaying vessel and prevents the pipeline from bending excessively between the vessel and the seabed.

The laying of an offshore pipeline is generally a continuous process. Barges (towed by tugs) or self-propelled vessels bring the line pipe and other supplies to the pipelaying vessel. An offshore pipelaying operation typically comprises:

- A pipelaying vessel.
- Up to three anchor-handling tugs (depending on pipelaying vessel type; see Section 7.3.3).
- A general supply vessel.
- Line-pipe supply vessels in sufficient numbers to ensure a continuous supply of line pipe to the pipelaying vessel.
- Bulk carriers to transport line pipe to a location from which the line pipe supply vessels can supply line pipe to the pipelaying vessel.
- A dedicated survey vessel.

7.3.3 Pipelaying Vessel

Anchored laybarges are most commonly used for installing long-distance, large-diameter marine pipelines in relatively shallow water as typified by the portions of the Gulf of Papua and Torres Strait that will be traversed by the offshore sales gas pipeline in PNG waters. Typically, 10 to 12 anchors are deployed by up to three dedicated anchor-handling tugs. Anchors are placed on each side of (lateral anchors) and in front of and behind (forward and stern anchors) the laybarge. The anchored laybarge moves forward along the pipelaying route by simultaneously winching on the forward anchors and letting out line on the stern anchors. All of the anchors are sequentially picked up and moved forward by tugboats as the laybarge progresses forward. When there is tension on the lines, the anchors will slide along the seafloor until they become embedded. On a hard seabed, anchors may need to be picked up and repositioned more than once before they hold fast.

Figure 7.1 shows a typical anchored laybarge, its associated line-pipe supply vessel and a typical layout of anchor lines. The length of anchor line in contact with the seabed depends on the tension, which varies as the laybarge progressively takes up slack on the forward lines and pays out line on the stern lines. During this process, some portions of the anchor lines are dragged along the seabed and disturb the seafloor as the laybarge moves forward.

In tidal rivers and very shallow water depths, such as in the Omati River, a flat-bottomed variation of the anchored laybarge is typically used. These maintain position and forward movement either via anchors (as described above) or via spud piles driven into the seafloor. Only line-pipe supply and possibly crew accommodation vessels are required to support a spud-piled, shallow-draft laybarge.

7.3.4 Support Vessel Types

7.3.4.1 Anchor-Handling Tugs

Anchor-handling tugs are ocean-going vessels with sufficient deck space and winch capacity to pick up and reposition laybarge anchors. Under direction from the laybarge, they continually pick up the laybarge's anchors one at a time, moving them to the next position. Plate 7.1a shows a typical anchor-handling tug.

7.3.4.2 General Supply Vessel

The general supply vessel continuously moves between the pipelaying vessel and the onshore support base to:

- Deliver general stores (food, water, fuel) and supplies (field joint-coating material, welding materials).
- Return waste that cannot be disposed of offshore or treated onboard, in compliance with national and international regulations.

Plate 7.1b shows a typical general supply vessel. The pipelaying contractor will set up a supply base close to the offshore work. During pipelaying in PNG waters, it is anticipated that the supply base will be located in or near Port Moresby, but the exact location will only be determined following contract award.

7.3.4.3 Line-Pipe Supply Vessel

Line pipe will be transported from the coating yard (location not yet determined) via bulk carriers to a sheltered offshore location (location to be determined) as close as possible for transport to the pipelaying vessel. Dedicated line-pipe supply vessels will bring the line pipe to the pipelaying vessel. The number of line-pipe supply vessels required depends on the distance between the bulk carrier and the pipelaying vessel and on the pipelaying progress rates. Plate 7.1c shows a typical line-pipe supply vessel with line pipe on deck.

7.3.4.4 Survey Vessel

A dedicated survey vessel may be employed for the duration of the pipelaying operation. This vessel (a typical example is shown in Plate 7.1d) may do a prelay survey of the seabed prior to the mobilisation of the pipelaying vessel. This vessel would continually scout the seabed immediately ahead of the pipelaying vessel for any obstructions and would also survey the as-installed position of the pipeline behind the pipelaying vessel.

7.3.5 Omati River Landfall Construction

The pipeline landfall at the Omati River has a river depth of approximately 2 m, with a diurnal tidal range of 4 m. The onshore section is swampy and is flooded frequently when high tides coincide with river flood flows in the Kikori and Omati rivers.

If the river bank is unstable, the pipeline may need to be laid at a depth of 8 m. Currently, a swan-neck design (Figure 7.2) is proposed, which reduces the extent of deep burial.

A dry working environment is required for pipe burial, and this will be achieved using a cofferdam, envisaged as 4-m-wide sheet piling installed from a point some 20 m onshore, over a distance of approximately 60 m into the river. The cofferdam concept may change during detailed design, but the objectives and principles will remain the same. When works are completed, the sheet piling may be left in place or buried or cut off at or below the level of the river bed in order to maintain stability and current riverbank configuration.

Two methods of placing the pipeline through the landfall have been considered. The offshore-pull method uses a barge anchored in the river to haul a long welded pipestring floating in the trench from a pipeline stringing facility that would need to be constructed on firm terrain, about 10 km further inland.

The other method considered (and currently preferred) is the onshore-pull method, whereby a winch onshore pulls welded pipestring from a laybarge anchored immediately offshore. This method better suits the swan-neck design. The sequence of onshore-pull landfall construction is shown schematically in Figure 7.2.

7.3.6 Offshore Construction

Offshore installation of the sales gas pipeline will be achieved using an anchored laybarge as described in Section 7.3.3.

7.3.7 Pipeline Stabilisation and Protection

The offshore pipeline will require stabilisation to prevent movement on the seabed and to protect it against impacts from vessels and anchors, particularly in the Omati River, and potentially at other crossing points of commercial shipping lanes in Torres Strait. For the remainder of the route in the deeper waters of the Gulf of Papua and in Torres Strait, the pipeline is not likely to require any additional stabilisation or protection other than that provided by the weight of the concrete weight-coating. The pipeline will rest on or be partly embedded in the seabed, depending on local conditions. In the soft sediment found in the majority of the offshore route through the Gulf of Papua, the pipeline will most likely become buried naturally over time.

In the Gulf of Papua prawn trawling grounds, self-burial of the pipeline in the soft sediments will reduce or avoid any risk of contact with trawl gear. However, the pipeline will be designed to withstand the maximum loadings that may occur during its lifetime. The pipeline’s concrete coating alone is designed to provide adequate stabilisation and to withstand any impact from equipment typically used by prawn trawlers operating further offshore in the Gulf of Papua and in Torres Strait.

In the shallow waters of the Omati River and near shore, it is expected that the pipeline will require protection against potential vessel or anchor impacts, extreme currents, and debris (such as large, submerged trees and logs). The first part of the offshore pipeline—from the tie-in to the swan-neck section at the landfall along the bed of the Omati River out to some distance offshore—will need to be protected from the above risks by burial. The appropriate depth of burial is still to be determined but could be achieved using one of the trenching methods discussed below.

Where the seabed is hard or the sediments are thin, the pipeline is unlikely to self-bury over time. Localised sections of the pipeline could then become unsupported (called spanning), if strong lateral currents scour the seabed underneath the pipeline. If the pre-installation geophysical survey or the post-installation inspection indicates any particular locations where long-term stability of the pipeline on the seabed cannot be guaranteed by weight-coating alone, then burial or other methods of protection, such as rock dumping or grout bag support, may be considered.

The preferred method for pipeline stabilisation and protection depends upon seabed conditions. Suitable methods include ploughing, jetting, cutting, and grout support, and these are described further below.

Ploughing. This technique is similar to conventional agricultural ploughing. A surface vessel pulls a plough along the seabed to create a V-shaped trench. This method works in most seabeds, including sand, clay and low-strength rock. An advantage of ploughing is that there is very little environmental impact beyond the trench and spoil banks, and the trench will naturally fill and bury the pipeline over time. A typical subsea plough, a trench profile and an artist’s impression of a plough in use on a seabed are shown in Figure 7.3.

Jetting. Jetting is suitable for sand and soft to medium clays but will not work in hard clay or rocky seabeds. Low-pressure, high-volume water jets dislodge soil around the pipeline and deposit the soil away from the trench. Trenches excavated by jetting will normally backfill naturally. A typical jetting machine and a trench profile along with preswept sand waves being trenched are shown in Figure 7.4. This method may be used in the Omati River and nearshore shallow waters and also in parts of the Torres Strait.

Cutting. Mechanical cutters use a series of chains to cut a trench and remove the excavated material. Cutters are usually self-propelled and produce trenches with steep sidewalls. This method only suits hard seabeds, such as very stiff clays or rock, and may be used in the shipping lanes in Torres Strait. A typical mechanical cutter and a trench profile are shown in Figure 7.5**.**

Grout Support. Grout bags are sometimes used to support an offshore pipeline in areas where spanning might occur. The bags are placed in position, then filled with cement slurry, which sets after positioning, thus providing the support. While there are no areas along the proposed offshore pipeline route where this method is thought likely to be necessary, it may be considered if span rectification is required.

7.3.8 Post-Installation Work

When the offshore pipeline installation work is complete, a post-installation video survey will confirm the pipeline integrity. The pipeline will be checked for potential irregularities caused during construction, and span rectification and trenching will be performed where necessary, using one of the methods described above.

The installation contractor will also be required to fill, clean and gauge the pipeline to prove the integrity of the work, as described in Section 7.4.

7.4 Commissioning

Commissioning is the process of confirming that all equipment is installed safely and correctly and will operate as designed when sales gas is introduced into the system and pipeline.

The commissioning activities for the offshore sales gas pipeline involve the following activities:

- Filling, cleaning and gauging.
- Hydrotesting.
- Dewatering and drying.
- Final commissioning.

The offshore section of the sales gas pipeline will be installed in a dry, air-filled condition with the line completely sealed from ingress of seawater throughout the pipelaying process. After installation, the offshore pipeline will be cleaned and gauged, prior to hydrotesting and drying. The exact sequence of these operations will be determined by the construction contractor.

7.4.1 Filling, Cleaning and Gauging

These processes begin with the controlled water filling of the pipeline, using a train of selected pigs. These processes will:

- Remove all free air in the pipeline.

- Allow the controlled introduction of seawater into the pipeline.
- Enable the pipeline to be cleaned.
- Prove that the bore of the pipeline is free from dents or other mechanical damage, by virtue of gauging plates attached to one or more of the pigs.
- Enable the pipeline to be hydrotested.

7.4.1.1 Filling

Filling of the offshore pipeline will consider the cleanliness of the source seawater, which is better drawn from an area where diurnal tides and prevailing currents carry little or no suspended sediment.

As the base case, it is proposed to fill the entire offshore pipeline (including the shallow water section) with seawater from the Cape York end. Water from the Omati River is expected to contain organic debris and suspended sediments and is expected to be brackish. In contrast, seawater from Cape York is expected to be relatively clean, with low levels of suspended solids.

A sample of water from the proposed suction point(s) will be tested prior to its introduction into the pipeline to determine the level of particle contamination. Based on the results of that testing, appropriately sized mesh filters will be selected to ensure the removal of particles from the test water.

7.4.1.2 Water Treatment

Prior to insertion into the pipeline, the seawater will be tested for microbial content to establish the optimum treatment package. Seawater generally requires a lower dosage of oxygen scavenger because of its higher salt content and its slightly lower dissolved oxygen level than freshwater, further supporting the preference for filling the offshore sales gas pipeline with seawater.

Depending on the quality of the test water and/or the length of time it is left in the pipeline after hydrotesting, it is normal practice to protect the pipeline by the addition of a small amount of a biocide and an oxygen scavenger. In some cases of prolonged containment (generally defined as more than 6 months), the addition of a corrosion inhibitor may also be required. In the base case, the water retention time will be limited, and it is unlikely that any corrosion inhibitor will be required. The use of any fluorescein or rhodamine dye (sometimes used for leak detection) is not proposed, as welding integrity testing will be performed prior to laying the welded, coated pipeline on the seabed.

Oxygen-scavenger chemicals are used to reduce the dissolved oxygen in the seawater so as to prevent corrosion. Proven oxygen-scavenger chemicals include sodium sulfite, sodium bisulfite and ammonium bisulfite solutions, which oxidise to sulfate. The dosage rate will depend on the amount of dissolved oxygen in the water.

A biocide is added to control sulfate-reducing bacteria, which can form hydrogen sulfide (H_2S), which in turn can cause corrosion in anoxic, water-filled pipelines. Failure to control biological activity can result in not only the loss of steel wall thickness but also the development of tenacious deposits, which may cause difficulties during subsequent drying. Samples of the source water will be biologically tested in the field or laboratory for sulfate-reducing bacterial activity in order to determine the amount of biocide treatment necessary.

The combined effects of the biocide and the depletion of dissolved oxygen will kill any marine organisms in the test water and prevent their introduction into the Omati River environment. Biocides are water-miscible fluids designed to kill sulfate-reducing bacteria in an anaerobic environment. The oxygen scavenger is therefore injected before the biocide to ensure that anaerobic conditions occur in the hydrotest water within the pipe. Common biocides used include polymeric biguanide hydrochloride, quaternary ammonia and glutaraldehyde.

These chemicals will be mixed in an enclosed tank onshore or added separately at the suction side of the pumps used to fill the pipeline during the hydrotesting process. Appropriate bunding will be constructed as necessary to contain any accidental spillage of chemicals or treated water.

7.4.1.3 Cleaning

The protection of the pipe and its condition is an ongoing process. During transportation from the steel mill to the coating yard and then to the pipelaying vessel, all reasonable precautions will be taken to keep the inside surface of the line pipe clean and dry. The use of vinyl or polyethylene end caps will accomplish this.

After welding on the pipelaying vessel, it is important for the installation contractor to remove rust, dust and other fine debris from each pipe joint by using an approved swabbing procedure immediately before the joint enters the line-up station. This is a critical operation, especially for an internally uncoated pipeline; and thorough cleaning at this stage will simplify cleaning operations following pipelaying completion.

The following methods are available for cleaning the pipeline:

- High-velocity flushing.
- Gel cleaning.
- Brush pigging.

High-velocity flushing involves passing water at high velocity through the pipeline. This technique is not very effective for cleaning large-diameter pipelines and is used mainly on small-diameter lines.

Gel cleaning combines the cleaning action of brush pigs with the debris pick-up capability of a carrier gel.

For an uncoated pipeline, a train of 6 to 8 brush pigs, nominally 500 m apart, travelling at approximately 0.50 to 0.75 m/s is likely to be required to optimise the cleaning process.

Brush pigging is the only practical and acceptable method of cleaning an uncoated pipeline. Other types of cleaner pigs may be used depending on the condition of the pipeline.

The cleaning process normally begins by injecting a volume of treated water equivalent to approximately 500 m of pipe length ahead of the first pig in order to wet and reduce friction in the pipe. Some turbulence in the water flow is required in order to keep any loose particles in suspension and to reduce the risk of the pigs becoming stuck due to a buildup of debris ahead of them.

7.4.1.4 Gauging

In the gauging operation, the pipeline will be checked for defects, such as ovality and dents. The gauging process will normally occur concurrently with the cleaning process. The penultimate pig at the rear of the cleaning train is normally fitted with one or two aluminium gauging plates and transits the entire length of the pipeline. After receipt and acceptance of the gauging plate(s), the pipeline can be readied for hydrotesting.

7.4.2 Hydrotesting

Hydrotesting is performed to confirm pipeline integrity and will use the same water used to fill the line during cleaning. The volume of treated test water will be approximately 160,000 m^3 for the entire offshore pipeline, as indicated in Section 7.4.1.

The base case for the discharge of the line fill/hydrotest water is to release it into the Omati River, at the PNG landfall site. The discharge rate will depend on the speed of the dewatering train. This is typically held at 0.5 to 0.75 m/s, resulting in a discharge rate of 11 to 16 m^3 per minute over a period of 7 to 10 days. The method of discharge may consist of one or more discharge lines extending into the Omati River.

7.4.3 Dewatering and Drying

Once dewatering of the hydrotested offshore sales gas pipeline is complete, the pipeline has to be dried. It is proposed that this will be achieved by vacuum extraction. Whether this is operated from the Cape York or Omati River end is yet to be determined.

7.4.4 Final Commissioning

The sales gas pipeline will be commissioned in sections, as described below. For the purposes of commissioning, the offshore section is one section, as there are only pig receiving facilities at the beginning and the end of the offshore pipeline section.

- Inert gas (usually nitrogen) will be introduced to purge the pipeline of air.
- A pig will then be placed in the pipeline to physically separate the inert gas from the following sales gas.
- Low-pressure sales gas will be introduced behind the inert gas from the onshore PNG section of the pipeline. This propels the pig and the inert gas along the pipeline to the next receiving facility.

- When the sales gas is received at the next pig receiving facility, venting to atmosphere will be stopped and that section of the pipeline will be isolated.

8. Operations and Decommissioning

It is intended that, from the commencement of natural gas production, the operation of the PNG Gas Project and the existing crude oil production from gas fields will be integrated. The new gas facilities and pipelines will be incorporated into an operations management system to address the full range of routine and non-routine operations and maintenance programs and systems. The main activities following commissioning are operational monitoring and control (Section 8.2) and periodic inspection and maintenance (Section 8.3). At the end of the project, facilities will be decommissioned (Section 8.4).

8.1 Operational Staffing

8.1.1 Staff Requirements

The principles underlying the staffing for the operational phase of the project include the following:

- The transition from the construction development mode to a gas production operations mode will be completed at startup.
- At Kutubu, existing staff will be used for both gas and oil operations to the maximum practical extent. New staff will be required to service the Hides Production Facility, and there are anticipated to be synergies with the existing operation.
- The long-term goal is to maximise the use of PNG nationals in all functions.
- PNG nationals will replace expatriates at a rate consistent with safety, reliability and strategic goals.
- Staffing levels are based on a 24 hours per day/7 days per week operation, with staffing reduced at night but sufficient for safe operations and effective emergency response.
- End of project ramp-down will follow the decline in gas production. Necessary staff reductions will be achieved through attrition and retirement to the extent possible.

The operational staffing requirements may vary slightly depending on the final selection of equipment types and production schedules. However, it is expected that at project startup in 2009, the combined oil and gas operations staff (including contract service providers) will be approximately 2,400. The workforce will be similar in nature to the composition of the existing oil operations—approximately 70% contractors and 30% employees. The number of expatriates is estimated to be approximately 10% to 15% of the workforce, and it is expected that the number of expatriates will steadily decline over time, with commensurate increases in the number of PNG nationals and will be managed in accordance with training and localisation plans as approved by the State.

Technical and managerial staff will be suitably qualified. Operators and tradesmen will have appropriate trade qualifications or will be apprentices, with a minimum of 12 years of schooling.

In addition to the operations personnel, a number of project (construction) team members from the commissioning phase will be retained following startup, until the transfer of knowledge is complete, workforce competence is assessed and demonstrated, and the new facilities are operating reliably.

8.1.2 Training and Employment

The Operator's policy regarding the training and employment of PNG nationals is that employment opportunities, all things being equal, will be offered to appropriately skilled individuals from communities in the project area and then to other suitably skilled and qualified PNG nationals.

Training of PNG nationals will be carried out utilising a variety of methods/programs, which could include the existing Kutubu Academy (which uses a competency-based training system), on-the-job (OTJ) training, assignments at other Operator facilities, and participation in commissioning activities. Training will cover all aspects of the operation, including specific equipment training for selected operations, maintenance and engineering staff.

8.2 Monitoring and Control

Oil and gas operations will be monitored and controlled for the most part from the existing control room at the Kutubu Central Production Facility. The Kutubu control room will communicate via the integrated control and safety system with the Central Gas Conditioning Plant, the new Hides Production Facility, the Kumul Marine Terminal, scraper stations, mainline valve stations and other facilities.

The local section of the new gas pipeline network will be controlled and monitored telemetrically and operated from the control room at Kutubu, as well as being monitored at Hides.

Equipment status information will be reported by the remote locations to the Kutubu control room, where it will be processed and displayed on video terminals. Operators at the Kutubu control room will be able to observe the status of the entire pipeline system and the production facilities and to respond to changing conditions, faults or emergencies. Remote shutdown of plants, opening and closing of mainline valves, and other ancillary functions will all be possible from the Kutubu control room.

Gas pressure in the sales gas pipeline will be continuously monitored from the Kutubu control room. A significant pressure drop that is not related to known process conditions may indicate a gas leak, and the affected section of pipeline will be immediately isolated by mainline valves until the reason for the pressure drop is established by direct inspection.

Flows in the sales gas export pipeline will be controlled at the pipeline inlet at Kutubu and monitored all the way to Cape York from the Kutubu control room.

All facilities will have provision for local control in addition to remote monitoring and control. Local control rooms will be or are located at Hides, Gobe and Agogo.

The integrated control and safety system combines safety-system, process-control, SCADA and communications hardware with data-acquisition and data-display software. The system will be based upon the latest Honeywell Experion technology, which allows integration with the existing oil production systems.

Each facility will have its own dedicated safety instrumented system, which will ensure the facility remains within safe operating limits.

Gas facilities will be monitored and operated to achieve customers' contractual reliability requirements. To this end, operations will include in-line sparing of equipment, on-site storage of critical replacement parts, and a computerised preventative maintenance system.

8.3 Inspection and Maintenance

An inspection and maintenance program for the PNG Gas Project facilities and pipelines will be in place at the commencement of operations. The following sections describe this program.

8.3.1 Onshore Facilities and Pipelines

Equipment at production facilities will be subject to preventative maintenance programs, and spare parts will be stocked locally in the Ridge warehouse. Gathering systems will have a physical surveillance program, as well as control room remote monitoring.

Once the new pipelines are installed, the area in the vicinity of the pipelines will be kept clear of tall vegetation (i.e., trees). Routine ground and/or aerial patrols will be undertaken to monitor the pipeline RoWs for operation and maintenance issues such as tree regrowth, soil erosion, and pipeline marker sign maintenance. Particular attention will be paid to third-party activities along the RoW.

In-line inspection tools (intelligent pigs) will be passed through the pipelines at programmed intervals to internally inspect the pipeline wall for thinning. Additionally, pipeline integrity will be monitored using corrosion coupons.

Mainline valve and pig launcher and receiver sites along the pipelines will be located inside fenced areas, along with the associated instrumentation and electrical systems. Functional and maintenance checks will be conducted on these sites on a regular basis.

There are no compressor stations along the pipelines in the initial development since these exist inside the facilities to be constructed.

8.3.2 Offshore Pipeline

External inspection of the offshore portion of the sales gas pipeline will occur immediately after the pipeline is laid. Further external surveys will be conducted at 5-year intervals. These external surveys will, at a minimum, include the running of side-scan sonar to allow detection of excessive free-spans, to determine any movement of the pipeline, and to confirm areas of pipeline self-burial. In addition, a remotely operated vehicle may be directed along the pipeline to visually inspect it for physical damage and to ascertain the status of the corrosion-prevention anodes.

Internal maintenance may include cleaning pig runs. However, the system will be transporting dry, warm natural gas and process upsets are not expected to introduce any water into the offshore pipeline. Cleaning runs are therefore likely to be required only under exceptional circumstances.

In-line inspection tools (intelligent pigs) will be passed through the pipeline at programmed intervals to inspect the pipeline wall for thinning. The pipeline will be protected from external corrosion by a combination of a fusion-bonded epoxy coating and a cathodic protection system. The condition of the external corrosion-protection system will be confirmed during pipeline commissioning.

Maintenance activities for the offshore portion of the sales gas pipeline will include, as required:

- Removal of any large debris from the seabed, especially immediately following construction, to prevent pipeline contact and consequent potential damage.
- Responding to third-party contact incidents, such as contact with the pipeline by a fishing vessel trawl board or vessel anchor.

8.4 Decommissioning

The PNG Gas Project is designed to operate for at least 30 years, and this could be extended in the event of the addition of gas reserves. When project decommissioning ultimately occurs and subject to the State’s rights to acquire facilities under the Gas Agreement, the focus will be on rendering the pipeline and its facilities safe by:

- Purging and flaring gas from within the pipeline, which will then be filled with water and capped.
- Dismantling above-ground facilities, including production facilities, wells, flowlines, compressor stations and scraper stations, and removing all equipment, followed by site clearance and revegetation.
- Removal of all above-ground components of mainline valves.

The pipelines will remain buried, because recovery of the pipe would result in unnecessary environmental disturbance. If the pipelines are still in an operable condition, cathodic protection facilities will be retained to prevent corrosion and to leave open the option of recommissioning at some future date.

Closure plans will be prepared for each facility prior to any decommissioning activities and will be documented in the project's Environmental Management Plan (see Chapter 18).

Project decommissioning activities will comply with regulatory requirements that are in force at the time of decommissioning, as well as standard industry practice at that time.

9. Onshore Environment

9.1 Introduction

This chapter of the EIS describes the onshore physical and biological environment in the areas pertinent to the PNG Gas Project. Subsections include the physical environment (Section 9.2), terrestrial biological environment (Section 9.3), aquatic biological environment (Section 9.4), terrestrial and aquatic resource use (Section 9.5) and Regeneration (Section 9.6).

Geographic nomenclature used in this chapter varies for the terrestrial and the aquatic environments.

Terrestrial environment:

- The onshore 'project area' extends from the Hides gas field to the Omati River and forms part the 'KICDP area', which is the 2.3 million ha area designated by the World Wildlife Fund (WWF) as the Kikori Integrated Conservation and Development Program (KICDP), and covers the Kikori River catchment (Figure 9.1).
- The 'pipeline RoWs' are the rights of way of the various proposed gas and liquids pipelines (see Section 2.4).
- The 'pipeline corridor' is generally the land 10 km on either side of the pipeline RoWs.
- 'New Guinea' refers to the island of New Guinea, which contains the country of Papua New Guinea and the province of Irian Jaya in Indonesia. The term includes the immediately adjacent islands, such as Waigeo and Karkar.
- The 'PNG mainland' refers to that part of 'New Guinea' that forms the country of Papua New Guinea.

Aquatic environment:

- The 'Kikori basin' is the entire catchment of the Kikori River and comprises three sub-basins that are crossed by the proposed pipeline RoWs and access way alignments:
  - The 'Tagari-Hegigio sub-basin'.
  - The 'Lake Kutubu-Digimu-Mubi sub-basin'.
  - The 'Kikori sub-basin'.
- The 'Omati basin' is the catchment of the Omati River, which is crossed by a 21-km section of the pipeline RoW to reach landfall on the lower Omati River.

Within the lower reach and estuarine section of the Omati River, the onshore 'pipeline RoW' becomes the 'pipeline route' when referring to the subriver sections of the sales gas pipeline.

9.2 Physical Environment

This section describes the onshore physical environment of the project area and environs and includes descriptions of location and geomorphology (Section 9.2.1), landforms (Section 9.2.2), tectonic setting and regional seismicity (Section 9.2.3), geology (Section 9.2.4), soils (Section 9.2.5), climate (Section 9.2.6), river systems and hydrology (Section 9.2.7), and water quality (Section 9.2.8).

9.2.1 Location and Geomorphology

The Kikori basin is one of the more remote areas of Papua New Guinea. The Kikori basin stretches from the alpine grasslands of Doma Peaks in Southern Highlands Province to the extensive mangrove wetlands of Gulf Province. Digital elevation models of the upper and lower Kikori basin are shown in Figures 1.3 and 1.4, respectively, in Chapter 1.

The structural history of the Kikori basin is strongly reflected within the geomorphology of the project area. Northeast of the Mubi River, intense thrust faulting has generated a series of northwest-striking ridges and narrow, cliff-bounded valleys. Further to the south between the Mubi and Kikori rivers, thrust faulting becomes subordinate to folding, resulting in topography characterised by broad anticlinal ridges and synclinal valleys. Reduced structural disturbance southwest of the Kikori River is reflected in a gentle arching of the Darai Limestone Formation to form the Darai Plateau. Thrust and secondary faults are associated with several of the ridges and valleys of the project area (see Section 9.2.3).

9.2.2 Landforms

The Kikori basin comprises a system of limestone ridges, valley and plains running in a northwest to southeast direction from the central cordillera of New Guinea. It forms part of the extensive southern fold mountains that cover some 2,000,000 ha between the Gulf of Papua and the Irian Jaya border. Descending from Hides and from Kutubu at elevations of 2,700 m ASL and 1,500 m ASL respectively, the terrain becomes progressively gentler across the limestone Darai Plateau to the floodplain and delta landforms of the Kikori River.

Figure 9.2 shows landforms or terrain types, which are derived from the PNGRIS database.

9.2.2.1 Karst Landforms

Limestone is the dominant surface geological feature in the region, and karstification (erosion by solution) has been a major influence in the development of the present landforms. These eroded surfaces often lack defined stream patterns, and most runoff is vertical, filtering down through cracks in the limestone into cave systems, aquifers and underground streams that can emerge as surface streams at long distances from their sources. Karst can vary from flat, featureless plains lacking significant subsurface features to tall pinnacles or towers with sharp-edged escarpments, cones, sinkholes, and dolines, underlain by extensive and intricate cave systems.

Karst covers the vast majority of the Kikori basin, and Löffler (1977) distinguishes three major types, namely, karst plains, limestone plateaux with karst corridors and polygonal karst.

Karst Plains

Undulating plains of limestone, where the base level of karst erosion has been reached, occupy the central part of the Kikori basin at about 40 to 100 m ASL, the Kikori River itself being confined to a channel cut in the coastal plains. These plains present a more or less uniform limestone pavement, although local pinnacle and doline relief may occur. Because karst plains are at the base level of erosion, subsurface caves are unlikely. Karst plains appear to underlie the depositional plains and fans that occur throughout the Kikori lowlands.

Limestone Plateaux with Karst Corridors

Flat-topped plateaux with narrow, often ill-defined and discontinuous incised karst corridors occur extensively southwest of the lower sections of the Kikori basin and form the southeastern section of the Darai Plateau. The corridors can be deep and wide; and in places, towers and pinnacles are obvious on the plateaux. Löffler (1977) considers these to be former karst plains that are being redissolved by lowering of the base level.

Polygonal Karst

The remaining karst areas of the region are of the polygonal karst type, a general term given to a very variable landscape of complex topography from uniform hummocks to steep tall towers. Polygonal karst forms in areas where the limestone surface is completely pitted with closed depressions that divide the surface into a crudely polygonal pattern. The depressions are typically referred to as dolines and can form as a result of direct dissolution at the surface or by collapse into a subsurface void. Dolines can also occur as scattered, separate circular depressions that typically range in size from 50 to 100 m in diameter and up to 50 m deep in the project area (Dames and Moore, 1987). Dolines that have surface water flowing into an open void in the floor of the depression are commonly referred to as sinkholes.

Three types of polygonal karst are recognised, namely, cockpit (or cone) karst, pinnacle (or tower) karst, and unclassified polygonal karst.

Cockpit Karst. The Darai Plateau in the west consists of cockpit karst (Plate 9.1), which is characterised by the presence of conically shaped residual hills with rounded tops and relatively steep, convex side slopes. This large area of cockpit karst comprises rounded hills up to 70 m high with intervening pits that may or may not connect to other pits, presenting a formidable barrier to movement and development. This plateau is between 200 and 600 m ASL with peaks up to 1,000 m ASL.

Pinnacle Karst. Around Kikori, pinnacles and small towers between 40 and 100 m high stand out from the surrounding plain and form an area of pinnacle karst (Plate 9.2). A typical karst pinnacle is an isolated hill or ridge consisting of an erosional remnant of limestone with vertical or near-vertical convex side slopes and commonly surrounded by an alluvial plain or deep rugged ravines.

Unclassified Polygonal Karst. The third type of polygonal karst is unclassified polygonal karst and occupies the remaining areas of the Kikori, Hegigio, Mubi and Ai'io river valleys. This karst forms a rugged terrain of cones, pinnacles, towers, dolines and hummocks, caves, and underground rivers.

9.2.2.2 Volcanic Landforms

The major volcanic landform in the Kikori basin is the symmetrical cone of Mt Bosavi, a Pleistocene volcano, which rises to 2,530 m ASL in the far northwest of the basin. Its fans and footslopes extend over an area of approximately 200,000 ha north of the cockpit karst of the Darai Plateau. The Mt Sisa and the Doma Peaks volcanic landforms are located to the north and northeast of Mt Bosavi, respectively.

9.2.2.3 Landforms of Fluvial Erosion and Mass Movement

The mountain systems to the north and east of the Kikori basin are a complex of karst and other landforms altered by the fracturing of limestone beds through intense folding, faulting and gravity-sliding into parallel-trending slabs separated by underlying clastic sediments. They comprise hogback and strike ridges, hills or mountains with no structural control, and homoclinal ridges and cuestas.

Hogback and Strike Ridges

Sharp-crested ridges under structural control formed on highly tilted beds form a discontinuous rampart in the east of the Kikori basin. Hogbacks are homoclinal ridges where the bedding dip of the strata is steep (more than 30 to 40 degrees). The term homoclinal pertains to strata that dip in one direction with a uniform angle.

Hills or Mountains with No Structural Control

Strike ridges are interspersed with these limestone mountains and hills with no structure control. Steep, with irregular slopes and caused by intense gullying, this landform has a highly complex drainage pattern. This type of landform forms the higher parts of the Kube Kabe, Wasuma, Iwa, Hurutami and Mosa ranges in that part of the Kikori basin between Lake Kutubu and the Mubi River. Peaks rise to 1,320 m ASL in the Iwa Range and on Mt Kemanagi to the southeast of Lake Kutubu.

Homoclinal Ridges and Cuestas

Homoclinal ridges are formed by resistant beds of rock and are typically asymmetrical with a steep scarp slope and a more gentle dip slope. The dip slope lies at or less than the angle of dip of the beds while the scarp slope maintains a steep slope by undermining and mass wasting due to the rapid weathering of a less resistant stratum below. Cuestas are asymmetric, homoclinal ridges capped by resistant rock layers of slight to moderate bedding dip (less than 15 degrees) and are produced by differential erosion of interbedded resistant and weak rocks.

In the Kikori basin, this landform is found on the eastern slopes of Mt Bosavi and also in the southeast and is characterised by the presence of structurally controlled ranges with asymmetrical ridges and steep outcrop slopes. The homoclinal ridges and cuestas have developed where limestone is layered with harder, more resistant beds of rock.

9.2.2.4 Littoral Plains and Dune Complexes

Recent littoral or relict alluvial plains are found along both banks of the lower reaches of the Kikori and Omati rivers, and old dune complexes occur within the Omati-Kikori delta, forming thin layers of sediment over the underlying limestone plain.

9.2.2.5 Fluvial Plains and Fans

Areas of fluvial deposition, comprising plains, fans, back plains and swamp, are most widespread in the lower Kikori basin, surrounding the littoral plains and dune complexes to the west and east. Significant depositional areas also occur in perched valleys of the Ai'io and Mubi rivers at higher elevations.

9.2.3 Tectonic Setting and Regional Seismicity

The tectonic setting and regional seismicity of the project area are described below.

9.2.3.1 Tectonic Setting

The onshore project infrastructure is located on the northern portion of the tectonic Australian Plate. Figure 9.3 shows the tectonic plates and major fault lines of New Guinea. The northwesterly moving Australian Plate is colliding with the southwesterly moving Pacific Plate. Plate movement is principally accommodated by oblique convergence along the Wewak Trench with the Pacific Plate being subducted beneath the Australian Plate. The overall convergence rate between the two plates is about 110 mm per year based on global positioning satellite (GPS) geodetic surveys (URS, 2005).

The collision between the Australian and Pacific plates was initiated during the Eocene, and there have been several phases of extensional and compressional deformation in Papua New Guinea since then. Compressional tectonism has resulted in the formation of a thrust and fold belt (the Papuan Fold Belt) and an uplift of the central PNG highlands. Historical seismicity indicates that the thrust and fold belt is actively deforming.

9.2.3.2 Regional Seismicity

The seismicity of the Kikori region is classified as Zone 3, which is moderate according to the PNG building standards (PNGS, 1982). Figure 9.4 shows the location of all earthquakes recorded in the vicinity of Papua New Guinea from 1900 to 1997 and indicates that the project is located in an area in which seismic activity is generally less than that in other areas of Papua New Guinea.

Papua New Guinea is situated on top of the converging Australian and Pacific tectonic plates and is therefore seismically active. In general, the expected level of shaking due to earthquakes increases as one moves inland. A seismic hazard study for the project area was carried out by Geomatrix (2005), who conducted a probabilistic seismic hazard assessment. URS (2005) also conducted a complementary geohazard study.

Active fault lines are present in the Kikori basin, and a major fault was recognised to cross the sales gas pipeline RoW near the Mubi River crossing. This and other faults were studied in the probabilistic seismic hazard assessment (Geomatrix, 2005) and were considered in the project design process (see Section 2.5).

9.2.4 Geology

The proposed pipeline RoWs and access ways traverse the following four primary geological units that are strongly reflected in the physiography and geomorphology of the Kikori basin (URS, 2005):

- Eocene to Miocene limestone.
- Miocene to Pliocene marine mudstones.
- Pleistocene volcanics.
- Holocene alluvium and colluvium.

The lithology and geology of the project and surrounding areas is presented in Figure 9.5. The most extensive geological unit within the project area is the Darai Limestone, which is a late Eocene to Miocene reefal and bioclastic shelf carbonate. The Darai Limestone forms the strike ridges, anticlines and karstic landforms characteristic of the project area.

The Darai Limestone was overlain in the late Miocene to Pliocene by the Orubadi Beds, which are a sequence of marine mudstones with intercalated siltstones and sandstones. The Orubadi Beds typically develop thick clay-rich soils and have a subdued topography compared to the adjacent limestone karst country. Stronger sandstone beds may form low linear ridges in places.

A number of basaltic to andesitic volcanic centres developed within the Papuan Fold Belt during the Pleistocene. Mt Kerewa, Mt Sisa and Mt Bosavi are located in the northwestern end of the project area; and Mt Murray and Mt Duau occur in the southeast (see Figure 9.5). These extinct or dormant volcanoes were responsible for the presence of a wide variety of volcanic and volcaniclastic materials, including agglomerate, breccia and tuff, as well as extensive pyroclastic and laharic deposits that form apron and valley fill deposits. Lake Kutubu was formed by the damming of its valley by volcanic ash and debris.

Pleistocene to Holocene fluviatile and lacustrine deposits, including gravel, sand, silt, mud, clay and peat, with interbedded volcanic ash, form extensive ribbon-shaped deposits in many of the northwest-trending valleys.

9.2.5 Soils

Soil orders of the project area are shown in Figure 9.6. Soils along the pipeline corridor are predominantly of the following soil orders:

- **Entisols.** Young soils with little profile development, typically occurring on recently deposited alluvium, but also on erosional surfaces. This soil order occurs along the Hides Ridge and the sales gas pipeline RoW between Gobe via Kopi to the landfall on the Omati River.
- **Inceptisols.** Well-drained, very permeable soils with weakly developed subsurface horizons. This soil order occurs along the proposed Hides rich gas and liquids pipelines RoW between Homa and Idauwi, where volcanic soil types prevail.
- **Mollisols.** Slightly to moderately weathered soils with accumulation and decomposition of relatively large amounts of organic matter in a base-rich environment. This soil order occurs along the sales gas and Gobe rich gas pipeline RoWs between the Kutubu Central Production Facility and Gobe.
- **Histosols**. Poorly drained peaty soils with a strong accumulation of organic matter (at least 12% to 18%), which gives rise to very dark brown, dark brown, or black horizons occurring at or close to the surface. This soil order occurs in upland sago swamps and poorly drained areas of montane *Nothofagus* forest.

Other soil observations in the project area include the following:

- A thin layer of terra rossa soil over hard and weathered limestone rock is found on the ridge line and steep slopes of the Hides Ridge, which is the location of the Hides gas field.
- A skeletal organic soil cover over hard limestone rock is typically found on steep slopes between the Kutubu Central Production Facility and the Ai'io River and on the steep slopes north of the confluence of the Mubi and Hegigio rivers.
- Deep profiles of weathered limestone (terra rossa) are found in the upper Mubi River valley around Manu village and in the middle Kikori River valley between the confluence of the Mubi and Hegigio rivers and Kopi.
- Transported soils with varying depth and drainage properties are typically found on floodplains and on numerous alluvial and colluvial fans south of Kopi.
- Areas of alluvium or lacustrine deposits occur along the northwest shore of Lake Kutubu, where the soils are loose sands and silts that also have granular deposits from sedimentation along the floodplains of the lake's inflow tributaries (Kaimari and Taga creeks).
- Soils of the Kikori and Omati swamplands and deltas are primarily soft silts and clays.

Pain and Blong (1979) grouped most of the PNG highland soils as hydrandepts. Hydrandepts are moderately well-drained to well-drained soils that have a surface layer high in organic matter. The subsoil is dark-brown or dark yellowish-brown silty clay loam or silty clay.

9.2.6 Climate

The climate of the Kikori basin is under the seasonal influence of the northwest monsoon (November to May) and the southeast trade winds (June to October). Both seasonal systems bring copious amounts of rain to the basin, with mean annual precipitation rates in excess of 3,500 mm.

9.2.6.1 General Meteorological Data

General meteorological data for the project area is given in Table 9.1.

Table 9.1 Project-area meteorological data

Feature	Hides 1 Well	HGP	APF	KCPF	GPF	GC	Kopi	Omati Landfall
Altitude (m)	2,740	1,207	812	910	559	54	11.5	0
Mean barometric pressure (kPa)	73.0	87.9	92.0	91.0	94.7	100.4	101.0	101.0
Air temperature (ºC)								
Extreme minimum	-4	4	6	5	7	15	18	18
Mean daily minimum	7.9	15.8	17.8	17.3	19.1	21.7	22.0	22.0
Mean	13.3	21.4	23.5	23.0	24.8	27.5	27.7	27.8
Mean daily maximum	18.7	27.0	29.2	28.6	30.5	33.3	33.5	33.5
Extreme maximum	29	37	39	39	41	38	37	37
Soil temperature (ºC)								
Minimum	10.3	18.4	20.5	20.0	21.8	24.5	24.7	24.8
Mean	13.3	21.4	23.5	23.0	24.8	27.5	27.7	27.8
Maximum	16.3	24.4	26.5	26.0	27.8	30.5	30.7	30.8
Mean relative humidity (%)								
0900 hrs	84	84	84	84	84	84	92	92
1500 hrs	73	73	73	73	73	73	82	82
Maximum rainfall (mm)								
1 month	680	680	1,060	1,060	1,200	1,280	1,800	1,800
24 hours	120	120	150	150	190	190	250	250
1 hour	60	60	80	80	80	80	90	90

Notes: HGP, Hides Gas Plant; APF, Agogo Production Facility; KCPF, Kutubu Central Production Facility; GPF, Gobe Production Facility; GC, Gobe camp.

9.2.6.2 Wind

In the project area, the wind regimes of the coastal plain differ from those in the mountainous hinterland.

Coastal Plain

The coastal plain, including the Omati-Kikori delta, is affected by southeast trade and northwest monsoon seasonal winds. During the northwest monsoon, variable winds (predominantly northwest or west) are accompanied by rain and thunderstorms. During the southeast trade wind season, variable winds (predominantly from the southeast) also bring copious amounts of rain to the delta. In general, higher winds are experienced during the northwest monsoon season and higher waves are experienced during the southeast trade wind season.

In the Gulf of Papua, storms of up to one hour's duration occur occasionally during the northwest monsoon season and cause northwesterly winds, typically up to 65 km/hr, or 18 m/s (ExxonMobil, 2005).

Mountain Area

The mountain area of the Kikori basin is also affected by the southeast trade and northwest monsoon seasonal winds. In addition, the wind regime at Hides Ridge is affected by the local topography. There is constant air movement along Hides Ridge and surrounding mountain ridges, and at higher altitudes strong winds prevail through most of the day.

9.2.6.3 Rainfall and Humidity

The Kikori basin exhibits high annual rainfall, typical of its tropical climate and mountainous topography. There is a strong orographic effect from the coastal to highland areas.

Rainfall distribution varies over the Kikori basin, tending to be highest along the coastal plain and lowest in the high-altitude areas, such as Hides Ridge. Figure 9.7 shows mean monthly rainfall at Tari, Lake Kutubu and Kikori.

Hides Ridge

Mean annual rainfall at Tari, the nearest pluviograph station to Hides Ridge, is about 2,560 mm, with a maximum 24-hour rainfall of 120 mm. Humidity is generally high all year round, with mean relative values between 73% and 84%. A dominant climatic factor in the upland areas is cloud and fog; and for most of the year, they are important sources of moisture. However, the uplands can become dry enough to burn; and the region shows widespread evidence of fires from the 1997 drought.

Lake Kutubu

Mean annual rainfall at Lake Kutubu is about 4,500 mm, with a mean annual fluctuation of only 200 mm. Humidity is consistently high throughout the year, with mean monthly values of between 85% and 90% at 0900 hrs and between 70% to 80% at 1500 hrs.

Coastal Plain

In the lowland coastal plain at the town of Kikori, the rainfall is heavier, with an annual average of 5,700 mm. The rainfall is also more seasonal, with mean monthly values varying from about 300 mm in the period November to February to over 700 mm in May and June. Again, the humidity is consistently high.

9.2.6.4 Droughts

Droughts associated with El Niño-Southern Oscillation events occur regularly in Papua New Guinea and tend to recur at an interval of between 7 and 10 years. Previous El Niño-Southern Oscillation event years were 1965, 1972, 1982 and 1997. In the latter half of 1997, the Kikori basin experienced a severe drought, which was reflected in the monthly rainfall for August at Moro. In August 1997, the total rainfall was 27 mm, while in August 1995 before the drought it was 787 mm and after the drought in August 1988, it was 717 mm (James, 1999).

Periodic swings in rainfall from one year to the other caused by El Niño-Southern Oscillation events can cause serious disruptions to village food supplies and dry up traditional sources of drinking and domestic water (Allen, 2002).

9.2.6.5 Tropical Cyclones

Tropical cyclones pass through Torres Strait and the Gulf of Papua offshore of the Omati-Kikori delta about twice every seven years but do not track northward of latitude 9.5°S and, as such, are unlikely to reach landfall in Papua New Guinea.

9.2.7 River Systems and Hydrology

Natural flow regimes in the main rivers of the project area are dominated by surface runoff, which causes many rivers to have flow rates that increase sharply in response to regional rainfall. In streams of the karst landscape, a significant portion of base flow is groundwater inflow from subterranean streams. All rivers and most streams in the project area are perennial, except during severe El Niño-Southern Oscillation droughts when smaller streams may dry up. Figures 9.8 and 9.9 show the drainage system of the project area.

The project area includes two river systems, namely the Kikori and Omati. The following subsections describe these river systems and their hydrology.

9.2.7.1 Kikori River System

The Kikori basin comprises three sub-basins that are crossed by the pipeline RoWs, namely, the Tagari-Hegigio sub-basin, the Lake Kutubu-Digimu-Mubi sub-basin, and the Kikori sub-basin (see Figures 9.8 and 9.9).

The Kikori basin contains one of the major river systems of Papua New Guinea and drains the southern slopes of the central cordillera. The system is highly confined within its limestone bed, and opportunities for formation of meanders and oxbows are limited to areas of deep overlying sediments. The Kikori delta has remarkably few oxbows for a river of its size.

The sub-basins of the Kikori basin are described below.

Tagari-Hegigio Sub-Basin

The Tagari River is an upland tributary of the Hegigio River. The Hegigio River begins at the confluence of the Tagari and Bakari rivers and continues downstream until its confluence with the Mubi River, at which point the Kikori River commences.

Two tributaries of the upper Tagari River, Hanimu Creek and the Tamalia River, drain the northern and southeastern slopes, respectively, of Hides Ridge via both surface waters (streams) and groundwater (sinkholes). Further downstream, the Dagia, Wada, Benaria and Bakari rivers join the Tagari River. These rivers drain the slopes of Mt Kerewa.

A tributary of the Hegigio River, the Ai'io River, drains the southern slopes of the Iwa Range, which a section of the sales gas pipeline RoW will cross.

The mean flow of the Tagari River at Nogoli Bridge is estimated to be 119 m^3/s. NEC (2004) estimated the mean flow of the Hegigio River just upstream of the Hegigio Gorge (Plate 9.3) at 740 m^3/s for a catchment area of 3,600 km^2.

Lake Kutubu-Digimu-Mubi Sub-Basin

This sub-basin comprises Lake Kutubu, the Digimu River (which drains the lake) and the Mubi River of which the Digimu River is a tributary.

Lake Kutubu is the largest perched lake (808 m ASL) in Papua New Guinea, and it is the country's second largest lake. The lake has a catchment area of 4,924 ha and is about 19 km long and 4 km wide at its widest point, with a maximum depth of about 70 m (Osborne and Totome, 1992). Plate 9.4 shows an aerial view of Lake Kutubu.

The lake is of volcanic origin and lies within karst terrain. The lake was formed originally as a result of volcanic-derived debris and ash blocking the valley in which the lake now lies. Fertile soils occur in the lake's catchment where volcanically derived soils were deposited.

Delineation of the lake's catchment is complicated owing to the extensive karst terrain. The most important surface water inputs are Taga and Kaimari creeks in the northwest catchment of the lake. Sama'a and Gesege creeks are of secondary importance. Numerous minor streams also drain into the lake, but most of these have very small catchments and flow only following local rain events. In the southeast of the lake's catchment area, groundwater inflows from elevated karst terrain predominate.

The outflow of the lake is located in the northwest and is known as the Soro River for a few kilometres but is essentially the beginning of the Digimu River, which is a tributary of the Mubi River. (In this EIS, the lake's outflow river is referred to as the Digimu River for consistency.) The outflow appears to act as a 'spillway' for the lake that tends to dampen seasonal fluctuations in water level, although a water-level amplitude of 2 m occurs, being highest at the end of the wet season and lowest at the end of the dry season (Jenkins et al., 2001). The Digimu River flows west then south through the deep and narrow elongate valleys between the Iwa and Kube Kabe ranges to join the Mubi River.

The Mubi River arises in fine dendritic tributaries and swamplands to the east of the lake, flowing southeast and southwest in steps before flowing northwest around the Kuba Kabe Range where it receives the waters of the Digimu River before flowing out via Wassi Falls into the Kikori River. It is likely that much of the flow in these streams is derived from subterranean streams from the extensive karst terrain that dominates the upland catchments.

The Digimu River has not been systematically gauged, but Rooke (1988) inferred a mean flow of 44 m^3/s, which is consistent with a once-off gauging performed on 12 September 1988, which calculated a flow of 40.1 m^3/s (NSR, 1998a).

The mean flow of the Mubi River above its confluence with the Hegigio River is estimated to be 618 m^3/s.

Kikori Sub-Basin

The Kikori sub-basin refers to the catchment of the Kikori River proper, which commences at the confluence of the Hegigio and Mubi rivers. Note that the Kikori sub-basin should not be confused with the Kikori basin, as the latter refers to the entire catchment of the Kikori River system.

The Kikori River receives flows from numerous side tributaries along its floodplain, with some of the larger ones being Utitu and Pinini creeks, which are crossed by the existing crude oil export pipeline RoW.

A description of the lower Kikori River is required as this is the location at which the onshore sales gas pipeline reaches the Kopi Support Base. Because of concerns about laying additional pipe in the Kikori River, the proposed route of the sales gas pipeline runs due south from Kopi, leaves the Kikori basin, and enters the drainage of the Omati River system (see below).

The area of the sub-basin upstream of the hydrometric gauging station near Kaiam village (approximately 50 km upstream of the town of Kikori) is 13,400 km^2, and the mean discharge of the Kikori River at this point is 1,508 m^3/s.

9.2.7.2 Omati River System

A description of erosion and sedimentation in the lower Omati River is presented in Supporting Study 13. PMG-MHS (1997) described the lower Omati River as highly turbid, much more so than other rivers to the east and within the Kikori delta. Bathymetric survey data indicates the presence of fine surficial sediments on the river bed overlain by a nepheloid layer of very fine, suspended sediments. The latter is transient and is not always present. Tidal bores are a feature of the estuarine reach of the lower Omati River, and PMG-MHS (1997) observed a series of 0.5- to 0.75-m breaking tidal bore waves at the beginning of the flood tide. On one occasion, in otherwise calm conditions, these small tidal bores were observed coming upstream around the western side of Kerowaiai Island, which is located in the lower Omati River.

In the lower Omati River downstream of the proposed sales gas pipeline landfall, the river is a tidal channel up to 2 km wide with mid-channel bars and islands. The lower Omati River is affected by semi-diurnal tides, and tidally induced flow reversals occur. At Goaribari Island, which protects the lower Omati River from adverse sea conditions in the Gulf of Papua, the mean sea level (MSL) is 2.3 m, the highest astronomical tide (HAT) is 4.9 m, the lowest astronomical tide (LAT) is 0.0 m, and the tidal range is about 5 m (ExxonMobil, 2005).

While the drainage system of the Omati River is somewhat ill-defined owing to the presence of wetlands and swamps in which it is difficult to demarcate flows, the estimated catchment area of the Omati River is 1,600 km^2 (Supporting Study 13). Elevations in the upper catchment area are around 600 m. Some logging activity is present in the middle catchment area.

The Omati River has not been systematically gauged, but estimated mean flow adjacent to the landfall site is 243 m^3/s.

9.2.7.3 Subsurface (Subterranean) Waters

The extensive limestone karst terrain occurring within the project area has a complex hydrology, with many sinkholes and subterranean streams. These subsurface waters eventually emerge and augment the flows of surface waters (i.e., rivers and streams). Within limestone karst areas, nearly all surface runoff is channelled immediately into sinkholes or via short gully streams to sinkholes, with further runoff progress being subterranean. During major rainfall events, the sinkholes can flood rapidly, owing to the high inflow of water and the accumulation of debris in the sinkholes.

Limestone areas usually exhibit low runoff, high infiltration rates, and high storage potentials; thus, flows of surface rivers and streams draining these areas do not reflect total runoff. Furthermore, topographic divides, such as major ridgelines, often do not represent groundwater divides simply because of the ease with which water can pass through the limestone ridges.

9.2.8 Water Quality

9.2.8.1 Previous Studies and Historic and Baseline Data

Monitoring of streams within the Kikori basin has been undertaken as part of the Environmental Management and Monitoring Program (EMMP) for the Kutubu Petroleum Development Project (Chevron, 1990). Under this program, various water quality parameters were measured annually between 1991 and 1996 at fixed water sampling and monitoring sites in the Tagari-Hegigio and Lake Kutubu-Digimu-Mubi sub-basins (NSR, 1991, 1992, 1993a, 1993b, 1994, 1995, 1997a). Additional data are provided for the Tamalia and Tagari rivers, which are headwaters of the Hegigio River, in the Environmental Baseline Report prepared for the Hides 4 Appraisal Well (NSR, 1997b). Data for the Ai'io River (which drains to the Hegigio River approximately 10 km northwest of Sisibia) and Kaimari Creek (which drains to Lake Kutubu) are also available from the Moran Project Environmental Assessment Report (NSR, 1997c).

9.2.8.2 General Riverine Water Quality

Kikori River System

Table 9.2 summarises general water quality data for the rivers of the Kikori basin. The locations of the water sampling sites are shown in Figures 9.8 and 9.9.

The water quality of the mainstem rivers of the Tagari-Hegigio and Lake Kutubu-Digimu-Mubi sub-basins are typical of other mainstem rivers in Papua New Guinea that are near neutral to mildly alkaline (pH 7.4 to 8.2) and calcium-bicarbonate dominated. Major dissolved mineral constituents of the river waters, in descending order of concentration, are the cations calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}) and potassium (K^{+}) and the anions bicarbonate (HCO_3^-), sulfate (SO_4^-) and chloride (Cl^-). These properties are indicative of water draining a limestone catchment area. The lower calcium concentration, alkalinity and hardness of the Ai'io River, which drains to the upper Hegigio River, probably reflect the predominantly volcanic and sedimentary terrain at this location (NSR, 1997c).

Water hardness in all rivers except the Ai'io River (31 mg $CaCO_3$/L) is moderate (60 to 119 mg $CaCO_3$/L) to hard (120 to 179 mg $CaCO_3$/L). Conductivity values are generally similar in all streams, with median values ranging between 167 and 267 μS/cm. No marine influence is evident on the lower Kikori River at Kikori, which indicates sampling was undertaken during low tides or that tidal influence was not present at the times of sampling.

Nutrient concentrations are also low, with phosphate and nitrate concentrations generally less than or close to detection limits.

NSR (1997a, b, c) measured trace metal concentrations in the rivers and streams and showed that they were uniformly low. These results reflect a lack of natural sources for these elements and the relatively undisturbed nature of the environment, with uncontaminated waters draining karst limestone catchments.

Tributary streams within the Tagari-Hegigio and Lake Kutubu-Digimu-Mubi sub-basins are generally of low turbidity (less than 2 NTU), with corresponding low concentrations of total suspended solids (TSS), which are generally less than 2 mg/L. However, the mainstem of the upper Hegigio River is highly turbid with high TSS concentrations. Median concentrations of TSS measured in the upper Hegigio River are about 80 mg/L but vary widely, ranging between 48 and 420 mg/L. The same behaviour is also evident with regard to turbidity, which ranged between 1 and 120 NTU on the seven occasions that the two upper Hegigio River sites (SW10 and SW11) have been sampled.

Lowland tributary streams of the Kikori sub-basin have higher TSS concentrations than tributary streams in the upper catchment area, with median concentrations for Utitu and Howoi creeks ranging between 14 and 36 mg/L. Little variation is evident in TSS concentrations in the Mubi River and Utitu Creek; however, values range between 5 and 200 mg/L in Howoi Creek. A large variation in TSS concentrations is also evident in the Kikori River itself, ranging between 14 and 400 mg/L near Kaiam village (median 82 mg/L) and between 4 and 460 mg/L in the lower Kikori River, near Kikori village (with

Table 9.2 General water quality of Project area rivers in the Kikori River Basin

Site	Site Description	Reference	N‡	pH	Cond.	TH	Turb.	TSS	TDS	Alk.	Cations				Anions				
											Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	PO_4
					µS/cm	mg/L*	NTU	mg/L											
Streams in Tagari River catchment:																			
Hides 1	Tagari River	Ref. 1	1	8.2	260	140	-	12	-	140	47	5.5	1.1	0.36	-	2.0	0.75	-	-
Hides 4, 5 & 6	Tamalia River	Ref. 1	3	8.1	200	101	-	1.5	-	110	33	4.7	1.8	0.71	-	1.2	0.34	-	-
Streams in upper Hegigio River catchment:																			
SW10	Upper Hegigio River (immediately d/s of Kondari River)	Ref. 2	7	8.1	167	73	33	78	73	77	21	2.5	1.7	0.7	77	3.6	1.4	<1.0	0.075
SW11	Upper Hegigio River (approx. 22 km d/s of SW10)	Ref. 2	7	8.0	173	87	43	85	89	84	27	3.5	1.5	0.7	92	5.1	1.4	<1.0	0.05
MSW3	Aiu River	Ref. 3	1	8.0	-	31	4	<1	42	39	9.6	1.8	0.9	1.1	39	3.4	<1	-	-
Streams draining to Lake Kutubu:																			
SW5/SW6	Kaimari Creek	Ref. 2	10	7.5	228	137	1.3	2.3	160	131	48	4.5	0.45	0.2	130	1.1	<1	<1.0	<0.05
SW7/SW8	Tibi Creek	Ref. 2	9	7.4	221	133	0.8	1.1	140	130	48	4.3	0.1	0.1	135	0.5	<1	<1.0	<0.05
Streams draining to Digimu and Hegigio rivers:																			
SW1	Lake Kutubu outlet	Ref. 2	7	7.9	179	96	0.4	<1	128	94	36	2.6	0.5	0.2	91	1.6	<1	<1.0	<0.05
SW2	Doromora Creek	Ref. 2	7	7.5	169	94	0.5	<1	128	92	37	2.6	0.5	0.3	91	1.1	<1	<1.0	<0.05
SW3	Hamua Creek	Ref. 2	7	7.6	202	127	0.7	1.0	133	100	44	2.9	0.8	0.3	119	3.2	<1	<1.0	<0.05
SW4	Kara Creek	Ref. 2	7	7.5	188	109	0.9	1.2	136	96	39	3.1	0.8	0.4	117	3.8	<1	<1.0	<0.05
SW14/15	Ai'io River	Ref. 2	11	7.7	281	154	1.0	7.4	151	150	56	3.9	0.4	0.1	150	5.3	<1	<1.0	<0.05

Table 9.2 General water quality of Project area rivers in the Kikori River Basin (cont'd)

Site	Site Description	Reference	N‡	pH	Cond.	TH	Turb.	TSS	TDS	Alk.	Cations				Anions				
											Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	PO_4
					µS/cm	mg/L*	NTU	mg/L											
Streams crossed by Kutubu pipeline																			
SW16/17	Mubi River	Ref. 2	13	8.0	232	98	5.5	36	120	104	42	4.8	1.0	0.4	110	3.8	<1	<1.0	0.06
SW18/19	Kikori River	Ref. 2	13	7.9	227	122	6.6	82	157	120	37	5.8	0.9	0.3	120	3.0	<1	<1.0	0.075
SW20/21	Utitu Creek	Ref. 2	13	7.7	267	131	4.2	14	170	140	51	5.1	0.9	0.1	140	5.3	1.5	<1.0	0.06
SW22/23	Howoi Creek	Ref. 2	13	8.0	222	123	7.0	36	100	110	36	5.3	1.1	0.3	120	3.0	1.2	<1.0	0.07
SW24	Lower Kikori River	Ref. 2	7	7.8	209	125	8.0	43	115	110	37	5.0	1.0	0.4	110	2.5	<1	<1.0	0.043
SW25	Lower Kikori River	Ref. 4	4	8.0	224	114	5.2	20	143	110	34	5.2	1.2	0.3	120	2.7	1.8	<1.0	0.06
SW26	Lower Kikori River	Ref. 4	4	7.9	246	122	9.4	30	142	120	34	6.3	5.4	0.5	120	3.3	11	<1.0	0.08

‡ Based on the number of TSS samples. The actual number of samples for other water quality parameters may vary from this number.

Ref. 1 † NSR (1997b).

Ref. 2 # NSR (1991, 1992, 1993a, 1993b, 1994, 1995 and 1997a).

Ref. 3* NSR (1997c).

Ref. 4 †† NSR (1991, 1992 and 1997a).

medians ranging between 20 and 43 mg/L at the three sampling sites, SW24, SW25 and SW26). Note that median TSS concentrations are lower at these three downstream sites than at the sites near Kaiam village (SW18 and SW19) because the downstream sites were not sampled between 1993 and 1995, when high concentrations were measured near Kaiam village.

Lower Omati River

Sampling of the lower Omati River has not been undertaken. Therefore, water quality data for the lower Kikori River downstream of Kopi (sites SW24 to SW26) has been used as a surrogate until actual water quality data for the lower Omati River is available (see proposed monitoring in Chapter 18).

The water quality data for sites SW24 to SW26 are given in Table 9.2. The waters of the lower Omati River (without tidal influence) are expected to be mildly alkaline (pH 7.8 to 8.0) and calcium-bicarbonate dominated. Since median TSS concentrations in the lower Kikori River are in the range 20 to 43 mg/L, a similar pattern would be expected for the lower Omati River. However, anecdotal evidence, satellite imagery showing high turbidity, and the presence of logging activities in the middle catchment indicate that prevailing turbidity and TSS concentrations may be significantly higher in the lower Omati River.

9.2.8.3 Lake Kutubu

The water in Lake Kutubu is exceptionally clear, with a median TSS value of 1.4 mg/L based on 10 measurements taken at depths ranging from surface water (0 m) to 20 m (Osborne et al., 1990). Secchi disc depth readings ranged from 6.5 to 7.8 m, which emphasises the high clarity of the water. Aquatic plants have been observed growing profusely to depths of up to 6 m. The high water clarity is ascribed to, firstly, low nutrient loads and concentrations in the surface layers (epilimnion) of the lake and a low phytoplankton biomass as a consequence and, secondly, to the low and ephemeral TSS loads of inflowing streams (sites SW5/SW6 and SW7/SW8 in Table 9.2). The largest of these streams, Kaimari Creek, enters the northwest end of the lake after passing through extensive marshes and swamp forest where reduced water velocities settle out entrained solids.

Osborne and Totome (1992) identified a thermocline between the 10-m and 25-m water depth. Above this thermocline, dissolved oxygen levels were high, whereas below 25 m dissolved oxygen levels were less than 2 mg/L. A rise during the day of dissolved oxygen concentrations is consistent with photosynthetic activity, and elevated dissolved oxygen values were recorded by Osborne and Totome (1992) over the dense fringing beds of benthic macrophytes (Characeae).

Lake Kutubu water is alkaline (pH of 7.6 to 8.1), and its conductivity ranges from 166 to 203 μS/cm, which reflects the dominance of dissolved minerals, such as calcium and bicarbonates, derived from the dissolution of limestone of the catchment's karst terrain.

Lake Kutubu is oligomictic, which is a lake classification term that describes a lake having relatively stable stratification with only rare periods of circulation (Osborne and

Totome, 1992). Although Lake Kutubu's stratification appears to be generally stable, overturning has occurred on two recent occasions, one in 1978 and one in 1998. Reportedly, the upwelling does not affect the entire lake but only areas corresponding to the deepest parts. Mixing may be triggered when abnormally cold and stormy weather occurs, resulting in mixing of the deoxygenated hypolimnion (lower water column layer) with the epilimnion (upper water column layer) (Osborne and Totome, 1992). This results in low dissolved oxygen levels in the epilimnion, which causes mass fish kills due to asphyxiation. In addition, the upwelling of nutrients into the epilimnion triggers phytoplankton blooms, often involving blue-green algae, which are often red-coloured.

An anecdotal indigenous account of the phenomenon of the overturning in Lake Kutubu is as follows (Shearston, 1986):

> We have both seen it, when we were little boys. The water was down like this, but further. When we went for sago we had to leave the dugouts far out and walk to the trees—not like now, paddling into those small creeks. They were dried up. Everyone was very frightened to go out on the water—not just children—men too. Then in the night a horrible smell came. There was no wind—it just came, from all around. Everyone ran down the steps of their houses and were crying out and falling on the ground. My mother and father came too. That's when I was really afraid—all of us children—because we didn't know what was happening. In the morning, the water was brown and stinking. And everywhere dead fish floating and birds—the sky was full—diving down to eat them and flying up again. So noisy, we had to shout to each other to speak. My father said the lake had turned over—the bottom was on the top and the green water had sunk. It stayed like that I think one month, and afterwards was a hungry time because of the fish.

9.3 Terrestrial Biological Environment

This section describes the onshore terrestrial biological environment of the project area and environs and includes descriptions of previous studies, new studies and data sets analysed (Sections 9.3.1 to 9.3.3), vegetation and flora (Section 9.3.4), terrestrial fauna (Section 9.3.5), noteworthy areas of terrestrial biodiversity (Section 9.3.6), conservation areas (Section 9.3.7) and the conservation status of flora and fauna (Section 9.3.8).

9.3.1 Previous Studies and Historical Data

Prior to the cooperative arrangements between WWF and the various joint venture partners of the oil projects, which resulted in the establishment of the Kikori Integrated Conservation and Development Program (KICDP), the Kikori basin was one of the biologically least known areas of Papua New Guinea.

The first ornithological exploration appears to have been by Schodde and Hitchcock (1968), who collected birds around Moro and Lake Kutubu during the CSIRO land survey in 1961. McKean (1972) reported on bats collected in the Lake Kutubu area during the same survey. A few mammal specimens collected at Waro and Fogomaiyu villages in the Hegigio River valley are held in the Australian Museum; and a few from the Lake Kutubu area, Mt Bosavi and around Kikori village are in the collections of the University of Papua New Guinea and the National Museum of Papua New Guinea (Seri et al., 1995). No reptile or frog collections had been made in the region.

In the years since WWF has been working in the area, however, there have been numerous surveys; and the KICDP area (defined in Section 9.1) is now one of the biologically best-known in Papua New Guinea as evidenced by the numerous surveys listed in Supporting Study 1. The WWF vegetation surveys used plot-based sampling techniques while the fauna surveys used rapid assessment program techniques, which maximise the return of species located for the effort expended. Supporting Study 1 describes these techniques. The WWF survey expeditions targeted specific sites within the KICDP area, and each expedition sampled from one to several subsites within each site. For some biological groups, data was available for individual subsites, whereas for others data was only available grouped over several subsites. There are 70 identifiable locations where biological data has been collected in the KICDP area, including WWF subsites, grouped WWF subsites, and localities where museum specimens were collected.

All these locations are termed subsites in the analyses carried out for this EIS, and a full list of their locations and altitudes, the habitats and biological groups surveyed and the location data for the 2005 EIS surveys is provided in Supporting Study 1.

9.3.2 New Surveys for this EIS

The WWF survey data provides very good coverage of the southern parts of the KICDP area and the proposed sales gas pipeline RoW from Lake Kutubu south. However, there was little data from the proposed Hides rich gas and liquids pipelines RoW north of Lake Kutubu, the Hides well sites (Hides Ridge) or the Hides Production Facility site.

Surveys of flora and of mammals (including bats), birds, reptiles and amphibians were therefore carried out specifically for this EIS by a survey team of six scientists and local helpers (Plate 9.5) to characterise three areas:

- The Hides Ridge. The survey sites were at Hides 2 and Hides 3 well sites and were surveyed between 24 April 2005 and 1 May 2005.
- The lower montane section of the Hides rich gas and liquids pipelines RoW north of Lake Kutubu, where the RoW will traverse volcanic substrates. The survey site was at Benaria and was surveyed between 1 May 2005 and 8 May 2005.
- The proposed site of the Hides Production Facility. This site was surveyed between 21 April 2005 and 23 April 2005. The nature of the habitats, as well as security considerations, restricted the survey in time and scope. Birds, reptiles and amphibians only were surveyed because the original forest flora and the bulk of the mammals are no longer present in the degraded habitats of this site (kunai grassland and gardens; Plate 9.6).

The full results of these surveys are presented in Supporting Study 2 (flora), Supporting Study 3 (mammals), Supporting Study 4 (bats), Supporting Study 5 (birds) and

Supporting Study 6 (herpetofauna). An overview of the combined findings together with the WWF data appears in Supporting Study 1.

The new surveys, like the WWF surveys, used the rapid assessment program method, originally developed by Conservation International. Rapid assessment program methods maintain as many observation and collection protocols as possible but are adaptable and modify techniques to local conditions so as to maximise the chance of recording species. Basically, observers cover as many different habitat types as possible using as many techniques as possible. Table 9.3 presents the commonest techniques that have used in the KICDP area. The new surveys for the EIS used all these techniques except plot-based sampling of plants. The WWF surveys did not use electronic detection of bats or camera trapping.

Details of the sampling methodology and effort at the three new sample areas are given in the following subsections. Table 9.4 presents sampling effort at each site.

Table 9.3 Methods used in rapid assessment program surveys in the KICDP area

Non-volant Mammals	Bats	Birds	Amphibians and Reptiles	Plants
Trapping using small Elliot traps	Electronic detection (new surveys only)	Cruises along roads and tracks recording species seen and heard	Intensive searches on foot in all habitats by day and by night	Intensive searches on foot in all habitats by day
Trapping using large Elliot traps	Harp traps	Intensive searches of specific habitats for birds.	Spotlighting at night along trails and stream banks	Plot-based sampling (recording all species in a given small area)
Trapping using cage traps	Searching caves	Searches for bowers, display grounds and nests	Aural surveys at night along trails and stream banks	
Spotlighting along roads and trails	Spotlighting along roads and trails	Observations at fruiting and flowering trees	Interviews with local people	
Collecting bones and hair from dung and caves	Collecting bones and hair from dung and caves	Recording bird song and identifying species		
Listening for mammal calls	Interviews with local people	Collecting feathers and bones from dung and caves		
Looking for nests and dens		Spotlighting along roads and trails		
Checking spoor (tracks and droppings)		Camera trapping (new surveys only)		
Camera trapping (new surveys only)		Interviews with local people		
Interviews with local people				

Table 9.4 Sampling effort (for major techniques only in the new surveys for this EIS

Sampling Procedure	Hides 3	Benaria	Nogoli
Non-volant mammals			
Number of trap nights [1]	628	514	0
Camera trap hours (day + night) [2]	504	735	0
Spotlighting man-hours	84	84	0
Day searches man-hours	93	93	0
Bats			
Bat detector nights [3]	27	29	
Hours of recording [4]	286	290	
Number of call files generated and analysed [4]	28,926	42,719	
Mist net metre-hours (night) [5]	810	2,112	0
Birds			
Bird cruises man-hours	138	150	16
Camera trap hours (day + night) [2]	504	735	0
Spotlighting man-hours	36	44	0
Mist net metre-hours (day + night) [5]	2,754	6,768	0
Reptiles and Amphibians			
Spotlighting man-hours	40	96	16
Day searches man-hours	40	96	8
Plants			
Man-hours of survey	246	246	0
Number of fertile herbarium specimens collected	271	297	0

1. One individual trap open for one day (10:00 am Day 1 to 10:00 am Day 2).
2. One trap ready to trigger for one hour
3. One detector working for an entire night (dusk to dawn).
4. Summed for all bat detectors.
5. Mist nets were 6 or 12 m long.

9.3.2.1 Non-Volant Mammals

Non-volant mammals were surveyed by:

- Systematic small mammal trapping on transects along which three kinds of baited traps were placed – small and large Elliot traps and large cage traps. The traps were 10 m apart and laid either on the ground or on platforms nailed to trees at 1 to 2 m above the ground.
- Searches on foot for mammals, their droppings, tracks and signs by day along tracks, forest edges and access points.
- Spotlighting for arboreal mammals at night along tracks, forest edges and access points.
- The deployment of five 'Photscout' 35-mm infra-red-triggered camera traps to continuously record fauna. To operate the traps, each camera was loaded with 400 ASA 35-mm film, desiccant was placed in the housing, and the unit was closed and sealed. The trap was then tied to a tree and aimed so that any bird or mammal

crossing the ground within 15 m of the camera would trigger the infra-red beam and a photograph of the animal would be taken (Plates 9.7 and 9.8).

- Interviewing local villagers and landowners at length over several days. They were shown pictures of mammals and birds, and detailed conversations about behaviour and habits enabled a decision to be made as to the reliability of each record.

9.3.2.2 Bats

Bats were sampled using automated electronic call detection and mist netting.

For automated call detection, six Anabat™ echolocation call detectors (Plate 9.9) were operated in tandem with Zcaim control modules. Each detector divides the ultrasonic frequencies of microchiropteran bats by a known factor, and each sequence (bat call) is recorded onto a compact flash card in the Zcaim as a computer file. Each filename, created by firmware in the Zcaim using an internal computer clock, provides the time of occurrence with an accuracy of one second. After each recording session, each file was displayed via dedicated software on a field computer and analysed. This allowed analysis of the level of site usage and activity patterns. It is understood that this has been the most intensive 'detector-based' bat survey ever conducted in Papua New Guinea, and rates well above similar surveys for environmental impact assessments carried out in Australia and many other parts of the world (Supporting Study 4).

Mist nets were also used to capture bats.

9.3.2.3 Birds

Techniques used to sample birds were as follows:

- Most birds were detected by daytime cruises whereby trails, the forest interior and all accessible areas were walked slowly and all birds seen and heard were recorded. At all sites, birds were identified visually using binoculars (10X) or by their calls.
- Mist netting was used to help confirm the presence of secretive or cryptic species. All nets were erected close to the ground, checked at least every hour, and furled during periods of rain. Most birds were released immediately at the capture site. Some individuals, particularly those in juvenile plumage, were taken to camp to confirm their identity and subsequently released alive at the capture site.
- Night birds were targeted using mist nets and identified by voice or visually when spotlighting.
- Camera trapping (see above).
- Local information (see above).

9.3.2.4 Reptiles and Amphibians

Techniques used to sample reptiles and amphibians were as follows:

- Reptiles and amphibians were surveyed by intensive ground searches in all accessible habitats.
  - During the day, heliothermic (basking) reptiles were searched for along forest trails, clearings and stream banks. Small lizards were collected after being stunned with a large rubber band. Large lizards and snakes were collected by hand.
  - Non-heliothermic reptiles were searched for in deeply shaded forest, during rain or at dusk.
  - Nocturnal reptiles, including geckos, were searched for by walking along forest trails and stream banks at night with a headlamp.
  - Frogs were searched for at night by conducting visual-encounter and aural surveys along streams and in and around small ponds. Because a large proportion of New Guinean frogs have life cycles that are independent of free-standing water, searches were also made along forest trails away from water.
  - Diurnal frogs were searched for during the day along streams, and tadpoles of all species were sampled with a dip-net in all available water bodies. No attempt was made to sample aquatic reptiles (turtles, crocodiles) because all three sites were above the altitudinal ranges of these taxa.
- Frog calls are an important diagnostic character that assist greatly with species identification. Whenever possible, calls were recorded with a Sony TCM-5000 tape recorder and Sennheiser ME66 microphone.
- Local information (see above).

9.3.2.5 Plants

The botanical work was carried out by a botanist and two para-taxonomists who collected herbarium specimens during daily hikes at the study sites. Voucher specimens were obtained on an opportunistic basis from all fertile taxa encountered around the camps, using tree climbers and 15-m extensible pruning poles as required. Identifications were done primarily at the PNG Forest Research Institute (FRI) and at Lae National Herbarium (LAE), but a number of overseas specialists were also consulted. Whenever possible, taxonomic determinations were confirmed using keys from formally published literature or by comparing genuinely annotated reference sheets cited by authorities.

9.3.3 Data Sets Analysed for this EIS

All the data from all previous WWF surveys was recompiled and checked for accuracy specifically for this EIS. This data was then combined with the data from the new surveys to provide a final data set for the EIS (Table 9.5).

Table 9.5 Data set of vertebrates available for analysis in this EIS

Group	No. of Records with Localities	No. of Species
Non-volant mammals	412	79
Bats	195	41 + 3 [1]
Birds	2,180	389
Reptiles [2]	42	59
Amphibians	260	90

1. Three species not yet fully identified.

2. Many reptile records do not have specific locality data (e.g., it is known that saltwater crocodiles are common in the Kikori River but there are no data with latitudes and longitudes of sightings or actual specimens).

The major techniques used for non-volant mammals, birds, reptiles and amphibians in the new surveys were sufficiently close to those used in the WWF surveys to allow easy combination of the data and comparisons between different regions of the KICDP area.

The new bat survey, however, used ground-breaking electronic detection techniques not used before in the KICDP area, so comparisons between areas within the KICDP area could not be so easily made.

Similarly, botanical comparisons were restricted because most previous botanical surveys had used plot-based sampling, which is less efficient than rapid assessment program techniques in assessing floristic diversity within an area.

9.3.4 Vegetation and Flora

This section describes the vegetation and flora of the project area and its environs.

9.3.4.1 Overview

Virtually the entire Kikori basin is covered in tropical forest. Forest structure and floristics are influenced by altitude, climate, topography, soils, geology, degree of waterlogging and the disturbance regime. Species diversity and tree size tend to decrease with increases in altitude until the tree line is reached, generally at about 3,900 m ASL in Papua New Guinea (Paijmans, 1976), although this varies with local topography and relief.

The cooler climates, longer periods of rainfall and fogs of the uplands favour epiphytes, ferns, certain conifers, cooler-adapted broad-leaved trees and mosses. Trees at all altitudes are generally festooned with epiphytes. The physiological changes with increased altitude are reflected in the reduced size of tree crowns. Tree size is influenced by soil fertility, climate and time since the last disturbance. Bole (tree trunk) diameter, as well as leaf size and the variety of plant life forms, reduces with increases in altitude, although bole sizes of individual trees can still be very high in mid-altitude zones. Very large trees tend to occur where there has been a longer time since the last forest disturbance, giving trees time to develop great girths.

9.3.4.2 Forest Structure by Terrain Types

Terrain type is particularly important in determining forest structure in the KICDP area. As well as limestone producing poor soils, the variations in the degree of karstification of the limestone affect the quantity of soil and the capacity of trees to survive for long periods and attain large sizes. On the karst plains of the lowlands and on the tops of some upland ridges, there is a solid limestone pavement with little evidence of rock breakdown: a few cracks and fissures are seen in an otherwise smooth, featureless rock face. There is very little soil development in this situation, and the forest in these areas is supported by its own thin root mat covering the pavement (Plate 9.10), there being few opportunities for roots to penetrate cracks and develop secure toeholds. The forests in these situations are prone to wind throw that peels sections of forest off the limestone pavement (Plate 9.11). As these trees increase in size, their roots can only continue to spread over the rock; and the probability of being blown over increases. This incapacity of tree roots to penetrate into the substrate, combined with the poor limestone soils, limits the size to which trees can grow in this limestone pavement environ. Such forests therefore tend to be poorly developed (trees tend to have small crowns and thin stems, usually less than 60 cm diameter at breast height (dbh)), and numerous large gaps give the impression of an open forest. Nutrient cycling on limestone pavements is highly internalised, with the bulk of the nutrients tied up in the forest itself. Regeneration of these areas appears to require lichens and fine roots to form a mat in which larger plants and trees can germinate (Plate 9.12).

In areas of polygonal karst, in upland karst corridors and in the decomposing rock of the upper ridge slopes, tree roots can penetrate into the many fissures and weaknesses in the rock. Consequently, trees have bigger crowns and boles, producing better developed forests overall, similar to those on the richer valley alluvial soils. Most of the limestone landforms are very well drained; but perched valleys with terra rossa clays occur in the uplands, and the water table in many parts of the lowlands is close to the surface. In such areas of impeded drainage, forest gives way to swamp forest or swamps and wetlands. Palms and pandanus become more dominant, and specialist trees capable of surviving waterlogging occur. In areas of the Mubi River valley near Kantobo village, the karst has sections of internal drainage, and standing water can occur in heavy rainfall periods but is not retained long enough to favor swamp forest. Figure 9.10 shows areas with differing degrees of inundation in the vicinity of the pipeline RoWs.

Close to the coast, saline influences cause the swamp forests to merge into mangroves, but the latter will not be traversed by the sales gas pipeline RoW.

In the northern sections of the KICDP area, there are large areas of volcanic soils that provide better conditions for plant growth than the limestone areas. The soils on flat and rolling terrain are preferentially used for shifting cultivation, and the forest in these areas has been cleared or comprises a complex of secondary growth, primary forest and regenerating areas.

The dynamics of all the forests in the KICDP area are determined by disturbance. Gap-phase dynamics occur where individual tree deaths produce small canopy gaps (1 ha or less). Seedlings and saplings that have stayed quiescent in the shade of the understorey are 'released' and grow up to fill the gap. Which species fills the gap is a lottery, and this is one mechanism that maintains the high diversity in tropical forests. Gaps are forming all the time and producing continuous low-level disturbance.

Catastrophic dynamics, on the other hand, occur when large disturbances, such as landslides, floods, fire, frost, drought or clearing, devastate many hectares or even square kilometers of forest. The area then regenerates through successional processes either to a similar forest type to what was devastated or perhaps to another type. In these cases, individual species may be favoured and come to dominate the resultant forest stands. Supporting Studies 7 and 8 include examples of forests dependent on such catastrophic regimes. Where the disturbance has exposed large areas of mineral soil, species that can germinate in such conditions and thrive in full sun are favored over species that need organic soils and cannot tolerate open conditions.

It is not generally understood that fire is a potent force in rainforest dynamics. Even the wettest tropical forests can burn during drought years. Swamp forests on peat and forests on limestone pavements (where the soil is basically the organic root mat of the forest itself) are very sensitive to fire that burns these organic substrates. Fires that consume these organic substrates destroy the substrate's capacity to support forest growth, and so scrublands, grasslands or bare rock pavement replaces the forest. In most forests, fire, extensive clearing and/or frost can allow grasses and other flammable species to invade. Such species will carry fire indefinitely if there are continuing sources of ignition (people, lightning), and a permanent grassland results. Large areas of the grasslands in the highlands were generated this way (see Supporting Study 8).

Small-scale catastrophic dynamics, where the forest is killed over a few hectares by, for example, disease or a frost in small frost pockets, are also influential in determining forest structure and composition. Small areas can become dominated by a single species that has regenerated in such medium-sized gaps either from seed or root suckers.

Catastrophic dynamics, while a force for maintenance of some forests, can also produce ecosystem collapse and convert an area to some other habitat type, usually grasslands or scrublands. Supporting Study 8 gives several examples of catastrophic events that have eliminated forest in certain locales.

The need for dynamics in tropical forests tends to make them resilient to human-induced disturbance, but the extent, type and duration of disturbance is critical. Short-term, small-scale disturbances through clearing can mimic natural gap-phase or small-scale catastrophic dynamics, and this is the basis for sustainable tropical forestry. However, major changes to natural dynamics result in inevitable system collapse or forest conversion. This can be brought about by large-scale clearing destroying soils, continuous small clearings fragmenting the forest, disturbances being too frequent, fire and disease gaining a foothold, or hydrology being altered. Human behaviour that promotes clearing and fire is the single biggest factor influencing forest loss in Papua New Guinea (Supporting Study 8):

> Fire has therefore had a considerable impact on Papua New Guineas forests, from the lowlands to the sub-alpine zone. The climatic conditions for severe fire occur about once each decade. However, there is no evidence to suggest that forests can survive repeated

burns at this frequency. Although extensive areas of lowland forests may have originated from past catastrophic fires, such fires may occur once every 100 years or more. With increased population pressure across Papua New Guinea, the risk of repeated fires will increase as will the potential for conversion to permanent grasslands, as has occurred across large areas of the highlands.

9.3.4.3 Vegetation Classification

The vegetation classification system used for this EIS is a simplification of the PNG Forest Inventory Management (FIM) system (Hammermaster and Saunders, 1995). Seventy-five vegetation types or complexes are mapped by the FIM system within the KICDP area. These have been grouped into 22 broad vegetation groups for mapping (Supporting Study 1) and are shown in Figure 9.11. The proposed pipelines RoWs intersect 20 FIM types and complexes in 18 broad vegetation groups, and they are described below.

(In the following discussion, which is based on Supporting Studies 2 and 7, large crowned trees have canopies greater than 15 m in diameter, medium crowned trees between 15 and 8 m, small crowned trees between 8 and 4 m and very small crowned trees less than 4 m. In general, decreasing crown size indicates poorer growing conditions. A numerical value following an FIM code represents human impact on the FIM system.)

Lower Montane Zone Above 1,800 m ASL

Lower montane small crowned forest with Nothofagus. This vegetation group (Plate 9.13) includes FIM type LN/LsN (complex of small crowned forest with *Nothofagus* and very small crowned forest with *Nothofagus*) on the proposed pipeline RoW and is restricted to high elevations (above 1,800 m ASL) on the Hides Ridge. The closed, even to slightly undulating canopy is 20 to 30 m high and is dominated by *Nothofagus pullei* and *N. rubra.* This is a classical mossy forest. *Nothofagus* is concentrated along ridgelines and subcrests. In the drainage channel subcatchments, the canopies are usually lower and the mixed communities typical of Papuasian habitats become more apparent. Small patches of seral growth are scattered through the forest as a result of natural canopy-opening mechanisms (e.g., wind throws and tree senescence and death).

While, in general, the dynamics of *Nothofagus* communities tend to be site specific (Supporting Study 7), the forests on the Hides Ridge are clearly being maintained by a classic process of patch dynamics and spatial rotation of forest units in different stages of maturation (Supporting Study 2).

As in most other places that this vegetation group occurs, on the Hides Ridge it contains large numbers of epiphytic ferns and orchids (Plate 9.14), which may represent up to 75% of the plant diversity there (Supporting Study 2).

Lower Montane Zone Between 1,200 m and 1,800 m ASL

Lower montane small crowned forest. This vegetation group includes FIM types L and L5 (both small crowned forest) on the pipeline RoW and is concentrated on the northern section between the Tagari River and the swamp forest of Lake Kutubu (i.e., segments 3, 4 and 5 of the travelogue in Chapter 12) at elevations of 1,200 m ASL and above. This forest has an even to undulating canopy 20 to 30 m high and is very dense to almost closed. *Nothofagus* is absent or very rare; but in the vicinity of Idauwi and Nogoli, the forests on the ranges have many emergent *Araucaria*. Ferns and epiphytes are common. Trees tend to be thin, and oaks (*Castanopis* and *Lithocarpus*) tend to be very common, dominating in some areas. While somewhat less diverse in tree species composition than other forests, this area still shows reasonable vegetative diversity. At lower elevations in the river valleys, clearing for gardens has heavily disturbed the forest.

Lower montane small crowned forest with* Nothofagus*. This vegetation group includes FIM type LN (small crowned forest with *Nothofagus*). Large areas occur on the Doma Peaks and Mt Sisa, and the pipeline RoW traverses a tongue of this forest as it climbs above 1,600 m between the Maruba and Kondari rivers (segment 4 of the travelogue) and again near the Mubi River (segment 5 of the travelogue) north of Lake Kutubu. The canopy is more closed and even than the previous type and is dominated by *Nothofagus*. The crowns are bigger than in type LN/LsN forests, and different species of *Nothofagus* may occur.

Upper Hill Zone Between 600 m and 1,200 m ASL

In this zone the pipeline RoW crosses areas of FIM type L (small crowned forest) in the Mubi River valley north of Lake Kutubu between 600 m and 1,200 m ASL, as well as the following vegetation groups.

Low altitude medium crowned forest on uplands. This vegetation group includes FIM types Hm.N and Hm8.N (medium crowned forest *Nothofagus* suspected present) along the pipeline RoW and occurs between Lake Kutubu and the Kutubu Central Production Facility. It has a fairly even canopy approximately 30 m high with emergents up to 35 m in height. Tree crowns average between 8 and 15 m in diameter, and larger crowns are rare. Orchids and figs are very common, ferns are moderately common, and palms and pandanus are sparse. The understorey is generally open, and there is a ground layer of seedlings, ferns, *Selaginella* and gingers. Conifers such as *Papuacedrus* spp. and *Phyllacladus spp.* become abundant, and oaks (*Castanopis* and possibly *Lithocarpus*) are common.

Lower montane very small crowned forest complexes with Nothofagus. This vegetation group includes FIM types LsN (very small crowned forest with *Nothofagus*) and LsN/L (complex of very small crowned forest with *Nothofagus* and small crowned forest) along the pipeline RoW and is concentrated in the uplands around the Kutubu Central Production Facility. The forest has a dense, evenly textured, dark-toned canopy 5 to 15 m high. *Nothofagus* dominates in some areas, such as along ridges, but is far less obvious than in the higher regions to the north. There are fewer ferns but more vines in this forest type.

Medium crowned to small crowned forest complexes with Nothofagus. This vegetation group includes FIM type HsN/Hm (complex of small crowned forest with *Nothofagus* and medium crowned forest) and occurs between the Kutubu Central Production Facility and the Iwa Range. It has a canopy 25 to 30 m high with 60% to 80% closure and is a mixture of medium crowned forest and small crowned forest. The latter tends to have a more even canopy with no emergents; the former has emergents up to 40 m high. There is an abundance of a range of *Nothofagus* species.

Swamp woodland and forest complexes. This vegetation group occurs around the north of Lake Kutubu and is represented by FIM type Wsw/Fsw (complex of swamp woodland and mixed swamp forest). Swamp woodland is a dense layer of sago palms (*Metroxylon sagu)* with scattered broad-leafed trees and an understorey of sedges, ferns, reeds and/or grass. Mixed swamp forest has an irregular open canopy of medium to very small crowned trees 20 to 30 m high and an understorey of sago palms visible in gaps in the canopy. Sago and tree density varies, giving this type of forest a very patchy appearance.

Lowland Hill Zone Between 200 and 600 m ASL

The pipeline RoW passes through more swamp woodland and forest complexes (FIM type Wsw/Fsw) in the Ai'io River valley, as well as the following vegetation groups

Medium crowned to small crowned forest complexes. The pipeline RoW passes through two types of this vegetation group between the Ai'io and Mubi river crossings. They are both complexes of FIM types Hm/Hs and Hs/Hm (small crowned and medium crowned forest) and vary according to whether patches of medium or small crowned trees dominate. These forest types have a canopy 25 to 30 m high with 60% to 80% closure, the smaller crowned forest having thinner trees and a more even canopy with no emergents, while the medium crowned forest has emergents up to 40 m high. The smaller crowned forest tends to develop on the more difficult pavement sites.

Open lowland forests and freshwater swamps. The pipeline RoW intersects this vegetation group near Kantobo village and it consists of FIM type Po8/Fsw8 and is a complex of open forest and mixed swamp forest (see descriptions in the lowland zone, including FIM types Po and Fsw, below).

Lowland Zone Between 0 and 200 m ASL

The pipeline RoW passes through some medium crowned to small crowned forest complexes vegetation group areas (FIM type Hm/Hs) near Kopi, as well as the following vegetation groups.

Low altitude medium crowned forest on uplands. Above about 120 m ASL, the pipeline RoW generally traverses medium crowned forest (FIM type Hm), which, at this altitude, tends to have a different species composition than in higher zones. The canopies are 25 to 30 m high and are slightly uneven with a 60% to 80% canopy closure and emergents up to 40 m high.

Open lowland forest. Between the Mubi and Kikori river crossings and below about 120 m ASL, the pipeline RoW passes through FIM type Po (open forest) of this vegetation group. The canopy is approximately 30 m high and consists of small and medium crowned trees with large crowned emergents up to 40 m high. The canopy profile is very uneven, with many large gaps probably produced by frequent tree falls on the limestone pavements. Several types of palms occur, and climbing rattans are common. In low-lying areas, sago palm stands develop; and where they have the opportunity, broad-leaved trees can attain very large dimensions (greater than 100 cm dbh).

Small crowned lowland forest. From the Kikori River crossing to Kopi, the sales gas pipeline RoW travels through FIM types Ps and Ps8 (small crowned forest) of this broad vegetation group. This type of forest has a canopy 25 to 30 m high composed of dense small crowns with no emergents, and the canopy is often dominated by a single species, such as *Intsia* sp., and dipterocarps. This type of forest often occurs on very poor or badly drained substrates, such as on limestone pavements.

Swamp forest complexes. The proposed route traverses mixed swamp forest (FIM type Fsw) between Kopi and the Omati River. The trees in this area can be of large diameter (up to 100 cm dbh) and up to 30 m tall. Thick and thin lianas are common, and epiphytes are abundant. *Selaginella* is common on the forest floor. A feature of this area is the abundance of palms. In frequently inundated areas, sago palms can form almost pure stands (FIM type Wsw (swamp woodland)). In areas where karstification has produced some relief within these basins or plains, sago palms dominate in the small hollows or dolines, while the raised ridges of limestone support medium crowned or small crowned lowland hill forest. Where inundation is less frequent, other palms, such as *Arenga* sp. and *Galubia* sp., are dominant (Plate 9.15).

Medium crowned to small crowned forest complexes. A complex of about 14,000 ha of FIM type Hm/Hs/Fsw vegetation (complex of medium crowned, small crowned and swamp forests) occurs southwest of Kopi where it is impossible to map all the individual patches of forest. The pipeline RoW traverses this vegetation group in the small karst range south of the Veiru River, but in this range the forest is FIM type Hm/Hs with no swamp forest intermingled.

Mangroves. The mangrove vegetation group (FIM type M) is extensive in the Kikori River delta, but only a thin line of nypa palms (*Nypa fruticans*) fringes the swamp forests at the lower Omati River landfall of the sales gas pipeline (Plate 9.16). The pipeline RoW does not cross any mangrove vegetation.

9.3.4.4 Flora

Floristic Diversity

New Guinea has one of the world's richest floras with more than 25,000 species of vascular plants (Supriatna, 1999). There are over 3,000 species of ferns (Parris, in press), and 2,800 species of orchids (Vogel and Schuitemann, in press). New Guinea has the highest numbers of indigenous and endemic plant species within Malesia (Balgooy et al., 1996; Welzen, 1997), and the proportion of endemics may exceed 70%

(Johns, 1993). This level of plant diversity ranks New Guinea fifth in the world in terms of the number of flowering plants and first for ferns (see Supporting Study 2).

A full botanical inventory of the KICDP area is not available and would take many years to prepare. Based on the work of Barthlott et al. (1996) who found that the density of tracheophytes (e.g., angiosperms, gymnosperms, ferns and mosses) in New Guinea ranged from 3,000 to in excess of 5,000 species per 10,000 km^2, the KICDP area may have a floristic diversity of between 6,000 and 10,000 species.

The WWF surveys investigated broad-scale patterns of vegetation composition and forest ecology based on small study plots (Balun and Gebia, 1998; Gebia and Balun, 2000, 2004), and the results confirm that the KICDP area has high floristic diversity (see Supporting Study 1). Balun (1995) estimated that 1.8 ha of an 'average Kikori forest' contains 372 tree species that attain 10-cm dbh or greater.

It might be expected that the richer volcanic soils in the northern parts of the KICDP area and the pipeline corridor, as well as the alluvial soils of the river valleys, would have higher species diversity than the limestone plains and karst. However, this need not be the case, and the forests on limestone may in fact be more diverse. Gebia and Balun (2004) claim the highest diversity areas so far sampled in the KICDP area are the Darai Plateau and the Libano River area, which together yielded 876 species, the plots on the rugged Darai karst having more species than those on the alluvial Libano sites. Supporting Study 2 recorded 661 plant species at elevations above 1,100 m at Hides Ridge, the Benaria River valley, and areas near Kutubu and Agogo, mostly on limestone.

Altitude is important in determining species diversity, and the early work at Gobe suggested that species diversity increased with elevation. However, local factors and forest type can be a major contributing factor controlling floral richness; and Supporting Study 2, quoting the work of Gebia and Balun (2004), indicates species richness increases in the sequence: lowland forest, mid-montane forest, lowland alluvial hill forest, and lowland limestone karst.

Over 100 families of tracheophytes have been recorded in the KICDP area. Dominant families in the Darai Plateau and Libano River areas were Orchidaceae, Rubiaceae, Meliaceae, Moraceae, Lauraceae and Araceae, which together accounted for 39.5% of the species (Gebia and Balun, 2004). The numbers of families, genera and species recorded in the northern parts (Hides and Benaria) of the KICDP area (see Supporting Study 2) are shown in Figure 9.12. These northern collections were not dominated by any particular groups of families. Only 10 families out of 111 were represented by more than 15 species, these being Araliacea, Polypodicaeae, Thelypteridaceae, Elaeocarpaceae, Ericaceae, Melastomataceae, Moraceae, Euphorbiacea, Myrtcaeae and Rubiacea. Between these 10 families, this only accounted for 25% of all species. Except for the Moraceae (figs), which are very diverse in the forests of the Malesian botanical region (New Guinea, Malayan peninsula, and Indonesia), this is a different suite of families from those present on the Darai Plateau and Libano River area. At this stage, it is not possible to determine general trends in family distribution in the KICDP area.

The data from the WWF surveys and general understanding of forest composition, however, allow the lowland, lowland hill and upper hill zones (below 1,200 m ASL) to be floristically characterised to some extent. Although species density (species per hectare) may be similar across forest types, different species will have different habitat and altitude preferences. In the medium and small crowned forest of the upper hill zone between 600 m and 1,200 m ASL, around the Ridge Camp and the Agogo Production Facility, the genera *Castanopsis, Chisocheton, Cinnamomum, Cryptocarya, Syzygium, Elaeocarpus, Elmerillia* and *Opocumonia* are common. The swamp forests in the intermontane basins near, for example, Kantobo village are richer in such genera as *Nauclea, Pangium, Pometia, Sloanea, Terminalia, Dracontomelon, Myristica* and *Aglaia.* The lowland forests below 400 m ASL share many species and genera with the uplands, particularly *Elaeocarpus, Sloanea* and *Syzygium*, but typically contain the more characteristically lowland genera, such as *Planchonia, Intsia, Nauclea, Bischofia, Terminalia, Ficus, Cananga, Alstonia, Pometia, Diospyros, Garcinia, Maniltoa, Anisoptera, Canarium,* and *Pterocarpus.*

The swamp forests and swamp woodlands contain a mix of lowland forest and swamp species, such as sago palm and the coastal lowland species *Dillenia alata,* as well as some mangroves (e.g., *Xylocarpus granatum*). Except for the genus *Podocarpus*, conifers are rare in the lowlands.

Palms, of which 55 species have been recorded in the KICDP area (Baker et al., 2000), are more common in wetter forests, such as those that occur in the lowlands and the intermontane swamps. There is no data yet to suggest that the lowland sections of the KICDP area support any endemic species or genera, but further field studies may identify some.

Karst areas worldwide tend to have their own specialised floras, but there is no indication that the karst in the KICDP area has its own specialised flora. There are certainly many species that are only found in karst areas, but they tend to be broadly distributed over karst in New Guinea and not necessarily restricted to the KICDP karst areas. Endemism is expressed on a much larger regional scale than on the local scale of the KICDP area.

Epiphytes

Forest inventories concentrate on tree species, but epiphytes and ferns may be dominant in many areas. There may be more epiphyte and fern species in the KICDP area than tree species. A total of 133 of the 661 species recorded around the Hides Range and Benaria River area were ferns (see Supporting Study 2 and Figure 9.12). Orchids, most of which are epiphytic, may be the most speciose family in the KICDP area. Clements and Harris (no date) recorded 342 species from 58 genera from Lake Kutubu and surrounding areas between 700 m and 1,400 m ASL, and Harris (2003) collected 156 species from the Darai Plateau and 134 from the Libano River area. In the higher forests above 1,800 m ASL, epiphytes and ferns may account for 75% of species diversity.

High-altitude forests are the least studied. Thirteen species new to science were found in the Hides Range, including a tree fern (*Cyathea* sp.) and three unusual calcium-depositing ferns, during the field studies associated with the PNG Gas Project's EIS in

2005 (Supporting Study 1). Examples of rare flora found on the Hides Range are given in Plate 9.17, which shows *Melodinus forbesii*, and Plate 9.18, which shows *Agalymyla formosa*.

The forests of the KICDP area are highly diverse from a floral viewpoint, and it must be assumed that all areas along the proposed route are highly diverse. However, the most significant aspect of floristics in relation to impact assessment is whether certain forest types, plant groups or species are concentrated in small areas along the pipeline RoWs and could therefore be disproportionately impacted. The forest types associated with the pipeline RoWs and other project infrastructure are generally widespread, the karst flora does not appear to be locally endemic, and the more restricted montane forest above 1,200 m has a flora typical of the New Guinea highlands in general (Supporting Studies 1 and 2). It is extremely rare that plant species have distributions restricted to one very small area within a forest; most species are broadly and sparsely distributed.

The knowledge of floristics and vegetation distribution within the KICDP area suggests that only three forest types (or broad vegetation groups) need particular consideration for impact analysis, namely, the lower montane small crowned forest with *Nothofagus* on Hides Ridge, the swamp forest complexes and the swamp woodland and forest complexes. These broad vegetation groups are the most restricted in distribution within the KICDP area and have particular sensitivities to fire and dieback. The lower montane small-crowned forest with *Nothofagus*, in particular, is very rich in epiphytes and has produced a large number of species new to science.

9.3.5 Terrestrial Fauna

The combined terrestrial fauna data of the WWF and the 2005 PNG Gas Project EIS surveys comprises 3,089 field records (i.e., a species definitely recorded at a single subsite) and several records of species occurring in the KICDP area but with no specific location data. All subsites are mapped in Figure 9.13.

Supporting Study 1 presents an overview of the entire fauna in the KICDP area, while details of individual faunal groups are presented in Supporting Study 3 (mammals), Supporting Study 4 (bats), Supporting Study 5 (birds) and Supporting Study 6 (herpetofauna).

This combined fauna database is sufficient to allow some regional analysis of the KICDP area, and bioregions (regions with similar ecology and biodiversity) have been designated for this purpose (see Supporting Study 1). Table 9.6 presents these bioregions, and they are mapped in Figure 9.14. Bioregions are not precisely defined geographic entities with sharp boundaries but are approximate regions that can be characterised by the data from a group of subsites.

Table 9.6 Biodiversity regions of the KICDP area

Bioregion	Pipeline Segment*	Description
Kikori Lowlands	13, 12, 11, 10 (part)	Floodplain of the Kikori River below about 200 m ASL.
Sirebi Lowlands	none	A lowland region to the northeast of the Kikori River, ranging up to 400 m ASL.
Libano-Hegigio	none	Floodplain and hills of the Libano and Hegigio rivers upstream of the Kikori junction, ranging from about 200 to 600 m ASL.
Darai Plateau	none	Rugged polygonal karst plateau from about 300 m to 1,100 m ASL.
Mubi River Karst	10 (part), 9, 8, 15	Karst and limestone plateaux from the Mubi River's junction with the Kikori to Lake Kutubu, covering most of the drainages of the Digimu and Mubi Rivers. Elevation range from approximately 200 to 1,300 m ASL.
Western Volcanics	none	The volcanic cones of Mounts Bosavi and Sisa.
Moro Region	7 (part)	The region around Lake Kutubu at about 800 to 1,000m altitude. Combined with the Iagafu Agogo Limestone Uplands in bird, reptile and frog surveys.
Iagafu Agogo Limestone Uplands	7 (part), 6, 14	The high limestone from about 1,000 to 1,400 m ASL that contains the bulk of project facilities west of Moro and south of the Hegigio Gorge. Combined into the Moro Region in bird, reptile and frog surveys.
Eastern Upland Volcanics/Karst	5, 4, 3, 2	The upland region of mostly volcanics between Nogoli and Kutubu, ranging from about 800 to 1,800 m ASL.
Northern Montane Karst	1	The high karst of the Hides Range over 1,800 m ASL.

*See Chapter 12 for the segment descriptions.

9.3.5.1 Non-Volant Mammals

There are 412 field records of 79 species of non-volant mammals in 10 families in the KICDP area. Forty-three of these (54%) are rodents. A full list of mammal species recorded at each subsite is given in Supporting Study 3. Table 9.7 presents data on the diversity of mammal families in the bioregions. After rodents, the most speciose families are the cuscuses, the marsupial carnivores and the kangaroos. The genus *Phalanger* (cuscuses) is particularly diverse with seven species: mountain cuscus (Plate 9.19), ground cuscus, common cuscus, cuscus (*P. mimicus*), silky cuscus, Stein's cuscus and spotted cuscus. In general the number of species declines with altitude, but marsupials, particularly arboreal species, increase with altitude. The richest bioregions are the two volcanic bioregions where there are better soils and the Mubi River Karst bioregion where there are many sample subsites.

Several species have only been recorded from one bioregion. The short-beaked echidna, long-nosed murexia, an undescribed species of murexia, white-striped dorcopsis, great tailed triok, long-fingered triok, Fly River leptomys, groove-toothed shrew mouse, white-eared rat, greater small-toothed rat, grey black-eared rat, Thomas's melomys, Shaw Mayer's pogonomelomys, New Guinea rat, Stein's rat, and Lorentz's melomys have, for example, only been recorded in the Western Volcanics bioregion. All of these species could, however, occur elsewhere in the KICDP area and along the pipeline RoWs.

Table 9.7 Number of species in each mammal family in the bioregions of the KICDP area

Family	Kikori Lowlands	Sirebi Lowlands	Libano-Hegigio	Mubi River Karst	Darai Plateau	Western Volcanics	Moro Region	Iagifu Agogo Limestone Uplands	Eastern Upland Volcanics/Karst	Northern Montane Karst	Entire KICDP Area
Non-volant Mammals											
Tachyglossidae (echidnas)			2	1	2	1			1	1	2
Dasyuridae (marsupial carnivores)			5	3	2	6		1	3	2	6
Peroryctidae (bandicoots)	4		2	4	2	4			3	3	4
Phalangeridae (cuscuses)	4		4	3	3	6		1	5	5	7
Macropodidae (kangaroos)	2		3	5	4	5			4	3	6
Burramyidae (pygmy possums)				1		1			1		1
Pseudocheiridae (possums)	1			3		5			4	3	5
Petauridae (gliders)	2		2	2	1	4			3	1	4
Acrobatidae (feather-tailed gliders)	1		1	1	1	1	1		1	1	1
Muridae (rodents)	10	3	11	19	8	35	4	4	19	6	43
Total Species	**24**	**3**	**30**	**42**	**23**	**68**	**5**	**6**	**44**	**25**	**79**
Bats											
Emballonuridae	1		4		2	3			3	3	**4**
Hipposideridae	5	1	3	4		4			1		**7**
Rhinolophidae	1		2	1		2			5	2	**5**
Vespertilionidae	3	1			5	4		2	7	7	**14**
Molossidae									2	2	**2**
Unknown microbat									2	2	**11**
Pteropodidae (flying foxes and blossom bats)	9	5	7	5	8	9	4	3	5	1	**3**
Number of Species	**19**	**7**	**16**	**10**	**15**	**22**	**4**	**5**	**25**	**17**	**46**

The WWF surveys have discovered five mammal species new to science (four species of *Rattus* and a *Murexia* species of marsupial carnivore), and a noteworthy discovery on the 2005 surveys was a capture of a rock-dwelling giant rat on the scree slopes of the wellpad at Hides 3 well (Plate 9.20).

The mammal fauna of New Guinea is highly endemic. Seventy per cent of the species are restricted to New Guinea or to the PNG mainland. Seventy-five per cent of the species so far recorded from the KICDP area are New Guinea endemics. Table 9.8 shows that endemism increases towards the northern upland sections of the KICDP area where the montane marsupials are located.

No species, except those new to science, are restricted to the KICDP area.

Table 9.8 Endemicity of non-volant mammals in the bioregions of the KICDP area

Bioregion*	No. of Species	No. of Species in Endemicity Categories**		Per Cent Endemic
		NG	PNG	%
Kikori Lowlands	24	7	2	37.5
Libano-Hegigio	30	12	2	46.7
Darai Plateau	23	10	3	56.5
Mubi River Karst	42	20	6	61.9
Western Volcanics	68	40	7	69.1
Eastern Upland Volcanics/Karst	44	26	4	68.2
Northern Montane Karst	25	17	1	72.0

* Bioregions with only a few records excluded.
**NG = restricted to New Guinea. PNG = restricted to the PNG mainland.

9.3.5.2 Bats

There are 195 field records of 43 identified and 3 unidentified bat species from the KICDP area. A further 30 species could occur. Supporting Study 4 presents a detailed account of the results of the 2005 surveys and the bat species relevant to this impact analysis. An overview of bats is presented in Supporting Study 1.

Bats fall into two major groups. The family Pteropodidae includes the large to medium-sized frugivorous (fruit-eating) flying foxes and the small nectarivorous (nectar-feeding) blossom bats. None of these species echolocate, and they use vision to navigate. The other families of bats are small to medium-sized, insectivorous species (the microbats) that forage on the wing and echolocate. The latter are difficult, sometimes impossible, to capture and are best detected by recording their ultrasonic echolocation calls, which, like bird calls, are mostly species specific. The PNG Gas Project's EIS surveys, conducted in 2005, used technology capable of doing this.

The geological history of New Guinea has produced a bat fauna that is a mixture of New Guinea endemics that appear to be rainforest specialists, southeast Asian or Old World taxa (such as horseshoe, leafnosed, bentwing and pipistrelle bats) that have speciated over many millions of years, and open-habitat Australian bats (including vespertilionids, such as S*cotorepens, Chalinolobus* and *Nyctophilus*). The Australian bats are recent infiltrators since low sea levels during the Pleistocene ice ages (10,000 to 20,000 years ago) allowed the connection of New Guinea with Australia. The great extent of undisturbed bat habitats, including the rainforests of the central cordillera of New Guinea and the mangroves, swamp forests and woodlands of the Gulf region, provide a vast array of ecological niches for the bat fauna. A large number of foraging guilds are represented, within both generalist and specialist assemblages (G. C. Richards, 2002).

Table 9.7 presents data on the diversity of bat families in the KICDP area bioregions. The herbivorous flying foxes and blossom bats tend to have a lowland distribution, while the insectivorous microbats (all other bat families in Table 9.7) are more widely distributed.

The total 76 recorded and possible bat species in the KICDP area are listed in Supporting Study 1. The species of most relevance to impact analysis are those that roost or breed in caves, because the populations concentrate in these specific localities. Thirty-six of the 'recorded' and 'all possible' species use caves exclusively (Supporting Study 4). The remaining species roost and breed in the canopy or other sheltered places; the flying foxes (genus *Pteropus*) usually congregating in large colonies, particularly in the lowlands.

9.3.5.3 Avifauna

There are 2,180 field records of 389 bird species in the KICDP area, and a further 155 species could occur. Supporting Study 5 presents a detailed account of birds, and an overview is presented in Supporting Study 1. The latter also presents a breakdown of the avifauna by families and bioregions, and a simplified version of this data is presented in Table 9.9.

Table 9.9 Number of species in each bird family in the bioregions of the KICDP area (excludes birds only identified to genus)

Family	Kikori Lowlands	Sirebi Lowlands	Libano-Hegigio	Darai Plateau	Mubi River Karst	Western Volcanics	Moro Region*	Eastern Upland Volcanics/Karst	Northern Montane Karst	Entire KICDP Area
Cassowaries and game birds	3	2	2	1	4	2	4	6	1	8
Ducks and waterbirds	12	2	2		6		9	2		20
Other non-passerines	3	2	2	1	3		3	3		3
Kingfishers	9	4	2	3	9	2	7	2		11
Cuckoos	11	4	4	1	12	4	9	5	1	14
Parrots	16	11	6	6	23	14	23	10	5	29
Swifts	5	2		2	4	2	3	3	1	6
Night birds	3	1	3	4	7	6	7	4	1	11
Pigeons	22	10	7	10	22	9	19	9	6	28
Rails	4		1		3		4		1	7
Waders	24	1	1		3		1			25
Gulls, terns and seabirds	12				1					12
Raptors	13	2	2		10	3	15	6	4	20
Other passerines	18	9	9	10	23	14	20	12	3	35

Table 9.9 Number of species in each bird family in the bioregions of the KICDP area (excludes birds only identified to genus) (cont'd)

Family	Kikori Lowlands	Sirebi Lowlands	Libano-Hegigio	Darai Plateau	Mubi River Karst	Western Volcanics	Moro Region*	Eastern Upland Volcanics/Karst	Northern Montane Karst	Entire KICDP Area
Warblers and scrubwrens	8	3	4	3	10	12	13	7	8	23
Honeyeaters	17	4	5	6	16	16	18	10	5	32
Robins	3	1	1	4	9	11	9	8	4	17
Whistlers	4	2	2	5	9	10	8	9	5	15
Birds-of-paradise	6	2	2	4	10	12	10	8	9	21
Cuckooshrikes	9	3		1	10	5	11	5	2	14
Flycatchers	13	6	7	5	14	7	15	12	6	25
Sunbirds and berrypeckers	7	4	1	4	7	7	7	4	2	13
Totals	222	75	63	70	215	136	215	125	64	389

*Includes the Iagifu Agogo Limestone Uplands.

Parrots, pigeons, honeyeaters and birds-of-paradise are the largest families; and between them account for over 28% of the total species in the KICDP area. Both the lowland bioregions and the mid-montane bioregions have higher species numbers than the higher-montane bioregions, a well-known phenomenon in mountain avifauna. Mid-montane regions are an overlap zone where the ranges of montane and lowland species intersect.

The high diversity of many of the non-passerine forest birds reflects a long history in the region. New Guinea's rainforests support a high proportion of frugivores and nectarivores (Beehler et al., 1986). There are 16 species of fruit-doves (*Ptilonopus*) and imperial-pigeons (*Ducula*), all specialist fruit eaters and important dispersers of seeds of hundreds of rainforest trees, as well as 14 species of brush-tongued lories and lorikeets, which are significant pollinators of rainforest plants. Other important dispersers are the cassowaries, two species of which occur in the KICDP area, namely, the dwarf cassowary (*Casuarius benetti*) and the double-wattled cassowary (*C. casuarius*). They are dispersers of a large number of trees and vines, many with fruits too large to be dispersed by any other specialist frugivores. Cassowaries are still abundant, particularly along the section of the existing crude oil export pipeline RoW in the Mubi River Karst bioregion.

Many of the passerine families recorded in the area belong to a larger group with its centre of evolution based around the Australasian region. Notable groups with many species recorded include four species of fairywrens (family Maluridae), 32 honeyeaters (Meliphagidae), 16 warblers and scrubwrens (Pardalotidae) and 17 robins (Petroicidae). The Corvidae is a large passerine family with 87 species recorded within the project area. In its current form, the family comprises a number of taxa until recently identified as separate families and includes the jewel-babblers, whistlers and allies, birds-of-paradise, cuckooshrikes, fantails and monarch flycatchers. They have been subdivided in Table 9.9.

Of particular note is the high diversity of birds-of-paradise. The KICDP area supports at least half of the 40 living species and over two-thirds of the 31 species recorded in New Guinea. Many have restricted distributions (total area and/or altitude), and a number are of significant conservation status.

Table 9.10 presents broad habitat preferences of the avifauna in the bioregions. Forest species comprise the majority of species recorded, particularly the passerines. Most forest species can tolerate disturbance to some extent, and the majority can be recorded in secondary forests and sometimes scrublands and gardens. Primary forest species, those that are restricted to primary forest and rarely, if ever, use secondary or non-forest areas, comprise 10% to 20% of the avifauna. There is a trend for the percentage of primary forest species to increase with altitude even though the numbers of species decline. The Northern Montane Karst bioregion (see Figure 9.14 for bioregion locations) has the highest percentage of primary forest species, which is an indicator of the less disturbed condition of these forests and the rarity of secondary habitats. The generalist forest species are most abundant in the lowlands where they comprise 30% of the forest avifauna.

Table 9.10 Habitat specialisation of birds in the bioregions of the KICDP area

	Forest Species			No. of Wetlands and Grasslands Species	No. of River Species	No. of Aerial Species	No. of Seabirds
	No. of Forest Species	Primary Forest Species* (%)	Secondary or Non-forest Species* (%)				
Kikori Lowlands	163	9.3	30.4	43	4	9	9
Sirebi Lowlands	68	8.8	25.0	3	2	2	
Libano-Hegigio	56	7.1	30.4	4	2	1	
Darai Plateau	67	16.4	19.4		1	2	
Mubi River Karst	196	12.8	21.9	10	4	7	1
Western Volcanics	134	14.2	13.4			3	
Moro Region**	192	11.5	22.4	16	3	7	
Eastern Upland Volcanics/Karst	117	7.7	25.6	3	1	6	
Northern Montane Karst	63	25.4	9.5			2	

*Primary forest species are restricted to primary forest (% of all forest species). Secondary or non-forest species use a range of forest, open areas and scrublands (% of all forest species).

**Includes the Iagifu Agogo Limestone Uplands.

While the forest species are the obvious component of the avifauna, a wide range of wetland and grassland species has also been recorded in the KICDP area. Well-represented taxa include the seven species of rails and crakes (Rallidae), 23 wader species (curlews, sandpipers and plovers – Scolopacidae and Charadriidae), 10 species of herons and egrets (Ardeidae), and the 11 species of the predominantly marine gulls and terns (Lariidae). These birds are most abundant in the lowlands around Moro and Lake Kutubu, where these habitats are most widespread.

Endemism increases from the lowlands to the montane bioregions, and the most important bioregions in terms of avian endemism are the Western Volcanics bioregion and the Northern Montane Karst bioregion, with 75% of the avifauna being endemics restricted to New Guinea or to the PNG mainland (Table 9.11). None are restricted to the KICDP area.

Table 9.11 Endemicity of birds in the bioregions of the KICDP area (includes species identified to genus alone)

Bioregion	No. of Species	No. of Species in Endemicity Categories*		Per Cent Endemic (%)
		NG	PNG	
Kikori Lowlands	224	44	3	21.0
Sirebi Lowlands	74	13	1	18.9
Libano-Hegigio	63	14	1	23.8
Darai Plateau	70	25	1	37.1
Mubi River Karst	217	75	3	35.9
Western Volcanics	137	85	6	66.4
Moro Region*	217	76	3	36.4
Eastern Upland Volcanics/Karst	127	51	5	44.1
Northern Montane Karst	65	47	3	76.9

*NG = restricted to New Guinea. PNG = restricted to PNG mainland.

**Includes the Iagifu Agogo Limestone Uplands.

Many of the endemic species have very restricted ranges in New Guinea, many of these are found only in high areas of the central cordillera, and several occur in the KICDP area.

Species with small ranges have been used by Birdlife International to identify the most important global areas for bird conservation (Stattersfield et al., 1998). Endemic Bird Areas (EBAs) are areas of the globe with a very high concentration of restricted-range species (defined as having a global range of 50,000 km^2 or less). The KICDP area intersects two EBAs: the South Papuan Lowlands and the Central Papuan Mountains. The Central Papuan Mountains EBA has the second highest number of restricted-range species of all EBAs in the southeast Asian island region and includes nine endemic genera (BirdLife International, 2003). The Central Papuan Mountains EBA ranks seventh in the world (out of 128 EBAs) in terms of numbers of restricted-range species. Papua New Guinea as a whole ranks fourth among all countries in the world in terms of numbers of restricted-range species.

Eighteen restricted-range species of the Central Papuan Mountains EBA have been recorded in the KICDP area, and a further 29 could occur there. All but five of them are high mountain specialists (see Supporting Study 5). There are far fewer restricted-range species within the South Papuan Lowlands EBA. Two restricted-range species of the Southern Papuan Lowlands EBA have been recorded in the KICDP area, and three more could occur (see Supporting Study 1).

Plates 9.21 through 9.27 show avifauna typical of the project area.

An account of migratory bird species and the kinds of migratory behaviour is presented in Supporting Studies 1 and 5. Migrants are concentrated in the Kikori Lowlands bioregion and include the migratory waders (Scolopacidae and Charadriidae) that breed in the northern hemisphere and visit tidal and coastal mudflats from September to April. These habitats in Gulf Province have not been surveyed extensively, and the numbers of wader species recorded for the KICDP area is relatively small. Whether they are significant wintering grounds as Diamond and Bishop (2000) and Watkins (2000) suggest remains to be seen.

The pipeline RoWs do not traverse any areas that are important for concentrations of migratory waders.

A smaller number of Australian and Eurasian migrants visit the KICDP area's forests and clearings from May to October. These include the forest and sacred kingfishers, dollar-bird, channel-billed cuckoo, brown falcon, Australian hobby, black-faced cuckooshrike and satin flycatcher from Australia and the oriental cuckoo and white-throated needletail from Eurasia.

9.3.5.4 Herpetofauna

Supporting Studies 1 and 6 present detailed accounts of the frog and reptile fauna of the KICDP area. There are 260 field records of frog species and 42 field records of reptile species from the KICDP area. The knowledge of the frog fauna of the KICDP area has improved considerably since the WWF surveys started.

The Microhylidae and the tree frogs (Hylidae) dominate the frog fauna (Table 9.12). Altitude plays a significant role in determining the distributions of most of these species. At very high elevations, the temperatures are cold and fewer amphibian species occur; those that do are specialised to these cool cloud forests. There is a distinctive component of the frog fauna occurring predominantly at mid or high altitudes, and many species occur only at lower altitudes. Tree frogs appear to have the highest diversity at intermediate altitudes. The general issues affecting these groups are similar at the different altitudes, but montane species may typically have smaller distributions. For example, the microhylid frogs *Choerophryne allisoni* (Plate 9.28) and *Hylophorbus richardsi* (Plate 9.29) are only known from two montane localities: Mt Sisa and the Hides Range.

Table 9.12 Number of species in each frog and reptile family in the bioregions of the KICDP area

Family	Kikori Lowlands	Libano-Hegigio	Darai Plateau	Mubi River Karst	Western Volcanics	Moro Region*	Eastern Upland Volcanics/Karst	Northern Montane Karst	Entire KICDP Area
Frogs									
Microhylidae	17	15	21	19	10	18	17	7	**51**
Hylidae	6	4	7	6	5	16	13	2	**32**
Myobatrachidae	1	1	1		1	1	1		**2**
Ranidae	4	2	4	1		3	2		**6**
Number of species	**28**	**22**	**33**	**26**	**16**	**38**	**33**	**9**	**90**
Reptiles									
Crocodiles	1+1[1]	1+1[1]		?					**2**
Freshwater turtles	?6[2]	?6[2]	?	?	?	?	?	?	**6**[2]
Gekkonidae	1	3	2				1		**6**
Scincidae	5	8	7		2		6	4	**23**
Agamidae	2	3	2				1		**3**
Varanidae	2	1							**3**
Elapidae	3								**3**
Pythonidae	2	2	1				2+1[3]	1+?1[3]	**4+1**[3]
Colubridae	4	2			1		2	1	**8**
Number of species	**20**	**20**	**12**	**0**	**3**		**0**	**6**	**52+7**

*Includes the Iagifu Agogo Limestone Uplands.

1 = *C. novaeguinea* likely to occur in these areas.

2 = Distributions of freshwater turtles not known.

3 = *Morelia boeleni* recorded at Mananda after herpetology report finalised.

Microhylids are small terrestrial frogs that have a reproductive strategy independent of free-standing water. They lay their eggs in terrestrial environments humid enough for their terrestrial embryos to develop. Hylid tree frogs occupy a range of niches, and some occupy specific microhabitats. Upland tree frog species, such as *Litoria* cf *arfakiana*, *Litoria wollastoni* (Plate 9.30), *Litoria* sp. nov 'yellow-legs', and *Rana* cf *grisea* (Plate 9.31), are specialised for life in torrents, while a range of tree frogs lay their eggs in water that has collected in stumps or dead branches. One particularly interesting adaptation some species have is to stick their eggs to leaves above pools into which the tadpoles drop after hatching. Plate 9.32 shows the life cycle of frogs in sinkhole swamps.

Many of the rarer herpetofaunal species are restricted to higher-altitude forests. Herpetofaunal surveys in the KICDP area have concentrated on frogs, and the reptile fauna is not as well known. Most of the reptiles are species inhabiting forest or forest clearings, but a significant group of aquatic turtles and crocodiles relies on large water bodies (rivers, lakes, swamps), and they are described in Sections 9.4.6 and 9.4.7, respectively. The WWF surveys and the PNG Gas Project's EIS surveys conducted in 2005 between them have found 50 species of frogs and 14 species of reptiles new to science. This is over half the known species of frogs in the KICDP area. Thirty-two of the new frogs have been found in more than one locality within the KICDP area, so it is unlikely that most of the new species have very restricted local distributions. The large number of new species reflects the poor state of exploration of the New Guinea herpetofauna.

The majority of these new species have been found during the WWF surveys, and S. Richards (2002) presents photographs of all the new frog species. Three of these species were captured during the PNG Gas Project's EIS surveys and are shown in Plate 9.33. The PNG Gas Project's EIS surveys also found three new reptile species, and these are shown in Plate 9.34.

9.3.5.5 Fauna Conclusions

The biodiversity surveys have confirmed the following generalisations about the KICDP area (summary from Supporting Study 1):

- The area is of high biological significance with high levels of endemism.
- The faunal communities are intact, with many rare species persisting next to petroleum development facilities, reflecting the relatively undisturbed nature of most of the KICDP area, the small footprint of the petroleum developments and the strict environmental controls that have been maintained to date.
- It is unlikely that many faunal species will be found to be restricted to small, localised areas of the KICDP area. Cavernicolous bats, on the other hand, may roost or breed in only certain caves.
- Species diversity declines from the lowlands to the highlands; however, for birds, species diversity is highest at intermediate altitudes where lowland and upland faunas overlap.
- The percentage of primary forest birds, marsupials, and the rarer amphibia, particularly arboreals, increases with altitude.
- The high-montane bioregions (i.e., the Western Volcanics and the Northern Montane Karst) do not have the largest fauna but have the most specialised and restricted fauna.
- The lowland regions are rich in species, but the faunas tend to have many species that are widespread and adapted to disturbed habitats.
- The Kikori Lowlands and the Moro Region bioregions are the most important for waterbirds and swamp fauna.
- The Kikori Lowlands are the most important habitat for over-wintering migratory waders.

9.3.6 Noteworthy Areas of Terrestrial Biodiversity

The WWF biodiversity surveys identified five areas within the KICDP area of the Kikori basin that have noteworthy biodiversity values and may be particularly sensitive to potential project-related impacts. Supporting Study 1 provides more detailed descriptions of these areas, which are summarised below.

9.3.6.1 Area 1: High-Altitude Karst (Hides Ridge)

The high-altitude *Nothofagus* on karst above 1,800 m shares with the higher regions of Mt Sisa a montane fauna in a mostly undisturbed environment. The broad vegetation group is lower montane small crowned forest with *Nothofagus* (Figure 9.15), and the FIM type is a mixture of very small crowned lower montane forest with *Nothofagus* and small crowned lower montane forest with *Nothofagus* (LN/LsN). The gas wells, flowlines, helicopter pads and seismic lines cut for exploration have had no significant impact in this area, and its ecological values are maintained by its difficulty of access. Supporting Study 1 lists over 16 notable features of this forest type. The epiphytes and ferns are the major component of plant biodiversity in this forest type, trees being the structure upon which this is developed.

This forest type is sensitive to fire, and the high altitude means slow growth rates and slow regeneration (see Supporting Study 7). *Nothofagus* is also susceptible to dieback, but existing evidence suggests that the species is not limited by this and that dieback-affected stands can regenerate.

How these high-altitude forests on karst respond and regenerate in relation to disturbance, fire and disease is poorly known. How the epiphyte and fern community responds to disturbance events is unknown.

9.3.6.2 Area 2: Caves

Caves are abundant in the karst areas of the KICDP area and are critical for the well-being of cave-dwelling bats. Particular species require particular types of caves and are very selective about the caves they roost and breed in (see Supporting Study 4).

9.3.6.3 Area 3: Sinkhole Swamps

These microhabitats are small pools or swamps at the bottom of some sinkholes and dolines where the water does not drain away (see Plate 9.32). They are the only habitats in which tree frogs and other water-dependent frogs can breed in these karst areas (which usually have few flowing streams). They are significant at high altitude where there is little or no surface water (see Supporting Study 1).

9.3.6.4 Area 4: Swamp Forest

Swamp forests support a range of specialist vertebrates, including the twelve-wired bird-of-paradise, the New Guinea flightless rail and a range of aquatic fauna (i.e., turtles and crocodiles). These forests tend to be resilient habitats but can be destroyed by fire in drought years and by permanent changes to hydrology. The upland swamp forests are of particular interest, having populations of normally coastal species, such as the twelve-wired bird-of-paradise (see Supporting Study 1). The term ‘swamp forest’ refers to all the vegetation types in the two broad vegetation groups swamp forest complexes and swamp woodland and forest complexes (see Figure 9.15).

9.3.6.5 Area 5: Streams and Riparian Vegetation

Stream condition in the higher-altitude hill and mid-montane forests is important for maintaining populations of specialist vertebrates, such as torrent frogs, Salvadori's teal, torrent-lark, and torrent robin. Riparian vegetation at these altitudes can be a specialised habitat for hydromyine rodents and less commonly for birds. Reducing damage to riparian vegetation will be a high priority to maintain the integrity of these species' populations (see Supporting Studies 1 and 5).

Lowland rivers are important for crocodiles and freshwater turtles. Within the KICDP area, there does not appear to be specialised birds restricted to forest along lowland rivers; however, a range of species are particularly abundant in these habitats. Many birds will move into these habitats in the drier parts of the year and at hot times of the day, particularly in the lowlands. At such times, the riverine forests act as refuges for these dry weather-affected birds (see Supporting Studies 1 and 5).

9.3.7 Conservation Areas

Papua New Guinea is recognised as a country of high biodiversity: it ranks sixth in the world in terms of endemism for mammals, birds and amphibians; and in terms of species per 1,000 km^2, it ranks fifth for mammals, ninth for birds and second for amphibians.

Papua New Guinea is in a special biogeographic position. It lies between Indonesia and Australia and is a transition zone between the flora and fauna of Eurasia and of Australasia. For example, woodpeckers, ungulates, monkeys, and placental carnivores extend east only as far as western Indonesia. Honeyeaters, birds-of-paradise, marsupials and echidnas only go as far west as eastern Indonesia. It is thought that New Guinea and Australia, together with South America, Antarctica and Africa, formed the super-continent Gondwanaland. The tectonic plate holding these land masses floated north, colliding into the plates that held Asia; and in so doing, it carried with it a 'southern' flora and fauna. The mix in New Guinea is most obvious by its vegetation: the montane flora is closely related to that of the southern continents (for example, the presence of southern beech (*Nothofagus* spp.)), whereas the lowland flora is more Asian in its affinities.

Biogeographers sometimes stress the affinities of Papua New Guinea's biota at the expense of its peculiarity. The high degree of endemism of the flora at the species and genus level and the fact that many plant families are better represented in New Guinea than anywhere else indicates strong, independent development of the biota of New Guinea over a long period of time and, in particular, that New Guinea has developed its own flora (Johns, 1993; Balgooy, 1976).

The complex geological history of New Guinea, particularly in the east of the island, has produced a similarly complex pattern of speciation in the biota. Different mountain ranges can have different species, and species replace each other along steep altitudinal gradients. Many species are superspecies consisting of several very distinct subspecies on different mountain ranges. This differentiation may be on a small geographic scale but can be genetically and morphologically large. It is best understood in birds, which are the most studied animal group in Papua New Guinea.

When this biological complexity is combined with the fact that much of Papua New Guinea is still forested, it is not surprising that large areas of the country have been recognised to be of very high conservation value. Sekhran and Miller (1994) and Beehler (1993) presented preliminary analyses of areas of particular importance and high conservation value. These areas cover most of Papua New Guinea, but the Kikori basin is given particular significance because of its remoteness and intactness.

Areas of particular biological significance in the southern section of the KICDP area have been designated by Leary (1996). She designated 11 areas of high biodiversity.

Area 1, Lower Kikori River delta mangrove and swamp forest, is, together with the Turama and Purari mangrove forests, one of the most extensive stands of mangroves in Papua New Guinea. The rich fish biodiversity found in them (Leary, 1996) and the importance of mangroves as breeding areas for fish and prawns warranted designation of this area.

Area 2, Veiru Creek catchment and lower swamp forest, is designated because it has many rock-walled tidal creeks, is habitat for the New Guinea flightless rail (*Megacrex inepta*), has a diverse bird and bat fauna, and has over 600 moth species.

Area 3, Utiti Creek area, is designated because of its diverse and abundant mammal fauna, including rare bats.

Area 4, Upper Seribi River and Lubi River, is designated because the cold waters, which pass through an extensive system of underground caverns, are anomalously cold and ‘harbour a displaced upland aquatic insect biota’ (Leary, 1996). It also has high fish, bird and flora diversity.

Area 5, Darai Plateau and associated limestone karst country, is designated because of the large tract of tower limestone and because the area is uninhabited and fauna populations are largely intact.

Area 6, Mount Bosavi, is designated because it is an isolated volcano and has a rich, basically undisturbed fauna and flora. It supports over 900 moth species, a very rich bird fauna, a diverse mammal fauna and unique characteristics of the aquatic insect fauna.

Area 7a, Kantobo/Wassi Falls and Gobi Karst ridge system, is designated because of its generally high biodiversity.

Area 7b. Blind cave-dwelling fish habitat, is designated because of the new species of blind cave-dwelling fish apparently restricted to the area.

Area 7c, Agogo and Iwa Ranges, is designated because of its generally high biodiversity.

Area 7d, Lake Kutubu WMA and catchment of Wage/Kaimari Creeks draining into the Digimu River near Moro, is designated because of the special values of Lake

Kutubu and the endemic species therein and the generally high biodiversity of its environs

Area 8, Mount Sisa, is designated because of the potentially rich mammal and moth fauna.

Leary (1996) made her assessment before most of the WWF surveys had been undertaken, and it does not cover the northern section of the KICDP area. At least one of her areas (Area 4, Upper Sirebi River and Lubi River) is being intensively logged. The findings of several WWF biodiversity surveys indicate high value for the whole KICDP area, and the designation of significance is more related to relative degree of isolation and human settlement. Figure 9.16 presents the original WWF significant biological areas.

None of the WWF significant biological areas has received official recognition as a reserve within Papua New Guinea. There are only two designated government conservation areas: the Lake Kutubu Wildlife Management Area (WMA), which is a Ramsar-listed wetland, and the Neiru/Aird Hills WMA southeast of Kopi (see Figure 9.16). The Lake Kutubu Ramsar site does not have a specific wetland management plan, and it is currently managed under the WMA arrangement. The proposed new pipeline RoWs follow the existing public road between Kutubu and Homa, which traverses the northwestern part of the Lake Kutubu WMA and Ramsar site. The project will implement site-specific mitigation and management measures to protect the northwestern catchments of this Ramsar-listed lake (see Section 13.4.3).

9.3.8 Conservation Status of Flora and Fauna

Supporting Study 1 lists terrestrial species of plants and animals recorded that appear on the 2004 IUCN red list of threatened species (IUCN, 2004), or are recorded under the Papua New Guinea *Fauna (Protection and Control) Act 1966, 1978* ('Fauna Act').

Of the fauna species, 40 are listed only by the IUCN, 43 are listed only in the Fauna Act and 15 species are on both lists. The discrepancy is due to the list for the Fauna Act being based on Table 8.2 of Sekhran and Miller (1994). The list for the Fauna Act is being revised by DEC (Laba, pers. com., 2005).

The Fauna Act lists 29 species as protected and 29 as restricted. These are mostly species that are hunted. Four non-volant mammals, 15 birds and 10 reptiles are protected, and 4 non-volant mammals and 27 birds are restricted. The majority of birds are raptors and birds-of-paradise, and the reptiles are crocodiles and turtles. Table 9.13 shows the number of species in the various IUCN categories. The critically endangered and endangered species are three mammals and one plant.

Table 9.13 Numbers of IUCN-listed species (entries are number of species recorded + bats and birds that could occur)

Group	Critically Endangered	Endangered	Vulnerable	Near Threatened	Data Deficient
Non-volant mammals	3	3	6	2	4
Bats	0+1		5+6	8+3	
Birds			6+2	10+5	1+5
Frogs					5
Reptiles			2		
Plants	1	1	2		
Total	**4+1**	**4**	**21+8**	**20+8**	**10+5**

No bioregion and no particular part of the pipeline RoWs has a concentration of listed species. Supporting Study 1 presents accounts of the critically endangered and endangered species as categorised by the IUCN.

9.4 Aquatic Biological Environment

This section describes the onshore aquatic biological environment of the project area and environs and includes descriptions of previous studies (Section 9.4.1), aquatic habitats (Section 9.4.2), aquatic flora (Section 9.4.3), fish fauna (Section 9.4.4), macroinvertebrate fauna (Section 9.4.5), freshwater turtles (Section 9.4.6), crocodiles (Section 9.4.7), amphibians (Section 9.4.8) and aquatic mammals (Section 9.4.9).

9.4.1 Previous Studies and Historical Data

A systematic survey program for freshwater fish and invertebrates in New Guinea was undertaken during the decade 1994—2004 by various research organisations, including the Bishop Museum, Smithsonian Institution, the PNG National Museum and Gallery, and Conservation International (Polhemus et al., 2004). During the same period, the World Wildlife Fund also undertook several freshwater fish surveys as part of the Kikori Integrated Conservation and Development Program (KICDP) in concert with Chevron Niugini and Oil Search Limited.

9.4.1.1 Fish

The fish fauna of the Kikori Basin have been studied by Allen (1995) during the WWF surveys and during previous visits to Lake Kutubu in 1983 and 1987. He recorded 88 species belonging to 55 genera and 34 families. Vui (2003) undertook a fish survey of the Libano River in the upper Hegigio River catchment.

9.4.1.2 Macroinvertebrates

Richards (2000) undertook a WWF-funded study of aquatic insects in mountainous terrain at Mt Sisa (two sites) and at a lowland floodplain site, the Sire River, a tributary of the Sirebi River, which flows into the lower Kikori River. The aquatic insects studied included damselfly nymphs (Zygoptera), dragonfly nymphs (Anisoptera), waterbugs (Heteroptera) and whirligig beetles (Gyrinidae).

9.4.2 Aquatic Habitats

The project area offers a wide variety of riverine, lacustrine, subterranean stream, swamp, estuarine and mangrove habitats.

9.4.2.1 Riverine Habitats

The mainstems of the major rivers (i.e., Tagari, Hegigio, Mubi, Digimu and Kikori rivers) provide a variety of habitats for aquatic flora and fauna. In-river habitats range from riffles (areas of rapid currents and shallow water), pools (areas of slow currents and deep water) and runs (areas of intermediate currents and water depth). Within these key habitat types are a suite of microhabitats used by aquatic flora and fauna. For example, riffles are essentially stones-in-current habitats, where the interstitial spaces (voids) between the stones and the stone surfaces themselves provide microhabitats that are colonised by benthic algae and diatoms (in non-turbid rivers), invertebrates and fish. Fallen trees and exposed root systems, large woody debris and other coarse particulate matter provide habitat for a myriad of fish species and the juveniles of mainstem fish.

9.4.2.2 Lacustrine Habitats

Off-channel water bodies and lakes provide lacustrine habitats. Floodplain and wetland habitats and swamps have high water tables and receive regular and seasonal flood flows from the river mainstems via interconnecting channels or overbank flow. However, there are few large permanent lakes in the Kikori basin, with the exception of Lake Kutubu, which lies within the project area.

Lake Kutubu provides a wide variety of aquatic habitats. The highly productive plant beds of Characeae (green algae that superficially resemble horsetail ferns or stoneworts) that dominate much of the lake margins (and the two ‘reefs’ in the centre of the lake) provide the major feeding, spawning and nursery grounds for most of the endemic species. The prevalence of Characeae is indicative of the high water clarity (Meier and Voser, 1994). The preferred habitats of Lake Kutubu fish are described in Section 9.4.4 (fish fauna).

9.4.2.3 Sinkholes and Subterranean Stream Habitats

Sinkholes and subterranean streams in the limestone karst country provide habitat for a blind cave-dwelling fish, which is a type of gudgeon (see Section 9.4.4.3). The regional distribution is not known, but most sightings are located to the north of the Mubi River near Kafa village. The proposed pipeline RoW/access way alignment passes through karst terrain to the south of the Mubi River, approximately 5 km to the southwest of this gudgeon’s known habitat area.

9.4.2.4 Estuarine Habitats

The tidal floodplain of the Omati-Kikori delta has numerous tidal creeks, connecting channels, sandbanks, scour holes and overhanging riparian vegetation, which provide a wide variety of habitat types for aquatic organisms. The tidal floodplain is inundated by tides twice a day, with salinity varying greatly throughout the area. The rich diversity of habitats and varying salinity allow for a mix of freshwater, estuarine and marine fish fauna, as well as crocodiles, turtles and dolphins. The dominant hydrodynamic process in the Omati-Kikori delta is accretion; but within this generally depositional environment, cycles of erosion occur episodically.

The river bed of the lower Omati River is an active zone of sedimentation, and sand bars and mud banks are formed but may subsequently be scoured by river flood and tidal flows. The 1- to 3-m-deep soft silts and fine sands in the bed of the lower Omati River are mobilised from time to time, which represents a poor habitat of low structural diversity for bottom-dwelling fish and invertebrates.

9.4.2.5 Overhanging Riverbank Vegetation

While mangroves are extensive in the Omati-Kikori delta, with about 22,000 ha occurring within the pipeline corridor (i.e., up to 10 km on either side of the pipeline RoWs), none of this aquatic habitat type is traversed by the proposed pipeline RoWs. Only a narrow fringing line of nypa palms (*Nypa fruiticans*) is present along the banks of the lower Omati River, including at the sales gas pipeline landfall site (see Plate 9.16). The submerged stems and roots of nypa palms provide habitats for estuarine macroinvertebrates, as well as for fish, such as mudskippers and gobies.

Nypa palm-lined tidal creeks provide nursery and breeding habitat for a wide range of fish species from offshore areas, such as the expansive network of coral reefs in the Gulf of Papua and northern Torres Strait.

9.4.3 Aquatic Flora

The aquatic flora of the Omati and Kikori river systems has not been studied to any significant degree. However, Lake Kutubu has received attention owing to its high conservation value and Ramsar site listing (Osborne et al., 1990; Osborne and Totome, 1992; NSR, 1990a).

9.4.3.1 Riverine Aquatic Flora

Many of the river mainstems of the project area are turbid, which precludes the establishment of submerged aquatic macrophytes, benthic algae, periphyton or diatoms. However, clearwater streams are found in the upper catchments of the Kikori River system, especially where they drain karst terrain. Although benthic algae and diatoms will be present in these streams, in-situ (autochthonous) primary productivity is minor compared to the large inputs of organic matter from the forested catchments. This ex-situ (allochthonous) terrestrial primary production forms the basis of the food chain in forest streams.

9.4.3.2 Lacustrine Aquatic Flora

Houston (1995) examined the habitats characterised by the presence of aquatic macrophytes in Lake Kutubu and described three vegetation groupings, or zones:

- *Tall emergent zone*: forming the fringing littoral margins of the lake to a maximum depth of 2.5 m (during maximum lake fill). There appeared to be a zonation pattern with tropical reed (*Phragmites karka*) occupying the more landward margins followed by the broad-leaved grass (*Miscanthus floridulus*) and pandanus palm (*Pandanus* sp.) and finally a mixture of reed (*Scirpus grossus*), bulrush (*Typha orientalis*) and several mat-forming grasses (e.g., *Leersia hexandra*). Sometimes the smartweeds of the family Polygonaceae (e.g., *Polygonum attenuatum*) formed a dominant component bordering the tall emergent zone.

- *Aquatic mixed plant beds zone:* comprising either a mixture of cosmopolitan species or one of the following species as a single species stand: water thyme (*Hydrilla verticillata*), hornwort (*Ceratophyllum demersum*), water nymph *(Najas tenuifolia*), eelgrass (*Vallisneria natans*), ducklettuce (*Ottelia alisimoides*) and pondweed (*Potamogeton malaianus*). The mixed community generally occurs in shallow waters to depths of 3 to 4 m, although it may extend locally into deeper waters.

- *Aquatic Characeae plant beds zone:* dominated by stonewort (*Nitella* sp.) This species forms a dense monospecific mat over the bottom of the lake. The Characeae community either abutted the mixed plant beds zone, the tall emergent zone or the non-vegetated lake edge itself where the bank is steep. The aquatic Characeae plant beds zone generally occurs at depths ranging from 2.5 m to depths of between 4.5 and 7.5 m.

The trophic structure of the lake is based on the primary productivity of the lake's marginal and submerged vegetation. High water clarity and adequate nutrient supply are required to maintain this productivity (Osborne et al., 1990).

Two aquatic plants found in the lake — water lettuce (*Pistia stratiotes*) and hydrilla (*Hydrilla verticillata*) — are recognised as having pest potential but neither seems to present a weed problem to date. No other plant pest species, such as water fern (*Salvinia molesta*) or water hyacinth (*Eichhornia crassipes*), has been recorded in the lake; but the potential for weed introductions may increase through in-migration and increases in the local population due to recent road access improvements.

9.4.4 Fish Fauna

The composition of the fish fauna of Papua New Guinea lacks primary freshwater groups (Ostariophysi) and is similar to that of northern Australia. The fish fauna of both regions is largely derived from marine fish that entered freshwater in recent geological times. The PNG fauna consists of relatively few families and is dominated by the Plotosidae (eel-tailed catfishes), Ariidae (fork-tailed catfishes), Teraponidae (grunters), Gobiidae (gobies), Eleotridae (gudgeons), Melanotaeniidae (rainbowfish and blue-eyes) and Atherinidae (hardyheads). Between them, these seven families account for about two-thirds of the freshwater fish fauna of Papua New Guinea.

9.4.4.1 Riverine Fish Fauna

Most fish species inhabiting the Kikori River system have a broad distribution and are common species with wide distributions across southern Papua New Guinea. However, a total of 15 species are endemic to the river system. The fish fauna of the Kikori River system has few specialist types that are restricted to a single food or habitat type, so most of the resident species are widely distributed. This overlap in diet and habitat requirements is an important mechanism for fish survival since floodplain habitats (e.g., swamps of the lower Kikori River) may dry out during severe El Niño drought years.

Riverine Fish Diversity and Distribution

The total fish fauna of the Kikori River catchment comprises 115 fish species belonging to 55 genera distributed among 34 families. Supporting Study 12 gives a detailed listing of the freshwater fauna of the Kikori River catchment. Table 9.14 provides a breakdown by family of the principal fish fauna that have more than one species represented in each family. The remaining 21 families are represented by one species each.

Table 9.14 shows that the riverine fish fauna are dominated by gobies (Gobiidae) and gudgeons (Eleotridae), with fork-tailed (Ariidae) and eel-tailed (Plotosidae) catfish and rainbowfish (Melanotaenidae) forming the principal subdominant groups. Many of the freshwater fish in the system are migratory, such as barramundi, tarpon, mangrove jack, mullet and eels, and move regularly between freshwater and estuarine/marine areas for feeding or reproduction.

Table 9.14 Principal freshwater fish families of the Kikori River system

Group Name	Family	Species	
		(n)	(%)*
Gobies	Gobiidae	27	23.5
Gudgeons	Eleotridae	22	19.1
Fork-tailed catfish	Ariidae	7	6.1
Rainbowfish	Melanotaenidae	7	6.1
Eel-tailed catfish	Plotosidae	6	5.2
Hardyheads	Atherinidae	4	3.5
Garfish	Hemiramphidae	4	3.5
Grunters	Teraponidae	4	3.5
Glass perchlets and nurseryfish	Ambassidae	3	2.6
Mullets	Mugilidae	3	2.6
Eels	Anguillidae	2	1.7
Freshwater herrings and sprats	Clupeidae	2	1.7
Blue-eyes	Pseudomugilidae	2	1.7

*Percentages based on the total of 115 species present.

The majority of the fish fauna highlighted in Table 9.14 and Supporting Study 12 are distributed widely across southern Papua New Guinea, the northern New Guinea-Australian region or the Indo-West Pacific region.

The number of fish species declines rapidly with increasing altitude: 71 species are recorded from the Kikori lowlands section of the pipeline corridor, 10 from the Ai'io and Mubi valleys section, and about 6 to 8 from the Moro-Agogo-Kutubu (excluding the Lake Kutubu endemics) and the Moro-Homa-Idauwi-Hides sections. This pattern of increasing fish diversity with increasing catchment area is typical of most PNG rivers. Note that there are no freshwater fish above 2,000 m ASL in Papua New Guinea (NSR, 1990a).

Upper Catchment Fish Fauna

A fish survey of the Libano River (Plate 9.35 in the upper catchment of the Hegigio River conducted by Vui (2003) is representative of the species matrix occurring or expected to be present in the Tagari-Hegigio sub-basin. Table 9.15 summarises the combined fish fauna caught or observed in the Libano River.

Table 9.15 Fish fauna of the Libano River

Family	Scientific name	Common name
Cyprinidae	*Cyprinus carpio*	Common carp
Ariidae	*Arius uterus*	Northern Rivers catfish
	Arius latirostris	Broad-snouted catfish
Plotosidae	*Neosilurus equinus*	Southern tandan
Hemiramphidae	*Zenarchopterus kampeni*	Fly River garfish
Atherinidae	*Craterocephalus nouhuysi*	Mountain hardyhead
	Craterocephalus lacustris	Kutubu hardyhead
	Craterocephalus pimatuae	Pima hardyhead
Mugilidae	*Liza alata*	Diamond mullet
	Liza subviridis	Greenback mullet
Melanotaeniidae	*Melanotaenia iris*	Strickland rainbowfish
	Melanotaenia catherinae	Weigeo rainbowfish
	Melanotaenia fredericki	Sorong rainbowfish
	Melanotaenia sp.	Unidentified rainbowfish
Apogonidae	*Gloassamia sandei*	Sande's mouth almighty
Teraponidae	*Hephaestus lineatus*	Line grunter
	Hephaestus fuliginosus	Sooty grunter
	Hephaestus adamsoni	Adamson's grunter
Eleotridae	*Oxyeleotris fimbriata*	Fimbriate gudgeon
	Oxyeleotris wisselensis	Paniai gudgeon
	Mogurnda cingulata	Banded mogurnda
Gobiidae	*Glossogobius* sp. 3	Mountain goby
	Glossogobius sp. 6	Twinspot goby
	Glossogobius sp. 11	Fly River goby
	Glossogobius sp. 12	Kutubu goby
	Glossogobius sp. 13	Bighead goby

Source: After Vui (2003).

Table 9.15 shows that 26 species of fish distributed among 11 families were sampled or encountered during the fish survey by Vui (2003). The most frequently encountered fish were rainbowfish (Melanotaeniidae), gobies (Gobiidae), grunters (Teraponidae) and gudgeons (Eleotridae). Mullets (Mugilidae) were the dominant family of fish, with large grazing schools of greenback mullet (*Liza subviridis*) observed. However, this is a migratory fish and may have been abundant because of the time of sampling (August).

Lower Catchment Fish Fauna

While the total number of freshwater fish in the Kikori catchment is currently estimated at 115 species, there are a significant number of estuarine fish species, including marine vagrants, that would increase the total number of fish species present. An exhaustive list of estuarine and marine vagrant fish species for tidal reaches of the lower Kikori and Omati rivers is not warranted. However, the principal large species of freshwater and migratory fish targeted by artisanal and subsistence fisheries in the Omati-Kikori delta are as follows:

- Fork-tailed catfish (Ariidae), including:
  - Salmon catfish (*Arius leptaspis*).
  - Threadfin catfish (*Arius stirlingi*).
- Mixed fish, mainly:
  - Barramundi (*Lates calcarifer*).
  - Jewfish (Sciaenidae).
  - Beach salmon (*Leptobrama mulleri*).
  - Threadfin salmon, such as king threadfin (*Polydactylus sheridani*) and fourfinger threadfin (*Eleutheronema tetradactylum*).
  - Mullet (approximately 10 species, with greenback mullet (*Liza subviridis*) being the most common).
- Sharks (*Carcharhinus* spp.) and sawshark (*Pristis microdon*).

9.4.4.2 Lacustrine Fish Fauna

There are few permanent lakes in the Kikori basin, and Lake Kutubu is the only major lake present. This lake is the second largest in Papua New Guinea after Lake Murray in the Western Province.

Table 9.16 lists the fish fauna of Lake Kutubu and their preferred habitat types. The lake is a Ramsar-listed site that contains 17 species of freshwater fish of which 12 species are endemic to the lake. This high level of lacustrine endemicity exceeds any other lake in the New Guinea–Australian region (Allen, 1995). Five of these endemics (*Hephaestus adamsoni*, *Mogurnda furva*, *M. spilota*, *M. variegata* and *M. vitta*) comprise up to 40% of the commercial fish catch in the lake (Houston, 1995).

The freshwater fish fauna of Lake Kutubu provide a very important source of dietary protein for the local communities residing within the lake's catchment (see 'Lake Kutubu Fisheries' in Section 9.5.2.3).

Table 9.16 The fish fauna of Lake Kutubu and their preferred habitat types

Fish Grouping	Scientific Name	Common Name	Preferred Habitat
Eel-tailed catfish (Plotosidae)	*Neosilurus equinus*	Southern tandan	Deep rock pools in inflow streams.
	Oloplotosus torobo	Kutubu tandan	Shallow muddy or vegetated edges.
Rainbowfish (Melanotaeniidae)	*Melanotaenia lacustris*	Kutubu rainbowfish	Pelagic surface feeder.
Hardyhead (Atherinidae)	*Craterocephalus lacustris*	Kutubu hardyhead	Shallow margins in both open water and marginal vegetation.
Grunters (Teraponidae)	*Hephaestus adamsoni*	Adamson's grunter	Juveniles in shallows and adults in deeper water below cliffs; pelagic.
	Hephaestus fuliginosus	Sooty grunter	Nearshore in areas of aquatic vegetation.
Gobies (Gobiidae)	*Glossogobius* sp. 12	Kutubu goby	Vegetated muddy substratum at mouth of creek.
	Glossogobius sp. 8	Bluntsnout goby	Mud, sand or gravel substrata.
	Glossogobius sp. 6	Twinspot goby	Nearshore in areas of aquatic vegetation.
Gudgeons (Eleotridae)	*Mogurnda furva*	Black mogurnda	Benthopelagic; often found in midwater of the lake.
	Mogurnda kutubuensis	Kutubu mogurnda	Nearshore in areas of aquatic vegetation.
	Mogurnda maccuneae	Iriguabi	Nearshore over beds of matted algae and eel grass.
	Mogurnda mosa	Mosa mogurnda	Nearshore in areas of dense reeds.
	Mogurnda spilota	Blotched mogurnda	Nearshore in areas of dense vegetation.
	Mogurnda variegata	Variegated mogurnda	Nearshore in shallow areas of aquatic vegetation.
	Mogurnda vitta	Striped mogurnda	Nearshore in areas of dense vegetation.
	Oxyeleotris fimbriata	Fimbriate gudgeon	Rock, mud or vegetated substrata.

9.4.4.3 Subterranean Fish Fauna

The underground stream system of karst country within the Kikori basin is home to the blind cave gudgeon (*Oxyeleotris caeca*), which is shown in Plate 9.36. This fish was first found by Kafa villagers in a small creek of the Mubi River (6°34'3"S, 143°29'30"E) that drains a sinkhole at an elevation of about 650 m ASL. According to the Kafa villagers, the blind cave gudgeon can be readily observed in sinkholes during the wet season. Note that the sales gas pipeline RoW/access way alignment in karst terrain is approximately 5 km to the southwest of the known habitats of the blind cave gudgeon.

This cave-dwelling fish is phylogenetically related to the fimbriate gudgeon (*Oxyeleotris fimbriata*), which is widely distributed in both northern and southern New Guinea. Allen (1996) describes the blind cave gudgeon as the first specialised hypogean (cave-restricted) fish described from Papua New Guinea. There are only about 50 species known worldwide.

9.4.4.4 Conservation Status of the Kikori Basin Fish Fauna

Table 9.17 lists the freshwater fauna occurring or likely to be present in the Kikori Basin that are listed as of conservation concern by the International Union for the Conservation of Nature (IUCN, 2005). The meanings of the IUCN codes are presented in Supporting Study 1.

Table 9.17 Fish fauna of the Kikori basin on the IUCN's Red List

Family	Scientific Name	Common Name	IUCN Red List Status
Eel-tailed catfish (Plotosidae)	*Oloplotosus torobo*	Kutubu tandan	Vulnerable (VU A2cd)
Mullets (Mugilidae)	*Liza melinoptera*	Cream mullet	Endangered (EN B1+2ab+3a)
Rainbowfish (Melanotaenidae)	*Melanotaenia lacustris*	Kutubu rainbowfish	Vulnerable (VU A1ac)
	Melanotaenia monticola	Mountain rainbowfish	Data Deficient (DD)
Hardyheads (Atherinidae)	*Craterocepahlus lacustris*	Kutubu hardyhead	Vulnerable (VU A2cd)
(Gudgeons (Eleotridae)	*Eleotris melanosoma*	Broadhead sleeper	Lower Risk/Near Threatened (LR/nt)
	Mogurnda furva	Black mogurnda	Vulnerable (VU A2cd)
	Mogurnda spilota	Blotched mogurnda	Vulnerable (VU A2cd)
	Mogurnda variegata	Variegated mogurnda	Vulnerable (VU A2cd)
	Mogurnda vitta	Striped mogurnda	Vulnerable (VU A2cd)
	Oxyeleotris wisselensis	Paniai gudgeon	Data Deficient (DD)
Grunters (Teraponidae)	*Hephaestus adamsoni*	Adamson's grunter	Vulnerable (VU A2cd)

Source: IUCN (2005).

9.4.4.5 Fish Endemism

Endemism describes species that are native to a particular geographic area or continent. It usually occurs in areas that are isolated in some way. Endemism at a local or regional level occurs when the populations of one species are separated so that they cannot interbreed. Both populations continue to breed and evolve separately, and in time, they may possibly become two separate species (speciation).

Polhemus et al. (2004) recognise 40 areas of freshwater endemism in New Guinea and nearby islands, which are grouped into six broad regions. In addition, 12 lacustrine subunits comprising individual lakes or lake complexes with distinctive endemic biota are recognised with Lake Kutubu being one of them.

The Kikori River system has more endemic species than any other river system in New Guinea, including the much larger Fly and Sepik river systems. A total of 15 species are endemic to the Kikori River system, and 12 of these are endemic to Lake Kutubu alone, including five species of freshwater gudgeons of the genus *Mogurnda*. The high lacustrine endemism shown by Lake Kutubu is due its isolation and unique habitats.

Table 9.18 compares the total number of fish fauna and endemism found in the Kikori River system and other major river systems of Papua New Guinea.

Table 9.18 Comparison of total fish fauna and endemism in the major river systems of Papua New Guinea

River System	Total Species	Endemic Species	
	(n)	(n)	(%)
Fly	128	5	3.9
Kikori	115	15	13.0
Purari	57	6	10.5
Sepik	57	0	0.0
Ramu	54	0	0.0

Source: Namo (2003).

9.4.4.6 Introduced Freshwater Fish

Twenty-one species of freshwater fish representing 19 genera, 11 families, and all six continents have been introduced into Papua New Guinea for various reasons (Miller et al., 1999). The reasons include sport, aquaculture, ecological manipulation, control of pests, ornamentation, and improvement of subsistence welfare. Most introductions have been unsuccessful or were never released into the wild. Nine to eleven are thought to be established in Papua New Guinea (Allen, 1991; Osborne, 1993). Of the successful introductions, most have had a negligible impact as either food fishes or in the control of mosquitoes (Allen, 1991).

The freshwater fish of Papua New Guinea are susceptible to the effects of introduced fish species because of the lack of specialisation per se. Two species of concern and present in the Kikori River system are the European carp and mosquitofish:

- *European Carp.* The European carp (*Cyprinus carpio*) is well established in the Kikori River system. The species increases water turbidity through its foraging and bottom-feeding habit and directly and indirectly destroys rooted vegetation. In general, this is often accompanied by a decline in native fish populations and a spread and increase in carp populations.
- *Mosquitofish.* The mosquitofish (*Gambusia affinis*) was introduced into Papua New Guinea for its supposed ability to control mosquitos and therefore help reduce the incidence of malaria. The species is present in Lake Kutubu. Mosquitofish are known to compete with small surface-feeding native fish, such as rainbowfish (Melanotaeniidae) and hardyheads (*Craterocephalus* spp.).

9.4.5 Macroinvertebrate Fauna

The macroinvertebrate fauna of the Kikori River system has been poorly documented save for the large macroinvertebrates, such as decapod crustaceans.

9.4.5.1 Decapod Crustaceans

Decapod crustaceans inhabit different habitats within the Omati and Kikori river systems, ranging from small and cold creeks, such as those of the upper subcatchments of the Kikori basin, to off-channel water bodies and swamps in the floodplains of the lower

Kikori and Omati rivers. In general, those decapod crustaceans inhabiting the headwaters are smaller in size than those that inhabit the floodplains.

Freshwater Crayfish

New Guinea has about 12 species of freshwater crayfish of the genus *Cherax*. The Kikori River system has three species present, namely, the red-claw crayfish (*Cherax quadricarinatus*), zebra crayfish (*C. papuanus*), and a new unidentified species of freshwater crayfish (*Cherax* sp. nov.*)* that inhabits sinkholes and subterranean streams of the karst terrain to the east of Mt Bosavi near the village of Kafa. The latter species is white and blind and is reported by Kafa villagers to be flushed out of sinkholes during the wet season.

The red-claw crayfish is one of the largest freshwater species and is found in the upland rivers and streams of the Tagari-Hegigio sub-basin. For example, Namo (2003) found these crayfish to be abundant in streams in the vicinity of Musula and Bona/Muluma villages near Mt Bosavi. The red-claw crayfish also occurs in the Libano River near Mount Bosavi (Namo, 2003). The zebra crayfish occurs in Lake Kutubu (Namo, 2003).

Freshwater crayfish are bottom-dwelling opportunistic scavengers, and a large part of their diet consists of decaying leaves and other plant detritus. Their life cycle is very different from their marine relatives. In the marine environment, newly hatched eggs are released into the sea as planktonic larvae, whereas freshwater crayfish hatchlings continue to develop on the swimmerets under the female's abdomen. The swimmerets move gently to provide a constant supply of well-aerated water, which is necessary for the survival of the developing young. When the developing larvae have absorbed their yolk sacs, they leave the female's protection and commence a free-living mode of life.

Freshwater Prawns

Freshwater prawns of the family Palaemonidae occupy a primary role as detritivores (animals that feed on detritus) in the Kikori and Omati river systems. They form a key component of both riverine and lacustrine (i.e., Lake Kutubu) food webs. About 10 species of palaemonid prawns occur in New Guinea, of which only a few species are present in the Kikori River system. The dominant prawn is the giant freshwater prawn (*Macrobrachium rosenbergi*) and other *Macrobrachium* species are present in smaller numbers. The systematics of the *Macrobrachium* genus is under review, thus the freshwater prawn fauna are subsequently referred to as *Macrobrachium* spp.

9.4.5.2 Aquatic Insects

The aquatic insect component of the macroinvertebrate fauna of the Kikori River catchment has been poorly researched or studied, except for the Odonata comprising damselflies (Zygoptera) and dragonflies (Anisoptera), waterbugs (Heteroptera) and whirligig beetles (Gyrinidae).

The WWF funded a study of aquatic insects in mountainous terrain at Mt Sisa (two sites) and at a lowland floodplain site, the Sire River, a tributary of the Sirebi River, which flows into the lower Kikori River (Richards, 2000). The waterbugs were by far the most numerous and diverse insect order that was present, with 75 species distributed among 35 genera in 14 families. Twenty species of dragonflies were collected at the lowland site, with a marked decline in diversity with altitude with 15 species recorded at the Mt Sisa sites. Odonate fauna are known to be depauperate at high altitudes in New Guinea (Polhemus, 1995), so this pattern is expected. While Richards (2000) recorded 15 species of damselflies at high altitude (i.e., Mt Sisa sites), Polhemus (1995) recorded no more than 10 species at Kopi and the Kikori delta.

9.4.6 Freshwater Turtles

9.4.6.1 Freshwater Turtle Species

A total of six species of freshwater turtle (Chelidae) inhabit the Kikori River system. The large pig-nosed turtle (*Carettochelys insculpta*) inhabits a wide variety of aquatic habitats. Adults tend to inhabit the river mainstems (both the freshwater and estuarine reaches), grassy lagoons, swamps, lakes and water holes in the lower Kikori and Omati rivers and the Kikori-Omati delta. The juveniles tend to be found in small creeks further inland (Rose et al., 1982). This species is omnivorous and feeds on the unripe fruits of the white mangrove (*Sonneratia alba*) as well as several other mangrove species and nypa palms. When available, aquatic macrophytes and algae are also consumed. Molluscs, crustaceans, small fish, bats and other small mammals are also eaten opportunistically. The wide range of food eaten provides great scope for opportunism, and the diet varies greatly between localities, according to the foods available.

Several other species, including Bibron's soft-shell turtle (*Pelochelys bibroni*), the New Guinea snake-necked turtle (*Chelodina novaeguineae*), Siebenrock's snake-necked turtle (*C. siebenrocki*), the New Guinea snapping turtle (*Elseya novaeguineae*) and the northern short-necked turtle (*Emydura subglobosa*), are known or expected to be present in the lower Kikori and Omati rivers, where they inhabit slow-moving rivers, swamps and seasonal wetlands.

Table 9.19 lists freshwater turtle species known to occur or expected to be present in the Kikori River catchment. Plate 9.37 shows the head of a pig-nosed turtle with its characteristic snout and nostrils.

Table 9.19 Freshwater turtles of the Kikori River system

Family	Scientific Name	Common Name	Conservation Status*
Carettochelydae	*Carettochelys insculpta*	Pig-nosed turtle	Vulnerable and PNG Restricted
Trionychidae	*Pelochelys bibroni*	Bibron's soft-shell turtle	PNG Restricted
Chelidae	*Chelodina novaeguineae*	New Guinea snake-necked turtle	-
Chelidae	*Chelodina siebenrocki*	Siebenrock's snake-necked turtle	-
Chelidae	*Elseya novaeguineae*	New Guinea snapping turtle	-
Chelidae	*Emydura subglobosa*	Northern short-necked turtle	-

* PNG Department of the Environment and Conservation.

Pig-nosed turtles and their eggs are a significant food source for local communities along the river system and around Lake Kutubu, and the remaining species are also a food source for local communities (see Section 9.5.2.5).

The northern short-necked turtle has broad jaws, which it uses to crush molluscs, fish, insects and worms, as well as aquatic plants, vegetable matter and seeds.

9.4.6.2 Conservation Status of Freshwater Turtles

In Papua New Guinea, the trade of freshwater turtles is strictly regulated by law as prescribed by the *Fauna (Protection and Control) Act 1966, 1978.* Papua New Guinea signed the Convention on International Trade in Endangered Species of Wild Fauna and Flora, more commonly known as CITES, in 1975. All exports of turtles require permits to be issued by the Conservator of Fauna. No turtles are listed in Papua New Guinea as protected species, which would limit legal permitted export. However, the pig-nosed turtle is listed as a restricted species with narrow guidelines limiting any legal export to only a few animals for legitimate scientific purposes.

Both the pig-nosed turtle and Bibron’s soft-shell turtle are classified under the IUCN Red List as ‘vulnerable’, while Siebenrock’s snake-necked turtle is classified as ‘lower risk’ (IUCN, 2005).

9.4.7 Crocodiles

Two species of crocodiles are found in the Kikori River system. These are the saltwater crocodile (*Crocodylus porosus*) and the freshwater New Guinea crocodile (*C. novaeguineae*).

9.4.7.1 Saltwater Crocodile

The saltwater crocodile is a very large crocodile reaching about 7 m in total length. This species is found mainly in lowland coastal rivers and swamps but is known to ascend the mountain reaches of rivers. For example, Groombridge (1982) recorded saltwater crocodiles about 500 km from the Gulf of Papua in the Fly River. They also swim out to sea and to coral reefs, where present.

9.4.7.2 New Guinea Freshwater Crocodile

The New Guinea freshwater crocodile is a moderately large crocodile reaching about 3.5 m in total length and occurring in lowland swamps, lakes and rivers of the Kikori and Omati basins. This species is able to ascend rivers up to an altitude of about 600 m (Hall, 1989). This species nests in the wet season, laying an average of about 22 eggs (Hall, 1989). The diet is broad, encompassing a variety of terrestrial and aquatic invertebrates and vertebrates.

The New Guinea freshwater crocodile is endemic to New Guinea. Hall (1989) has indicated that southern populations of the New Guinea freshwater crocodile (including those in the Kikori area) may warrant recognition as a taxon distinct from those populations inhabiting northern New Guinea.

9.4.7.3 Conservation Status of Crocodiles

Both the New Guinea freshwater crocodile and saltwater crocodile are classified under the IUCN Red List (IUCN, 2005) as 'vulnerable'. Under the PNG *Fauna (Protection and Control) Act 1966, 1978*, both crocodile species are classified as 'restricted' because of traditional utilisation (subsistence catch) within the country.

9.4.8 Amphibians

In general, the forests in the Kikori basin remain substantially intact, providing habitats that maintain a high diversity of frogs. Most of the frogs are forest-dwelling species. Some of these are essentially riparian, while others breed on the forest floor or in the canopy. Section 9.3.5.4 and Supporting Study 6 describe amphibian diversity in the project area.

The life cycle of a number of frog species in the project area includes an aquatic developmental stage (e.g., eggs or tadpoles). The presence of small foothill streams and torrents in the upland project area and the high diversity of tree frog (Hylidae) species present indicate the importance of project area streams as breeding areas for these frogs. Clear, torrential streams appear to be a favoured habitat for *Litoria* species (torrent-dwellers). Hylid tree frogs have a reproduction strategy that depends on access to free-standing waters or flowing streams for breeding, egg laying and larval (tadpole) development and, hence, rely on good riparian habitat and water quality for the successful maintenance of viable, self-sustaining populations. On the other hand, microhylid frogs have a reproductive strategy that is independent of free-standing water and have radiated extensively in the constantly moist habitats.

9.4.9 Aquatic Mammals

This section describes those marine mammals that may be found in the lower freshwater and estuarine reaches of the Omati and Kikori rivers, as well as other inshore areas (e.g., distributaries) of the Omati-Kikori delta. Section 10.3.3 describes those marine mammals that are found offshore (i.e., the Gulf of Papua and the Torres Strait). Note that there are no freshwater aquatic mammals in Papua New Guinea.

The marine mammals of Papua New Guinea have been poorly documented and researched. However, some species of marine mammals are known to occur or occasionally enter the lower reaches of the larger rivers and deltas. Information on the spatial distribution and abundance of cetaceans in the Omati-Kikori delta and offshore waters is sparse and limited to a few observations. The remoteness of the area partially explains the lack of cetacean distribution data. Large cetaceans are offshore marine mammals and are unlikely to visit the turbid waters of the Omati-Kikori delta. Note that seals are not found in Papua New Guinea.

Marine mammal species have been recorded in the Kikori delta, and those observed or expected to be present are coastal dolphins (delphinids) and dugongs (sirenians).

9.4.9.1 Delphinids

Three dolphin species, the Irrawaddy dolphin (*Orcaella brevirostris*), the Indo-Pacific hump-backed dolphin (*Sousa chinensis*) and the Indian Ocean bottlenose dolphin (*Tursiops aduncus*) frequent the delta. All three species are migratory.

Irrawaddy Dolphin

The Irrawaddy dolphin is discontinuously distributed mostly in coastal, shallow, brackish or turbid fresh waters at the mouths of rivers in southeastern Asia, New Guinea and Australia. Irrawaddy dolphins are known to frequent shallow, coastal, muddy water environments for feeding on prawns when they are seasonally abundant (Freeland and Bayliss, 1989). Sixteen Irrawaddy dolphins were observed in the Kikori delta (Leary, 2000).

Indo-Pacific Humpbacked Dolphin

The Indo-Pacific humpbacked dolphin rarely lives more than a few kilometres offshore but tends to prefer coastal areas with mangrove swamps, wetlands and estuaries, as well as areas with mudbanks or sandbanks. They are known to enter the lower estuarine reaches of turbid rivers. Leary (2000) observed a total of 16 Indo-Pacific humpbacked dolphins in the Kikori delta area.

Indian Ocean Bottlenose Dolphin

The Indian Ocean bottlenose dolphin occurs both offshore and in the lower reaches of the Kikori and Omati rivers. This species may occur in pods or individually. Those sighted in the Kikori delta were present as pairs or individuals (Leary, 2000); a total of seven dolphins were observed in the lower reaches of rivers forming the Kikori delta area and just offshore.

9.4.9.2 Sirenians

Dugongs (*Dugong dugon*) are herbivorous marine mammals that occur in the tropical and subtropical coastal and island waters of the Indo-Pacific Ocean (Nishiwaki and Marsh, 1985). Dugongs occur in both shallow- and deep-water habitats, including turbid and clearwater environments where seagrass occurs. However, the absence of seagrass meadows in the Kikori delta probably implies that they are unlikely to be present, but they may transit the area during migrations or other alongshore movements.

9.5 Terrestrial and Aquatic Resource Use

This section describes the subsistence terrestrial and aquatic resources used or exploited by local people in the project area.

9.5.1 Terrestrial Resource Use

Much of the Kikori basin is characterised by difficult karst terrain, which contains sinkholes, steep ridges and limestone outcrops. In addition, areas around Lake Kutubu and throughout the Omati-Kikori delta are regularly inundated by water, which restricts the proportion of land suitable for agriculture. As such, the Omati and Kikori basins remain heavily forested and sparsely populated. Consequently, agriculture contributes less to subsistence production than does sago production, hunting, gathering and fishing.

Sago palm stands are subject to group ownership, but exploitation is usually in the hands of individual families or individuals. Both males and females inherit rights to trees. Average yields from sago palm production are in the order of 100 to 150 kg per mature palm, so that a single palm is usually sufficient for a family of four for a month. Sago palm by-products, such as the leaves, are used for roofing and basket weaving.

Hunting, gathering and fishing differs according to the location of the terrestrial resources. A number of game and rainforest habitats are targeted during hunting forays, including ground-dwelling, lower-canopy and high-canopy taxa. Resources that are exploited include: a) ground-dwelling fauna, such as pigs, cassowaries, wallabies, bandicoots, hens, megapodes, rats and frogs; b) lower-canopy fauna, such as phalangers and snakes; c) high-canopy fauna, such as flying foxes and birds including hornbills; and d) stream banks, (rats, crocodiles and lizards). Aquatic fauna resources are described in Section 9.5.2.

Hunting is an important activity that is an almost exclusively male activity. Terrestrial fauna supply the major portion of hunted game, with pig and cassowary being the most eagerly sought (Rhoads, 1980). Other taxa include bandicoots, rodents, wallabies, bush hens and megapodes, lizards, bats, flying foxes, high-canopy birds (such as hornbills and pigeon), frogs, phalangers and snakes.

Bush plants are utilised or cultivated for various uses, such as *Derris* sp. for fish poison, timber for dugout canoes, paper mulberry (*Broussonetia papyrifera*) for plaited carrying bags, tobacco plants (*Nicotiana tabacum*) for smoking and bamboo (*Bambussa* spp.) for cooking and water-storage vessels.

In the area from Lake Kutubu via Homa to Tari, the following bushland resource uses are noted:

- Tigasso (*Campnosperma brevipetiolata*) tree oil used for both self-decoration and rituals.
- Black palm (*Areca* sp. and *Ptychoccus* sp.) used for bows.
- Cassowary feathers and hornbill beaks used for trading.

The rainforest and waterways of the coastal plain of the Omati and Kikori basins abound in species (37 ethno-zoological species are recognised), which provide a primary reservoir of regularly consumed protein. The main limitation on hunting in this area is not availability but accessibility due to seasonal flooding.

9.5.2 Aquatic Resource Use

Aquatic resource use includes water uses, cultural or spiritual uses of water, artisanal and subsistence fisheries, and crocodile and freshwater turtle hunting.

9.5.2.1 Previous Studies and Historic and Baseline Data

A number of fishery studies were conducted in the KICDP area by the WWF:

- Subsistence fish catch monitoring of Lake Kutubu (Leary, 1997).
- Libano fish survey report (Vui, 2003).
- Kutubu Petroleum Development Project Environmental Plan (NSR, 1990a).

The social impact assessment study (see Supporting Study 10) provides additional information on previous studies of aquatic resource use by people living in the project area.

9.5.2.2 Water Uses

Throughout the river systems of the Omati and Kikori basins, local village communities use the mainstems of rivers extensively. These uses include cooking, washing garden produce and kitchen utensils, swimming, bathing, washing clothes, and the floating transport of heavy materials collected from upstream locations, such as timber and bamboo for building, down to villages.

Drinking Water

In the upper catchments of the project area, tributary rivers and streams of the major rivers (i.e., Tagari, Hegigio and Mubi rivers) and groundwater sources are the main source of drinking water for many villagers. In addition, mainstem water from the major rivers is sometimes used as a source for drinking water. However, the utility of mainstem river water for drinking is often a function of turbidity. Along turbid river mainstems where there are no permanently flowing clearwater side streams or creeks, communities are sometimes required to use the mainstream river for all normal domestic and other water use functions. During the wet season along these rivers, ephemeral streams can often provide better-quality fresh water.

Permanent springs and side streams are available to many riverine villages in Southern Highlands Province as alternative sources of water. These springs range in reliability from permanently flowing springs that can be used on a daily basis to seasonally available springs flowing only during the wet season. Many of these springs do not dry up during the dry season, including El Niño-Southern Oscillation years, and thus adequate water can be provided throughout both the wet and dry seasons.

Given the high annual rainfall throughout the Omati and Kikori basins, it is also common for rainwater to be collected for drinking and washing in drums and buckets from gutters and iron roof sheets. In this case, fishing, swimming, bathing and laundry are still carried out in main river channels.

Water for Sago Production

Sago provides approximately 75% of the food by volume for many of the villages in the Kutubu area, but this percentage varies along the river system. Throughout the project area, there are extensive sago stands in waterlogged or frequently inundated areas that are exploited mainly for sago starch but also for the collection of sago grubs for food and fronds for roofing and building purposes. Although the sago palm is a naturally occurring plant in swampy areas, most sago palms are now tended or planted, except for those that occur in the large swamps well away from villages. The processing of sago requires moderate volumes of water for washing, usually supplied from local streams or springs.

Cultural or Spiritual Uses

Reports of cultural or spiritual uses of river, stream, lake, or subterranean waters are given in Supporting Study 10 (Social Impact Assessment).

Sacred sites can be located either on riparian land or in the water and, therefore, both landscapes and waterscapes have been taken into account when mapping the cultural or spiritual uses and places within the project area. Some of the sacred sites associated with water link the places of the living—villages and the like—with places of the dead through the journeys travelled by the spirits of dead family and clan members.

There are few sacred sites associated with the rivers and streams of the upper Kikori basin and most are associated with the lower Kikori and Omati rivers and the delta. However, Lake Kutubu is the locale for a number of traditional myths and features the most prominent archaeological site in the region.

A number of sacred sites are located in the vicinity of the Kopi Support Base. For example, Plate 9.38 shows the sacred site at Ruriki Creek (site KG 28 in Supporting Study 10) along which the spirits of dead members of the Parua Uki Kopi clan travel on their way to the sacred mountain Ru. Immediately south of Kopi Support Base, a sacred sawfish (*Pristis microdon*) site is located near the mouth of Bagema Creek (Plate 9.39).

Numerous sacred sites are located along the river banks of the lower Omati River and within the river itself, where people commune with the spirits to attain special powers or safety in future endeavours. A number of sacred spirit sites (sites KG94 to 101 in Supporting Study 10) are located in the water adjacent to the Omati River landfall of the sales gas pipeline. Local clan members advised the project's archaeologists that the present pipeline landfall site and subriver pipeline route is not problematic, as long as correct protocols are followed by clan members communicating with the spirits of the sacred sites prior to any disturbance taking place. Current advice is that, once such communications have been undertaken by clan leaders, the spirits at these sites 'look after' the pipeline and ensure its safety in the vicinity of those sites. Failure to adequately communicate with the spirits is likely to lead to upheavals or 'natural' calamities in the region (one example of such a calamity was the death of a diver associated with previous underwater surveys near a spirit site in the Omati River).

It is beyond the aims of this section to enter into a detailed discussion of spirit forms in the study area. Supporting Study 10 provides details on all water-associated sacred and spiritual sites.

9.5.2.3 Artisanal and Subsistence Fisheries

Artisanal and subsistence fishing by local communities takes place throughout the Kikori and Omati river systems from the upper catchments through the middle catchments of the Kikori River including Lake Kutubu to the lower reaches of the Omati and Kikori rivers and the Omati-Kikori delta.

Riverine Fisheries of the Upper Kikori River System

Subsistence fishing takes place in many of the upland river mainstems and side tributaries in the vicinity of villages or outlying village gardens. However, the villagers are primarily gardeners, and subsistence fishing activity is of secondary concern. In general, fishing is undertaken when there are feasts and other important social occasions on the calendar. Fishing methods include gill nets, handlining, trapping, hand spearing and chemical stupefaction (derris root poisoning).

Many of the fish fauna caught are small species, such as gobies and rainbowfish, which are still consumed. Prized larger fish that are caught include mullet, grunters, gudgeons and catfish. Grazing shoals of greenback mullet (*Liza subviridis*) are also commonly observed in the tributary streams of the upper catchments, such as the Libano River (Vui, 2003) in of the Tagari-Hegigio sub-basin.

The major crustacean resource comprises red claw crayfish (*Cherax quadricarinatus*), zebra crayfish (*Cherax papuanus*) and giant freshwater prawns (*Macrobrachium* spp.). These are caught for subsistence use only, as there is no artisanal fishery present. In the upper catchment rivers (e.g., Libano River), zebra crayfish and giant freshwater prawns are abundant under logs and in mud holes, where they are caught by villagers.

Lake Kutubu Fisheries

Fish and decapod crustaceans provide a principal source of protein for the people living around Lake Kutubu, which contains at least 21 species of freshwater fish and decapod crustaceans (i.e., crayfish and prawns). Plate 9.40 shows a subsistence catch of Kutubu tandans (*Oloplotosus torobo*) and a fimbriate gudgeon (*Oxyeleotris fimbriata*) from Lake Kutubu. These lake-based subsistence fisheries are described below.

Fishery Catch. Leary (1997) estimates that a total of 1.2 million fish and crustaceans were caught per year during the period September 1995 to February 1997. As much as 70 tonnes of fish are removed from Lake Kutubu annually, but reports indicate that the fish catch is in decline, due to increases in human population and fish catch efficiency (WWF, 1998). The annual catches of fish for four Lake Kutubu villages were estimated by Leary (1997) as Gesege (5.96 t), Tugiri (5.86 t), Wasemi (4.86 t) and Yo’obo (7.26 t). Although the species caught varied between villages, the pooled catch revealed that three species accounted for 80% of the catch; namely, 35% for freshwater crayfish, 23% for Adamson’s grunters (*Hephaestus adamsoni*) and 22% for fimbriate gudgeons.

Fishing Methods. Fish are caught by a variety of methods, including more traditional methods such as poisoning with plant extracts. However, by pooling data for five Lake Kutubu villages, Leary (1997) showed that handlining (30%), handline/crayfish (24%), spearing (17%) and gill netting plus mixed gill netting (17%) were the principal fishing methods. Handlining and crayfishing are the two most important fishing activities as they contribute 54% of total catch weight for the five villages. Figure 9.17 shows a breakdown of total fish catch by fishing method as practised at Wasemi village, Lake Kutubu (Leary, 1997).

Fishing Effort. Leary (1997) observed that a large proportion of people (111 people, or 19% of five Lake Kutubu villages) engaged daily in fishing activity, indicating the importance of fishing to the Foi people. The number of person-hours/day spent fishing for the five villages combined was estimated to be 370 person-hours/day. Females undertook the majority of fishing (53% to 85% of the fishing effort for each village). Females were the main fishers for all fishing methods except spearing, spear-diving and mixed gill net fishing, which were predominantly male-dominated activities. Fishing generally started after 6 am and had finished by mid-evening (8 pm).

Current Threats to the Lake Fishery. Lake Kutubu was one of the most inaccessible areas in the country, with access only by light aircraft or on foot, until the 1990s. The development of oil and gas in the region has increased access with the development of road links and regular flights. At about the same time, concerns were expressed by local Foi communities at the perceived decline in fish catches and the decreasing size of fish caught in Lake Kutubu. This led to the establishment of a subsistence catch and fish population monitoring program. Fish monitoring transects that were established in a closed area of the lake (near Gesege) in December 1996 were resurveyed in October 1998 after almost two years of closure to fishing (WWF, 1998). A considerable improvement in the fish stocks was observed, in both the size and number of fish present. Since then, local landowners are aware how such management actions have been beneficial to the fish stocks of the lake. Lake Kutubu communities continue to manage their fisheries and to regularly open and close areas to fishing, as required.

Estuarine and Delta Fisheries

The saline and brackish swamps of the Omati-Kikori delta are among the largest in the South Pacific. The delta is also an area of exceptionally high conservation value. Fish, crabs and shellfish have traditionally been an important source of food for villagers in the delta, and they provide an important source of cash income. More than 60% of the households surveyed in the Kikori area reported cash income from fishing-related activities during the past year (Supporting Study 10).

The riverine resources comprise at least twenty-two ethno-zoological species of freshwater and saltwater fish, eels, turtles, crayfish and prawns. Commercial monofilament and multifilament nets have largely replaced historically old bamboo and bark cord nets, and the use of outboard motors on modern dinghies or dugout canoes has allowed ready access to river and delta waterways and their aquatic biological resources.

Key subsistence and artisanal fishing in the Omati-Kikori delta includes all the fish groups and species listed under the lower catchment fish fauna in Section 9.4.4.2. Most of the larger estuarine fish fauna (such as barramundi and threadfin catfish) and threadfin salmon are caught with gillnets, especially 6-inch mesh monofilament or multifilament barramundi nets. Smaller mesh sizes down to 3-inch are also used. Gillnets are typically set overnight and the catch retrieved the next morning, although daytime net setting with regular inspections is also practised, which ensures that the fish are freshly caught and are not beginning to spoil. Plate 9.41 shows a fisherman holding a barramundi that was caught in the Omati-Kikori delta.

9.5.2.4 Crocodile Hunting

Both the saltwater crocodile and the New Guinea freshwater crocodile are traditionally hunted by local villagers.

There is a long history of crocodile harvesting by indigenous Papua New Guineans, but subsistence hunting probably had limited impacts on populations (Pernetta and Burgin, 1980). However, during the 1960s, both species suffered intense hunting pressure for the skin trade, leading to severe depletion of wild populations (Hollands, 1987). Legislation implemented in 1969 placed controls on harvesting practices, and populations appear to have stabilised. Improved hunting technology, access to previously inaccessible areas, and increasing human populations along southern New Guinea rivers may be reducing crocodile populations in some areas.

Both saltwater and freshwater New Guinea crocodiles are heavily hunted and are probably threatened from overexploitation, especially within the last 10 years as outboard motors and fuel have become more widely available to people living in the Omati-Kikori delta. Villagers generally hunt crocodiles from canoes or outboard dinghies using torchlight and spears, bows and arrows, or nets. However, the greatest threat to crocodiles is mostly from the harvesting of their eggs and, to a lesser extent, the selling the juveniles to crocodile farms (Namo, 2003).

9.5.2.5 Freshwater Turtle Hunting and Egg Collection

All the six species of freshwater turtles occurring in the Kikori River system are hunted for their meat (adults) or for their eggs. Pig-nosed turtles and their eggs are a significant food source for local communities along the river system and around Lake Kutubu. The remaining species are also a food source for local communities.

Villagers mostly capture adult pig-nosed turtles (*Carettochelys insculpta*) by hook and line. Subsistence use of this species by local communities has a long history but apparently used to occur only at moderate levels. In recent decades, harvest pressures have escalated greatly, to levels that are widely perceived to endanger the species over much of its range. The species is widely and heavily exploited for its meat and eggs and represents an important component of the subsistence economies of local people. Plate 9.42 shows pig-nosed turtle eggs collected by local villagers in the Kikori delta, and Plate 9.43 shows captured pig-nosed turtles that are most likely to be sold on for cash.

Several other freshwater turtles, including the New Guinea snake-necked turtle (*Chelodina novaeguineae*), Siebenrock's snake-necked turtle (*C. siebenrocki*), New Guinea snapping turtle (*Elseya novaeguineae*) and northern short-necked turtle (*Emydura subglobosa*) are known or expected to occur in the lower sections of the Kikori and Omati rivers and are probably a food source for local communities dwelling around the fringes of the rivers.

9.6 Regeneration

This section presents a summary of the successes and failures of natural regeneration of sites disturbed by previous petroleum developments within the project area. Supporting Study 11 (Assessment of Regeneration, Rehabilitation and Degradation along the Oil Export RoW and Implications for the PNG Gas Project) provides a more detailed description of regeneration.

Gillison (1990) and Hartley (1991) examined vegetation regrowth on a range of the Kutubu petroleum development sites, such as wellpads, helipads and access ways to drill sites. The conclusions of these studies were that regeneration was vigorous. Many pioneer and forest tree species developed rapidly (within 3 years) on areas of disturbed soils, limestone scree mixed with soils, and sidecast spoil; but revegetation was poor to non-existent on areas of hard limestone pavement or compacted limestone.

The findings of Hartley (1991) are presented in Tables 9.20 and 9.21, which summarise the status of regeneration observed on soil-dominated and limestone-dominated surfaces, respectively. The dependence of regeneration on substrate penetrability is evident.

Example photographs of regeneration are presented in Section 13.3.3 (Soil Mitigation and Management Measures) to corroborate various impact assessment conclusions.

Table 9.20 Observed regeneration on soil-dominated disturbed surfaces

Site Type	Regeneration Observed
Disturbed forest floor	*After four months:* complete ground cover of grass with some fern and sedge. Vigorous growth of liane *Merremia* present. At least five genera of trees coppicing or growing from seed to a height of 1.5 m. *After 18 months:* at least 14 genera of regrowth forest trees including climax forest components as seedlings and some coppice present, the tallest to between 6 and 8 m. Vigorous liane growth. Complete ground cover. *After 24 months:* at least 18 genera of forest trees including seedlings represented, with a general height of 5 to 6 m; palms, lianes and wild banana common. Complete ground cover.
Mounded trench fill	*After four months:* complete ground cover of grass and fern, mainly *Paspalum conjugatum* and *Dicranopteris*. At least five genera of trees growing from seed, regularly controlled by slashing. *After 24 months:* at least 18 genera of forest trees coppicing and growing from seed. Complete ground cover.
Limestone scree mixed with soil	*After one month:* regrowth commencing from coppicing on the very recently cleared but not heavily vegetated side slopes. *After 12 months:* mixed vegetation comprising five genera of fern, three of grasses and at least 10 genera of trees established on slopes where there is old soil surface accessible under sidecast. Seedling height of 1 to 1.5 m. *After 18 months:* regrowth trees are 3 to 5 m tall and there is complete ground protection. The lower ground surface is shaded, with incomplete cover. *After 21 months:* at least nine genera of regrowth trees around 2 to 3 m tall on the slightly thicker limestone scree. *After 24 months:* at least 12 genera of regrowth forest trees present as seedlings and coppice up to 5 m tall. Clumps of tall *Saccharum* grass, fern and tree ferns present. *After 30 months (2.5 years):* under thin limestone scree, regrowth is 6 to 10 m tall with at least 10 genera of forest regrowth trees, together with wild banana and leafy substrata. *After 42 months (3.5 years):* at least 12 genera of regrowth trees including seedlings from 1 to 8 m tall. Wild banana, tall *Saccharum* clumps and lianes are prominent. Complete ground cover with a fern understorey. *After 90 months (7.5 years):* complete cover of trees 6 to 10 m tall with an understorey of fern, *Saccharum* and lianes.
Loose soil sidecast	*After 4 months:* complete ground cover of grass *Imperata* with some fern and sedge. Invading lianes present on the margins. *After 18 months:* at least 14 genera of regrowth forest trees including climax forest components as seedlings and some coppice present, the tallest to between 6 and 8 m. Vigorous liane growth. Complete ground cover. *After 24 months:* at least 18 genera of forest trees including seedlings represented, with a general height of 5 to 6 m; palms, lianes and wild banana common. Complete ground cover.
Exposed earth cut in forest or grassland	*After 18 months:* at least 14 genera of regrowth forest trees including climax forest components as seedlings and some coppice present, the tallest to between 6 and 8 m. Vigorous liane growth. Complete ground cover. *After 24 months:* at least 18 genera of forest trees including seedlings represented, with a general height of 5 to 6 m; palms, lianes and wild banana common. Complete ground cover.

Source: Hartley (1991).

Table 9.21 Observed regeneration on limestone-dominated disturbed surfaces

Site Type	Regeneration Observed
Compacted fine limestone road and hardstand	*After six months:* generally no vegetation over most upper surfaces. Mixed weed flora, notably around the edges, with very small sedges in shallow depressions. *After 12 months:* mainly bare surface apart from very few individual stands of *Eleusine* grass and small sedges. Also *Bidens* and *Paspalum*. *After 18 months:* approximately 50% ground cover of sparse, patchy sedge with other individual clumps of thin-stemmed *Saccharum* to 400 mm tall. *After 90 months (7.5 years):* a moss cover with weathered surface between limestone fragments of clay mixed with gravels. *Saccharum* 1 to 3 m tall with an understorey of ferns, lianes and occasional *Spathoglottis*. Very few seedling trees, mostly *Ficus*.
Semi-compacted coarse limestone hardstand	*After nine months:* 10% ground cover with *Alsomitra* vine, *Asteraceae* weeds and minor grass. *After 12 months:* 20% ground cover of weeds with emerging tree seedlings. *After 18 months:* up to 30% ground cover of ferns, weeds, individual tree seedlings and vine. *After 36 months (3 years):* incomplete cover of fern with up to 6 species of sapling tree from 100 mm to 1.5 m tall, including *Ficus* and *Spondias*.
Thick limestone sidecast obscuring all former surface	*After 12 months:* very little growth except for surface moss and lichen in wet areas. Scattered *Miscanthus* in clumps at lower locations and very low weed in patches: *Ageratum*, *Eleusine*, *Bidens* and *Echinochloa* or low *Ageratum* and fern with very patchy *Saccharum*. *After 18 months:* sparse fern growth. On stable areas, scattered clumps of *Saccharum* and individual seedling trees of *Ficus*, *Trema* and *Alstonia* from 30 mm to 1 m tall. *After 21 months:* incomplete cover, predominantly fern with patchy, thin-stemmed *Saccharum* and tussocks of *Pennisetum*. Vines migrating from shallow limestone scree over old groundcover include *Merremia*, *Alsomitra*, *Dioscorea* and *Piper*. *After 24 months:* on thick limestone scree, 50% surface cover of fern with *Bidens*, patchy, thin-stemmed *Saccharum*, *Pennisetum* and scattered individual trees. *After 42 months (3.5 years):* about 50% ground cover of fern with few individual tree seedlings from 100 mm to 1.5 m tall.
Exposed limestone face	Limestone faces are slow to regenerate, apart from seams and faults where there is soil or weathered material. At these locations, moss, lichens and ferns are the early colonising plants, and ferns particularly spread across the nearby surface. The face develops a cover of moss and lichen that fluctuates in its intensity and maturity depending upon weather conditions. A relatively short dry period can cause attrition of the delicate vegetation, although the cumulative accretion of organic matter favours subsequent growth. Lianes may grow down from upper levels where there is soil cover at the top of the face, providing cover for less robust colonisers.

Source: Hartley (1991).

10. Marine Environment

10.1 Introduction

This chapter summarises the physical (Section 10.2), biological (Section 10.3) and resource use (Section 10.4) characteristics of the marine environment to be crossed by the proposed route of the offshore sales gas pipeline through the Gulf of Papua and Torres Strait. The scope of work required to describe these aspects of the EIS was set out in the Environmental Inception Report (Esso, 2005), and the detailed findings appear in the Marine Supporting Study (Supporting Study 9), which is summarised in this chapter.

The geographic scope of the EIS for the marine pipeline section includes the Gulf of Papua and the Torres Strait Protected Zone (TSPZ), most of which is in Australian waters. Torres Strait is the locus of long-standing customary interests of indigenous Papuan New Guinean and Australian citizens in fisheries, cultural heritage, recreation and social uses and rights of movement. These interests are recognised by an international treaty, which gives the governments of both Papua New Guinea and Australia an interest in what happens in the TSPZ.

10.1.1 Methods and Sources of Information

This chapter is based on several different methods and sources of information, which are summarised as follows.

- A review of recent scientific literature (and underwater video photography) on the oceanography and sediment transport in the Torres Strait – Gulf of Papua Region conducted by a number of international collaborating agencies, including Geoscience Australia (e.g., Harris et al., 2004, and other references cited below).
- A review of scientific information on the current status of commercial fisheries in the Gulf of Papua (e.g., Evans et al., 1995; Koren, 2004a, b).
- Discussions with Mr Barre Kare of the National Fisheries Authority in Port Moresby in April and in July 2005, from which information was provided on aspects such as current and future management arrangements for the Gulf of Papua prawn fishery; areas of operation of prawn trawlers (obtained from vessel monitoring systems); results of recent prawn stock assessment trawl surveys (where these coincided with the proposed offshore sales gas pipeline route); and relevant photographs of catches and by-catches taken during these survey cruises (Kare, pers. com., 2005a, b).
- Historical information and photographs of catches and by-catches taken from prawn trawlers operating in the Gulf of Papua during the period from 1978 to 1980 (e.g., Gwyther, 1980, 1982).
- A review of scientific information on the status of Torres Strait fisheries for prawns, rock lobsters, Spanish Mackerel, and of the status of other resources such as

dugongs and turtles traditionally hunted in Torres Strait (e.g., AFMA, 2003; DAFF, 2005).

In addition, a detailed marine survey of the proposed route across the Gulf of Papua was completed in November 2005. While primarily undertaken to determine geophysical characteristics of the seabed, underwater video photography and benthic grab samples were taken at a number of representative seabed sites along the proposed route across the Gulf of Papua in order to validate expected environmental conditions at these locations. The 2005 survey confirms previous understanding of marine habitat, and initial results are summarised in this chapter.

10.2 Physical Environment

10.2.1 Proposed Route

The proposed offshore route of the sales gas pipeline runs from the apex of the Gulf of Papua to the PNG–Australian international border near Pearce Cay, at the northwestern extremity of the reefs, cays, small continental islands and shoals of Torres Strait. The proposed route across the Gulf of Papua is shown in Figure 10.1, together with other major geographical features of the region. The results of the detailed marine survey, completed in November 2005, will be used to confirm this route. The proposed route across the Gulf of Papua differs from the proposal included in the1998 Environmental Plan (NSR, 1998a), and the route that was surveyed during 2000 for two reasons. First, liquefied petroleum gas (LPG) will not be processed and exported as a separate product, and there is no requirement for an offshore processing, storage and offloading facility to be built next to the existing Kumul Marine Terminal. Second, a better understanding of the stability hazards of the delta front of the Fly River enables a less conservative setback from the delta to be adopted.

10.2.2 Physiography

The proposed gas pipeline route crosses two principal environmental domains between its landfalls at the Omati River mouth in Papua New Guinea and Cape York in Australia:

- The Gulf of Papua, dominated by sediments of land origin transported by the numerous large rivers draining the PNG Highlands.
- The Torres Strait region, dominated by carbonate sediments of marine origin.

The bathymetry and satellite imagery (see Figure 10.1 and Figures 10.2 and 10.3) highlight these features, namely the shallow, prodelta apron of the Gulf of Papua, the relict channels off the Fly River delta, and the reefs, cays and channels of Torres Strait.

10.2.2.1 Gulf of Papua

The Gulf of Papua forms a crescent of some 50,000 km^2 bordering the southern coast of Papua New Guinea. The gulf shoreline is a low-lying swampland of the delta complexes of large rivers draining the mountainous highlands of central Papua New Guinea. The Fly, Kikori and Purari rivers discharge huge volumes of fresh water (15,000 m^3/s)

(Wolanski et al., 1995) and sediment (350 Mt/yr) (Wolanski et al., 1984, cited in Harris et al., 1996) into the Gulf of Papua. The Fly River itself discharges about 120 Mt/yr of sediment (Harris et al., 2002) into the Gulf.

The proposed gas pipeline route through the Gulf of Papua traverses three geomorphic zones:

- A prodelta and shore-attached sediment wedge associated with sediment accumulation and coastal progradation in the inner Gulf. Local short-term erosion and accretion is substantial, with organic material derived from the land ranging in size from small fragments of vegetation to submerged trees sometimes encountered in various stages of burial and decomposition.
- The delta front of the Fly River, a clinoform region of rapid sediment accumulation to around the 40 to 50 m depth contour.
- The northern section of the Fly River delta carbonate shelf, an extensive, stable platform of the calcareous alga *Halimeda,* to seaward of the Fly River delta and below the 40- to 50 m depth contour.

10.2.2.2 Torres Strait

To the southwest of the Gulf of Papua is Torres Strait, a shallow, epicontinental seaway between Papua New Guinea and Australia, bounded to the west and east by the Arafura and Coral seas respectively.

Extending approximately 150 km from north to south, Torres Strait is characterised by numerous continental islands, cays and coral reefs, including the northernmost sections of the Great Barrier Reef; shallow channels and shoals of mobile sediments; and, near the Papua New Guinea coast, low-lying, swampy islands.

10.2.3 Climate

10.2.3.1 Winds

Wind patterns in Torres Strait and the Gulf of Papua are highly seasonal, and the two wind regimes are:

- *Northwest monsoon* (November to April) winds are generally less than 31 kph (17 knots), with wind speeds exceeding this only 15% of the time.
- *Southeast trades* (May to October) are coherent winds over distances of approximately 1,000 km across the Coral Sea and Gulf of Papua, exceeding 31 kph (17 knots) for 30% of the time in the Gulf of Papua (NSR,1990b) and 37 kph (20 knots) for 66% of the time in Torres Strait (Williams, 1994).

10.2.3.2 Cyclones

The Gulf of Papua and Torres Strait are areas of low to moderate cyclone risk. The cyclones generate storm-force winds and long-period waves in the Gulf of Papua and Torres Strait, and substantial seabed scouring and sediment movement most often occur in shallow waters under these conditions. In the Torres Strait, fetch and maximum wave height are naturally limited by the number of reefs and islands. Cyclones occur mainly during the period from February to April.

10.2.3.3 Temperature and Rainfall

Daily mean air temperature maxima and minima are 28°C and 22°C (July) and 32°C and 25°C (November) at Daru (McAlpine et al., 1975) and vary little along the proposed route.

Annual rainfall varies across the region from about 1,500 to 2,000 mm, with the highest totals on the southern Papua New Guinea shoreline. Rainfall is high throughout the year (200 to 300 mm/month), with a major wet season from April to August when the average rainfall rises to 400 mm per month (Koren, 2004a).

10.2.4 Oceanography

10.2.4.1 Tides

Tides in the Gulf of Papua are semi-diurnal to mixed. A maximum spring tide of 4 m and mean spring tides of 2.5 to 3 m occur in the western Gulf (Wolanski and Eagle, 1991, cited in Woolfe et al., 1997). Tides tend to be smaller in the eastern gulf. Mean spring tidal ranges are amplified within the funnel-shaped Fly River delta from around 3.5 m at the seaward entrance to a maximum of 5 m at the delta apex (Harris et al., 2004).

Tides within Torres Strait are associated with strong currents and rapid spatial changes in tidal elevations. Tidal ranges are in the order of 3 m (Hemer et al., 2004). Torres Strait forms the intersection of the two separate and dissimilar tidal regimes of the Gulf of Papua/Coral Sea and the Gulf of Carpentaria/Arafura Sea. Although both regimes are semi-diurnal, they are out of phase with each other. Hence, the hydrostatic balance of the Arafura Sea (to the west) and the Coral Sea (to the east) affects tides and currents in passages between reefs, such that tidal heights and currents in Torres Strait are not predictable using standard harmonic techniques (Bode and Mason, 1994; Hemer et al., 2004).

10.2.4.2 Currents

Oceanic circulation within the Gulf of Papua is dominated by a clockwise gyre (Figure 10.4) generated as the northwards-flowing Coral Sea Coastal Current enters the Gulf of Papua along the eastern edge of Torres Strait and exits to the northeast (Woolfe et al., 1997). As a result, most of the fresh water and sediment delivered to the Gulf by the large Papuan rivers travels eastwards and only a small proportion flows towards Torres Strait.

Within Torres Strait, current speed and direction generally reflect the orientation of reefs and channels and the degree of constriction between channels. Maximum measured current speeds recorded in Torres Strait from 1988 to 1993 are shown in Figure 10.5 (Harris, 1995; NSR, 1997d). The maximum speed recorded was 137 cm/s (approximately 3 knots). Residual, wind-driven currents are generally weaker than the tidal component, with a seasonal reversal in direction. During the southeast trades season, the flow is generally westwards, and during the northwest monsoon season, it is generally eastwards (Hemer et al., 2004).

10.2.4.3 Waves

In the Gulf of Papua and Fly River delta area, the southeast trades dominate the wave pattern when the seasonally averaged significant wave heights of 1.5 and 2.1 m are relatively close to the coast. During the northwest monsoon, the offshore winds result in little or no swell (Hemer et al., 2004).

In contrast, Torres Strait is generally more protected from surface waves generated in the Coral Sea by the northern extension of the Great Barrier Reef and mainly locally generated waves are found. In Torres Strait, significant wave height is rarely more than 3.5 m and usually less than 1.5 m (Hemer et al., 2004).

10.2.4.4 Suspended Sediment

The Gulf of Papua has very high suspended sediment loads that originate from:

- High suspended sediment loads discharged from rivers into the Gulf of Papua.
- Continuous reworking of sediments by strong tidal currents and wave action.
- Fluid-mud bodies, which flow along the deepest parts of the subsea channels as dense, mobile, near-bed suspensions, typically around 1 m in thickness.

Concentrations of fine-grained suspended sediment rarely fall below 500 mg/L within the river mouths and the Fly River Delta but can reach from 10,000 mg/L to a maximum recorded of 40,000 mg/L in fluid-mud layers, which take around 35 hours to travel across the 20-km-wide, low-gradient delta front (see Harris et al., 2004; Dalrymple et al., 2003).

Surface turbid plumes typically extend as far as 50 km offshore, although suspended sediment concentration and thickness decrease with increasing distance offshore (Plates 10.1a and b).

In Torres Strait, total suspended sediment concentrations in surface waters are naturally high but much less than those of the Gulf of Papua. Typical values range from 2.2 to 37 mg/L (Figure 10.6) and are comprised of carbonate seabed sediments resuspended by the strong currents, particularly the high velocities of east–west currents flowing through the gaps in between the Torres Strait islands and in the Warrior Reefs (Harris and Baker, 1991; Harris, 1995). The heavily sediment-laden waters of the Fly River delta contribute relatively little to the bed or suspended sediments in the body of Torres Strait (see Harris, 1995; Wolanski et al., 1995; Harris et al., 2002; Hemer et al., 2004).

10.3 Biological Environment

10.3.1 Habitats of the Proposed Route

10.3.1.1 Gulf of Papua

The marine habitats of the proposed gas pipeline route through the Gulf of Papua are predominantly the deltaic muds of the main (Fly, Kikori and Purari rivers) distributary channels and delta front, descending to the carbonate (*Halimeda*) platform below depths of 40 to 50 m. Reef habitats and seagrass beds occur mainly to the west of Daru Island. The high suspended sediment loads inhibit their development in the Gulf of Papua east of Daru Island as far as Kerema.

The muddy substrates in the western Gulf of Papua do not feature any localised areas of special environmental significance as to form a constraint to route selection. The prodelta of the Fly River (and other rivers) consists of muds of land origin and because of their rapid but unstable deposition, these sediments show little evidence of bioturbation from benthic fauna (Dalrymple et al., 2003). Further offshore and away from the delta, the sediments become more stable and have higher densities of benthic infauna (Alongi et al., 1992).

The calcareous coralline alga *Halimeda* spp. is found offshore of the Fly River delta from a depths of 40 to 100 m (Harris et al., 1996). It can be seen in Figure 10.7 that the proposed gas pipeline route bypasses the main area of the known *Halimeda* beds.

10.3.1.2 Torres Strait

Torres Strait is part of the continental shelf, submerged to a shallow depth and studded with continental and volcanic islands, cays and coral reefs. This shallow-water environment creates the conditions needed for coral reef formation, and this habitat type is ubiquitous, albeit often widely separated by extensive tracts of shallow mud or sand seabed (Williams, 1994).

Seagrass stabilises sediments and provides nursery and feeding habitat for prawns, lobsters, turtles, dugongs and fish. Torres Strait supports extensive areas (17,000 km^2) of seagrass and algae on a diverse range of substrates, including the reefs, foreshore areas and the shallow inter-reef seabed (CSIRO, 1996b).

Seagrass in Torres Strait undergoes periodic cycles of dieback over a temporal scale of decades. These cyclical changes affect the distribution and abundance of dugongs and rock lobsters and also sediment movement. Recent evidence indicates that episodes of dieback occurred in the 1970s and the early 1980s (Williams, 1994; CSIRO, 1996b); and in 1993 and 2000, poor rock lobster recruitment coincided with periods of seagrass dieback (DAFF, 2005).

The inter-reef area accounts for 95% (about 40,000 km^2) of the Torres Strait Protected Zone (Figure 10.8) and comprises many different habitats with high diversity (more than 700 species) of infauna and epifauna (animals living in or on the seabed respectively) (CSIRO, 1996a).

10.3.2 Seabed Characteristics

Underwater video footage of the seabed was obtained by Harris et al. (2002) at three locations in northeast Torres Strait, two of which (A and B) are in the vicinity of the proposed sales gas pipeline route as shown in Figure 10.9. Site A lies just north of the proposed route and south of the southern entrance of the Fly River delta in depths of approximately 30 m. Site B lies in the eastern margin of Torres Strait further to the south of the proposed pipeline route in depths generally greater than 50 m, closer to the northern Great Barrier Reef. Representative pictures are provided in Plate 10.2, and the following descriptions come from Harris et al. (2002).

Sediments at Site A appear mainly terrigenous (of land origin), fine-grained and generally flat to undulating. Visible biota are generally sparse, although moderate to extensive bioturbation (e.g., burrows, casts, pits, trails) at most sites suggests a relatively abundant infauna. Live callianassid (burrowing shrimp) were retrieved from some samples; otherwise, the commonly observed fauna included soft corals, sponges, sea whips and fish.

Site B is generally a flat seabed, where sediments are typically muddy sand (coarser nearer reefs) with predominantly ripple bedforms. Evidence of bioturbation included burrows (present at about half the sites), pits and feeding trails. Epifaunal abundance was low, particularly in the most rippled areas of higher current, but the evidence of burrows suggests an abundant infauna. Reef areas typically contained such fauna as sponges, soft corals, gorgonians, whip corals, hydroids, gastropods and starfish. At non-reef sites, the observed fauna included sponges, polychaetes, sea urchins, prawns, soft corals, crabs, brittle stars, crinoids, anemones, sea whips, hydroids, sea cucumbers, gorgonians and some fish.

A more recent geophysical survey of the proposed offshore sales gas pipeline route through the Gulf of Papua was completed in November 2005.

Figure 10.9 shows the locations of 28 sampling sites along the proposed route from which video images and sediment grabs were made during the 2005 survey. The findings from the survey are included as an attachment (Attachment 1) to the Marine Supporting Study (Supporting Study 9), and a brief summary is provided here.

Sites 7 to 14 were all characterised by limited visibility, being relatively close to the Kikori River discharge, where sediments were comprised of fine, terrigenous material, easily suspended in the water column. There was little visual evidence of fauna and flora at these sites.

Sites 15 to 18 were slightly deeper (greater than 30 m), and visibility was better, revealing a predominantly muddy seabed with some evidence of biological activity and burrows.

Sites 19 to 28 and sites 1 to 6 included the region of the Umuda, Purutu, and Kiwai channels and the raised areas between. These sites are characterised by terrigenous, silt or clay sediments, have low ambient light and show evidence of epibenthic faunal activity in the form of mounds and burrows.

At the sites furthest to the southwest (Sites 1, 2, 27 and 28), hard surfaces, such as boulders or shells, protruding through the sediment have some attached fauna, such as sponges and gorgonians.

Plates 10.3 to 10.6 show selected video images from the 2005 marine geophysical survey that illustrate the seabed characteristics described above. The results of this survey confirm and validate the predominantly muddy seabed of the proposed pipeline route and that, as anticipated, the seabed environment is not critical to route selection for the offshore sales gas pipeline.

10.3.3 Marine Fauna

10.3.3.1 Gulf of Papua

The marine fauna of the Gulf of Papua is reasonably well known from observations of catches made from prawn trawlers that have operated in the area since the 1970s. Recent surveys carried out by the PNG National Fisheries Authority in 2004 and 2005 to investigate the current status of prawn stocks (Kare, pers com., 2005a; Koren, 2004b) included sample locations coincident with the proposed gas pipeline route and provide information on typical species observed. Figure 10.10 shows catches of adult and recruit-sized banana prawns taken at the sampling locations, including those in the vicinity of the proposed route. Plates 10.7 (a, b) show typical catches taken by the trawlers, comprised of prawns and small fish by-catch, with the occasional large rays or sharks. The commercial prawns include mainly the banana prawn (*Penaues merguiensis)* and tiger prawn (*Penaues monodon*) and usually form about 10% of the catch. Most of the remaining fish and crustaceans are small, of low commercial value and are most often discarded. These include numerous species of fish, such as pony fish, hairtails, anchovies, clupeids, jewfish, goatfish and Bombay duck, and invertebrates, such as squid, crabs and mantis shrimps.

Reptiles represented in trawl catches include several species of sea snakes (Plate 10.8) and marine turtles, such as the green and the olive Ridley (Plates 10.9a and b). There are no known nesting beaches for any species of marine turtle in the Gulf of Papua. Two species of crocodile, the estuarine or saltwater crocodile (*Crocodilus porosus)* and the freshwater crocodile (*Crocodilus novaeguineae*), occur in the estuaries of Papua New Guinea (Pernetta & Burgin, 1983; Genolagani & Wilmot, 1988).

Tropical rock lobsters (*Panulirus ornatus*) annually migrate from reefs in northern Queensland and Torres Strait across the Gulf of Papua to the reefs of Yule Island and further east along the Papua New Guinea coast (Figure 10.11). The migration is related to spawning and occurs during August to December each year. The migration path through the Gulf of Papua is coincident with the deeper part of the prawn trawl grounds, mostly between 40 and 80 m depth. There is no evidence of a return migration by adults (Moore & MacFarlane, 1984). This spawning migration was targeted by Gulf of Papua prawn trawlers during the 1970s and early 1980s, but this trawling was banned in 1984 to protect spawning stocks and the seasonal artisanal fishery around Yule Island (DAFF, 2005).

Marine mammals in the Gulf of Papua include the dugong (*Dugong dugon*), which occurs along coastal areas of Papua New Guinea, mainly to the west of the Fly River delta. The dugong is listed as vulnerable to extinction in the World Conservation Union Red Data Book of Threatened Species (IUCN, 2000). It is also a protected species under the PNG *Fauna (Protection and Control) Act 1976.*

Large whales are not often seen in the Gulf of Papua, but various dolphin species are present, including the bottle-nosed dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), the Indo-Pacific humpback dolphin (*Sousa chinensis)* (Plate 10.10), the Irrawaddy dolphin (*Orcaella brevirostris*) and the newly recognised snubfin dolphin (*Orcaella heinsohni*) (Beasely et al., 2005). These dolphins are frequently observed in inshore waters of the Gulf of Papua near prawn trawlers, attracted to fish by-catch discarded overboard.

Irrawaddy dolphins are a rare and poorly known species but are reported from the Kikori River, during surveys conducted in 1999 (Namo, 2003). They inhabit turbid waters and travel up large river systems but usually stay within 5 km of the coast.

10.3.3.2 Torres Strait

The reef, inter-reef channels and seagrass areas of Torres Strait support a variety of fish and shellfish species. Prawns, such as the tiger prawn (*Penaeus esculentus*) and blue endeavour prawn (*Metapenaeus endeavouri*), rock lobsters (*Panulirus ornatus*), Spanish mackerel *(Scomberomorus commerson*), pearl shell (*Pinctada maxima*), bêche-de-mer (e.g., *Holothuria scabra)* and trochus (*Trochus niloticus*) support significant commercial and subsistence fisheries.

Hunting for dugongs and turtles is important to the Torres Strait Islander culture and provides a major source of food for remote communities. Dugongs and turtles may only be taken by indigenous people for subsistence and other traditional purposes. Turtles and dugongs are the main source of meat for Islanders and are the focus of community and cultural activity (AFMA, 2003). The hunting of dugongs and turtles with nets or firearms is prohibited, as is the sale of dugong and turtle meat.

The dugong, or sea cow (*Dugong dugon*), is a herbivorous mammal and the only surviving member of the family Dugongidae (Williams, 1994; Marsh, 1996). It is believed that the dugong is currently represented across its range (between about 26° and 27° north and south of the equator) by relict populations separated by large areas where it is close to extinction or extinct. Torres Strait supports the largest known population of dugongs in the world (Marsh, 1996).

Dugongs feed on all available species of seagrass but prefer some species such as *Halodule* and *Halophila*. The highest densities of dugong in Torres Strait correspond broadly with the areas containing the highest densities of these seagrass species, particularly near the western islands (Badu, Mabuiag and Boigu) and on the Warrior Reefs. The distribution of dugong is shown in Figure 10.12.

Six of the world's seven sea turtle species have been recorded in Torres Strait. Five of these, the green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead

(*Caretta caretta*), olive Ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*), have circumglobal distributions and they are widespread in the Indo-Pacific region. The sixth, the flatback turtle (*Natator depressus*), has a restricted distribution and is endemic to Australia (CSIRO, 1996d). The three most commonly seen species in Papua New Guinea waters are the green, hawksbill and flatback turtles (Williams, 1994), and are represented by both nesting (Figure 10.13) and foraging groups. The loggerhead turtle forages in and migrates through the Torres Strait but is not known to nest there. The remaining two species (olive Ridley and leatherback) are rarely seen in Torres Strait.

10.4 Resource Use

10.4.1 Gulf of Papua

10.4.1.1 Prawn Trawling

The Gulf of Papua prawn trawl fishery began in 1967; and since 1974, commercial operations have been continuous and annual landings have been around 1,000 tonnes of tails of all species (Gwyther, 1982; Evans et al., 1997). The fishery is based mainly on the banana prawn (*Penaeus merguiensis*), which makes up 60% of commercial landings. It is now one of the most stable and valuable fisheries in Papua New Guinea, worth around K10 million per annum. Currently, fifteen licensed vessels (around 30 m overall length and up to 150 gross tonnes) operate twin or quad-rigged trawl gear (Plate 10.11). All processing and freezing is done onboard after each haul. As there are no harbour facilities adjacent to the fishing grounds, vessels operate from Port Moresby, about 24 hours steam away and remain at sea for periods of 4 to 5 weeks. Fishing takes place on a 24-hour basis and each trawl shot is, on average, about 4 hours, towed at speeds of around 3 knots. The commercial vessels are prohibited from fishing within 3 nautical miles of the coast.

The prawn trawling grounds in the Gulf of Papua extend from the Fly River delta to the village of Iokea in the east of the Gulf (Figure 10.14). The proposed route intersects the trawl grounds to the west of Cape Blackwood. Seasonal closure of the fishery during the period from 1 December to 31 March and within the area to the north of latitude 8°24'42"S and to the east of longitude 144°28'00"E protects juvenile recruitment areas. The most intensively fished grounds are between Orokolo Bay and Kerema Bay, but during the closure period, more fishing effort takes place to the west of Cape Blackwood and thus potentially in the vicinity of the proposed gas pipeline route.

All of the Gulf of Papua prawn trawlers are fitted with vessel monitoring systems, whereby the GPS coordinates of the vessels are recorded each day by the National Fisheries Authority. This system was introduced in 2000, and Figure 10.15 shows all records of daily vessel positions for 2004. The main fishing grounds are clearly centred around Kerema Bay. The figure also shows the travelling routes between Kerema Bay and Port Moresby, resulting from the daily position foxing of all vessels. The other concentrations of trawling effort are:

- Orokolo Bay and south of the Purari River delta.
- To the south of Cape Blackwood and the Omati River mouth.

- A small area east of the north arm of the Fly River delta.

The proposed gas pipeline route essentially passes between the two westernmost areas of concentrated prawn fishing effort. However, some trawling in the vicinity of the proposed route would be expected.

Seven prawn trawlers of the PNG Torres Strait Prawn Fishery (see Section 10.4.2) are also endorsed to operate in the Fly/Bamu fishing zone (see Figure 10.14), to the west of longitude 144º28'00"E. All of these vessels are less than 20 m overall length. Only three are currently operating and are based from Port Moresby, as Daru does not have fuelling facilities to support operations (Kare, pers. com., 2005a, c).

Only a small percentage of the by-catch from prawn trawling is retained, as the volume is too great and its value too low for commercial sale. When sea conditions permit, local canoes often pull up alongside the trawlers to trade garden produce for fish by-catch (Plate 10.12). The future development of the Gulf of Papua prawn fishery is likely to include vessel replacement (while not increasing overall total fishing capacity) and the development of an inshore fishery within 3 nautical miles of the coast. To date, ten licences have been created for this small-scale inshore fishery but only one has been allocated (Kare, pers. com., 2005a).

10.4.1.2 Other Gulf Fisheries

The variety and abundance of fish such as barramundi, threadfin salmon, jewfish, mud crab, prawn and lobster along the Gulf of Papua coast support fishing for subsistence, sale to local markets and other commercial ventures. Subsistence fishing involves the use of a variety of pots, traps and gill nets. V-shaped scoop nets are commonly used along the beaches, targeting fish and sub-adult prawns as they migrate offshore from the inshore nursery areas. These fishing activities occur along the coast of the Gulf and Western provinces. The proposed pipeline route leaves the shore due south of the Omati River mouth, from where its alignment remains more than 20 km offshore of the PNG coast (see Figure 10.1) and will not interfere with any coastal small-scale fisheries.

10.4.2 Torres Strait

10.4.2.1 Torres Strait Treaty

The Torres Strait Treaty was entered into by Australia and Papua New Guinea in February 1985. It is concerned with sovereignty and maritime boundaries in the area between the two countries and the protection of the way of life and livelihood of traditional inhabitants and the marine environment.

The Torres Strait Treaty (Part 4, Article 10) also established the Torres Strait Protected Zone (TSPZ), in which each country exercises sovereign jurisdiction for fish and sedentary species on the respective side of the agreed jurisdiction lines (see Figure 10.1). The Protected Zone Joint Authority (PZJA) is responsible for the management of commercial and traditional fishing in the Australian sector of the TSPZ. The Torres Strait Treaty also requires Australia and Papua New Guinea to cooperate in the conservation, management and optimum utilisation of the commercial fisheries of the TSPZ.

Articles 22 and 23 of the treaty allow for the sharing of catch on both sides of the border. Fisheries that Australia and Papua New Guinea have agreed to manage jointly, under Article 22 of the Treaty, include prawns, tropical rock lobster, Spanish mackerel, pearl shell, dugong and turtle. The current catch sharing arrangements (AFMA, 2003) allow:

- 8 PNG commercial prawn fishing vessels in the Australian sector of the TSPZ (currently 7, Kare, pers. com., 2005a).
- 27 PNG dinghies to take tropical rock lobster in the Australian sector of the TSPZ.
- 20 PNG dinghies to take Spanish mackerel in the Australian sector of the TSPZ.
- Monitoring and taking of dugong for traditional purposes.
- Monitoring and taking of turtle for traditional purposes in the Australian waters and for artisanal purposes in PNG waters.

These arrangements also extend outside the TSPZ boundaries, where part of the fisheries stock extends beyond the TSPZ boundaries into areas known as 'outside but near'. Since 1999, the PZJA has also assumed responsibility for the management of species previously managed under Queensland law, including fin fish, trochus, bêche-de-mer and crab.

Traditionally, Torres Strait Islanders have harvested a wide range of marine species for subsistence and cultural uses, and their consumption of seafood remains one of the highest in the world. Among the species they take are tropical rock lobster, dugong, turtle, fish, clams, crabs and octopus. Their methods include hand lining, diving, spearing, reef gleaning, cast netting, gill netting, trolling from dinghies, jigging and seining. There is a ban on the sale of clam shell meat and of turtle and dugong.

Commercial fishing is the most economically important activity in the TSPZ. The PZJA has a policy of maximising the opportunities for Islander participation in all sectors of the fishing industry. A limited number of non-Islanders participate in the TSPZ fisheries. However, since 1985, the PZJA has prevented further expansion by this group by not issuing new licences to non-Islanders. To gain access to a fishery in the TSPZ, non-Islanders must buy an existing licence. Any growth in the Torres Strait fisheries has been reserved exclusively for Torres Strait Islanders.

Even though not all of these allowances are consistently exercised, the proposed route through Torres Strait presents a potential for construction or operational impact to PNG-based fisheries and is therefore considered here.

10.4.2.2 Torres Strait Prawn Fishery

The Torres Strait Prawn Fishery is the most valuable fishery in the Torres Strait. It is based on the brown tiger prawn (*Penaeus esculentus*) and blue endeavour prawn (*Metapenaeus endeavouri*), and in 2003, the catch (1,597 t) was worth approximately

A$23.5 million (DAFF, 2005). The main prawn trawling grounds are located to the east and southeast of the Warrior Reefs, mainly around Yorke Island. Figure 10.16 shows the zones of relative fishing intensity (DAFF, 2005), from which it can be seen that the proposed gas pipeline route runs to the north and west of the most productive grounds. There is a seasonal closure from 1 December to 1 March of the following year in all of the fishery. In the grounds to the east of Warrior Reefs, the closure extends to 31 July.

The fishery is considered to be fully exploited, and the PZJA is considering management measures to reduce total effort in the fishery. However, under the Torres Strait Treaty, Papua New Guinea is also entitled to 25% of the catch. To give effect to this, PNG has been allocated seven vessel licences to fish in the Australian area. As there are no fuelling facilities in Daru, these vessels are currently based from Port Moresby, which is too far for economic operations, and since 2003, none of the licensed vessels has operated. Additionally, three licences with access to the area for the whole season have been allocated to Torres Strait Islander participation. The adopted management objectives of the PZJA for the Torres Strait Prawn Fishery, under Article 22 are:

- To control effort and to provide for catch sharing with Papua New Guinea.
- To achieve a level of fishing effort consistent with conservation and optimum use of the prawn resource.
- To encourage traditional inhabitants of the Torres Strait to participate in the fishery.

10.4.2.3 Tropical Rock Lobster Fishery

The tropical, or ornate, rock lobster (*Panulirus ornatus*) is the target of a major fishery in Torres Strait and, for many Islanders, provides their greatest economic opportunity (DAFF, 2005). The long-term potential yield is considered to be around 260 t of lobster tails from the combined Australian and Papua New Guinean areas (DAFF, 2005). The average catch over the past 10 years has been 210 t in Australia and 75 t in Papua New Guinea.

Most reefs in Torres Strait are fished by freezer-boat operators or by island-based indigenous fishers (Figure 10.17). Lobsters are taken by divers with spears or caught live with hand-held scoop nets. Divers work in pairs from small dinghies and either free-dive to depths of around 4 m or use hookah air compressors to extend the depth range of dive-fishing to around 20 m.

Management objectives agreed to by Papua New Guinea and Australia under Article 22 are:

- To conserve stocks.
- To maximise the opportunities for traditional inhabitants of both Australia and PNG to participate by implementing policies that manage the fishery for tropical rock lobsters as a dive fishery.
- To promote the dive fisheries for tropical rock lobster in both Torres Strait and Yule Island.

10.4.2.4 Torres Strait Spanish Mackerel Fishery

The Torres Strait Spanish Mackerel Fishery operates predominantly in eastern Torres Strait, targeting the narrow-barred Spanish mackerel (*Scomberomorus commerson*). In 1999, the fishery was expanded to include school mackerel (*Scomberomorus queenslandicus*), grey mackerel (*Scomberomorus semifasciatus*), spotted mackerel (*Scomberomorus munroi*) and shark mackerel (*Grammatorcynus bicarinatus*). Spanish mackerel are fished by trolling, hand lining or drop lining and generally from dories or dinghies operating either to a mothership or by themselves.

The areas in which the Spanish mackerel fishery operate are shown in Figure 10.18. The fishery is worth about $1.2 million and the 2001/02 catch was 120 tonnes (AFMA, 2003). The management objectives of the PZJA for this fishery are:

- To manage the resource to achieve optimal utilisation.
- To maximise opportunities for traditional inhabitants of both Papua New Guinea and Australia to participate in the commercial fishery.
- To promote the fishery as a line fishery.
- To continue monitoring and enter into a catch sharing agreement with Papua New Guinea.

10.4.2.5 Pearl Shell

The gold-lipped pearl shell (*Pinctada maxima*) and to a lesser extent, the black-lipped pearl shell (*Pinctada margaritifera*) are the main species collected in Torres Strait. All pearl shell is collected live by divers, using hookah equipment, and sold to pearl culture farms. Only a few boats specialise in this fishery and stocks are currently thought to be low (AFMA, 2003). As with other jointly managed Article 22 fisheries, objectives are for sustainable management and the maximisation of opportunities for traditional inhabitants of Papua New Guinea and Australia to participate.

10.4.2.6 Turtles and Dugong

Marine turtles are harvested from shallow reefs throughout Torres Strait (Plate 10.13). Annual estimates of catch made from the mid-1970s to the mid-1990s in the Australian sector of the TSPZ have remained at about 3,000 ($\pm$1,000) turtles (CSIRO, 1996d). In 2001, the estimated annual catch by communities in the Australian sector of the TSPZ was 1,619 ($\pm$574) turtles (AFMA, 2003). Green turtles are most commonly taken by hunters. Hunting occurs year-round but increases before and during the turtle-nesting season between September and January (CSIRO, 1996d). Although green turtle stocks are considered endangered on a global scale, non-commercial fishing by Torres Strait Islanders is unlikely to be a major contributor to their decline (AFMA, 2003).

Dugong hunting is culturally significant to many Aboriginal and Torres Strait Islander communities, and the dugong has long been ranked highest among traditional Torres Strait foods (Plate 10.14). Commercial dugong hunting is prohibited in Australia and Papua New Guinea, but the indigenous inhabitants of both countries can hunt dugongs all year for subsistence or for special occasions, such as weddings and funerals (AFMA, 2003). The migratory patterns of dugongs mean that overharvesting in some areas will decrease their populations across a much wider area.

Aerial surveys of dugong population are now carried out regularly. The total dugong catch for 2001 in the Australian Sector was estimated at 619 (±134) animals, which equates to 4.4% of the total population estimate of 14,061 (±2,314) animals (AFMA, 2003).

Similar field surveys for turtles and dugongs have been initiated in PNG although no data are reported (AFMA 2003).

10.4.2.7 Other Torres Strait Fisheries

Other non-Article 22 fisheries for barramundi and other species also involve Torres Strait islanders and Papua New Guinea inhabitants in the respective sides of the TSPZ. Most is exploited at the subsistence level and catch taken by the use of hand spears, traditional traps and monofilament nets. The barramundi fishery is limited to the territorial waters adjacent to the Papua New Guinean coast and Australian islands in Torres Strait.

10.4.3 Shipping Routes

The designated shipping channels are shown in Figure 10.1. The proposed pipeline route crosses the Great North East Channel (just inside the Australian Section of the Torres Strait Protection Zone) and the Adolphus Channel (south of the Torres Strait Protection Zone).In July 2005, Torres Strait was endorsed by the Marine Environmental Protection Committee of the International Maritime Organization (IMO) as a Particularly Sensitive Sea Area (PSSA), which now extends the Great Barrier Reef to include parts of Torres Strait. The endorsement relates to shipping and the risks to the reefs and other sensitive environments of Torres Strait from shipping accidents. The PSSA guidelines place obligations on all IMO member states to comply with the protective measures adopted to protect the PSSA and recommend[1] that governments inform ships flying their flag that they should act in accordance with Australia's system of pilotage for certain merchant ships, oil tankers, chemical tankers and gas carriers in the shipping lanes within Torres Strait.

10.4.4 Quarantine

Torres Strait is considered by the Australian Quarantine and Inspection Service (AQIS) to represent the greatest quarantine risk to Australia. The Torres Strait Treaty allows unrestricted passage between Papua New Guinea and Australia by the indigenous inhabitants. To address this risk, AQIS has established the Northern Australia Quarantine Strategy in collaboration with counterpart agencies in Indonesia and Papua

[1] It is a recommendation with no legal basis for mandatory pilotage (MEPC 2005)

New Guinea. The strategy includes scientific investigation of risk, an early pest and disease detection system, and promotion of awareness.

10.4.5 Shipwrecks

There are two known historic shipwrecks protected under Australia's *Historic Shipwrecks Act 1976* that appear to be near the proposed gas pipeline route. These are wooden cutters, the *Newton*, lost off Gabba Island in 1913, and the *Vida*, lost in 1914 (NSR, 1998a).

10.4.6 Torres Strait Islander Cultural Values and Heritage

Torres Strait archaeological sites are on land and therefore will not be affected by the gas pipeline or its construction, which is to take place entirely at sea or using existing land infrastructure. The potential for impacts on cultural heritage sites and other values of the sea and seabed surrounding Torres Strait islands has been investigated by the Islander Co-ordination Council (Cordell & McNiven, 1999; Hitchcock, 2000). Cordell and McNiven identified the cultural significance of Basilisk Passage, and Hitchcock established the preference of indigenous inhabitants for an alternative transit of Warrior Reefs via Tancred Passage (to the south of Basilisk Passage). To accommodate this request, the geophysical survey includes Tancred Passage and southeastern channel, south of Sassie island. Consultation will continue as the results of current engineering and environmental surveys become available.

11. Sociocultural Environment

This chapter provides a summary of the sociocultural environment of the project based on Supporting Study 10, the Social Impact Assessment (SIA). It begins with a description of the methods and sources of information used to prepare the study (Section 11.1), provides a brief overview of the country in which the project is set (Section 11.2) and then defines the project impact area (Section 11.3), and sets out linguo-cultural (Section 11.4), demographic (Sections 11.5 through 11.10), and archaeological and cultural heritage (Section 11.11) data related to the project impact area.

It then describes the organisation of the levels of government (Section 11.12) and the regulation of the distribution and expenditure of project-related income to host provinces and landowning communities (Section 11.13). The chapter closes with a discussion of sociocultural issues (Section 11.14).

Underlying all of the facets of the project's sociocultural environment is perhaps the single most important feature of Papua New Guinean society: the customary system of land ownership. Few social, economic or developmental issues can be described or assessed without reference to the fundamental features of this system (see Table 11.1).

Table 11.1 Characteristics of the alienated and customary land tenure systems in Papua New Guinea

Characteristic	Alienated Land Tenure System	Customary Land Tenure System
Origins	Based on traditional practice in Europe; unfamiliar and formal in Papua New Guinea.	Local practice; appropriate for traditional needs; established and well understood.
Responsiveness to change	Extensive and on-going modifications based on internal and external pressures; formalised through courts and legislation. Control of the tenure system and ownership of the land are separate.	Responsive to internal pressures; less responsive to external impacts; flexible since verbal. Control by landowners.
Political aspects	'Ownership' is limited to interests in land under the State. Activities are documented and recorded. Penalties for infringement. Conformity at the level of society.	Outright ownership by the clan; individual members have rights to use and occupy land. Based on verbal agreements. Penalties for infringement. Conformity at the level of the clan.
Social aspects	Planning and zoning system provides sporting, recreational, entertainment uses, etc.	The clan sets aside land for meetings, singsings, feasts, rituals and sports, etc.
Economic aspects	Economic specialisation generates surplus production, freeing much land and labour from direct production for basic needs. Estates/interests in land may be traded between individuals as an economic good. Identification of land, interests, ownership and transactions agreed and recorded by parties and by the State.	Role of land is to ensure survival of the clan, traditionally through a high level of self-sufficiency. Land is held, securely and in the long term, by the group for the benefit of the group. Identification of rights and interests validated by use.

Source: after Armitage (2001).

Some 97% of the land of Papua New Guinea – more than 46 million ha – is held under customary tenure. In simple terms, this means that there are very few places outside urban areas where activities can be conducted without the consent of those who own the land.

11.1 Methods and Sources of Information

The SIA method was developed by a multi-disciplinary team of social scientists with expertise and prior field experience in Papua New Guinea, with participation from researchers at the PNG National Museum and the National Research Institute. The work included an extensive review of published social, archaeological, and anthropological literature, as well as national and international legislation, protocols, and guidelines on social impact assessment.

The sociocultural environment of the project impact area has been assessed through ethnographic field investigations, including:

- Household Survey: 1,774 households were surveyed across 82 census areas in the project impact area during 2005 to obtain quantitative metrics on education, literacy, household standards, income and expenditure patterns, hunting, health, and governance. The survey is estimated to represent some 11,000 people and achieved a sampling rate of 43% of the project impact area households as recorded in the 2000 PNG census. The household survey also afforded project impact area inhabitants the opportunity to learn more about the PNG Gas Project and to express any issues, concerns and opinions that they might have regarding the project and other matters.

- Informant Interviews: Structured and unstructured interviews were undertaken to obtain qualitative information concerning general sociocultural conditions and issues and the locations of significant cultural heritage sites in the project impact area.

Archaeological field surveys were performed between Goaribari Island (at the mouth of the Omati River) and Kaiam, Kaiam and Kutubu, and Baguale (just north of Moro and Lake Kutubu) to Hides to determine the location, extent, and importance of cultural sites. The archaeologists worked closely with village liaison officers, local clan representatives, and many clans people.

The ethnographic and archaeological field investigations used information from and contributed information to the PNG Gas Project's GIS-based mapping system.

The Social Impact Assessment used independent business consultants familiar with the PNG Gas Project and PNG's Oil and Gas Act and regulations to estimate the economic benefits to Papua New Guinea associated with the project and to assess factors concerning the governance of these benefits (ACIL Tasman, 2005).

The Social Impact Assessment was prepared with due reference to applicable PNG laws, regulations, and guidelines. It also took into consideration international guidelines pertaining to project financing.

The purpose of the SIA was to:

- Provide a sociocultural profile of the communities in the project impact area.
- Provide baseline data for social and economic monitoring and project planning.
- Outline existing infrastructure and service delivery capacity in health, education, agriculture, and other sectors in the project impact area.
- Assess the sociocultural impacts of the PNG Gas Project and bring forward potential mitigation recommendations for the project to consider.

11.2 Papua New Guinea in Brief

Papua New Guinea is located in Oceania and consists of a group of islands, including the eastern half of the island of New Guinea, between the Coral Sea and the South Pacific Ocean, east of Indonesia. The country's total land area is approximately 453,000 km^2, slightly larger than the State of California in the United States. The country has a population of approximately 5.5 million people, and the current population growth rate is 2.26%. The capital is Port Moresby, with a population of about 320,000. Papua New Guinea is by far the largest and most populated of all Pacific Island countries.

The eastern half of the island of New Guinea was divided between Germany (north) and the United Kingdom (south) in 1885. The latter area was transferred to Australia in 1902; Australia occupied the northern portion during World War I and continued to administer the combined areas as a UN trusteeship until creation of the Independent State of Papua New Guinea in 1975.

The population of Papua New Guinea is ethnically diverse (most people are of Melanesian origin, but some are of Micronesian or Polynesian origin) and one of the most heterogeneous in the world. Papua New Guinea has several thousand separate communities, most with only a few hundred people. Divided by language, customs, and tradition, some of these communities have engaged in low-scale tribal conflict with their neighbours for millennia.

The population is widely dispersed in the landscape. The isolation created by the country's mountainous terrain is so great that some groups, until recently, were unaware of the existence of neighbouring groups only a few kilometres away. The diversity, reflected in a folk saying, 'For each village, a different culture', is perhaps best shown in the local languages. English, the official language, is spoken by only 1% to 2% of the population. Melanesian Pidgin is the lingua franca, and over 700 other languages are spoken. These languages are generally used by only a few hundred to a few thousand people, although Enga, a language used in the highlands, is spoken by some 130,000 people. Many of the languages used in Papua New Guinea are extremely complex grammatically.

While the overall population density in the country is low, there are pockets of high population density. Papua New Guinea's Western Province averages one person per square kilometre. The Chimbu Province in the New Guinea Highlands averages

20 persons per square kilometre and has areas containing up to 200 people farming a square kilometre of land. The Highlands are home to 40% of the country's population.

International migration of the citizen population is low, but internal migration from rural to urban areas and to rural non-villages is substantial. A considerable urban drift toward Port Moresby and other major centres has occurred in recent years. The trend toward urbanisation accelerated in the 1990s, bringing in its wake squatter settlements, ethnic disputes, unemployment, and attendant social problems.

Almost two-thirds of the population is Christian. Of these, more than 700,000 are Catholic, more than 500,000 Lutheran, and the balance are members of other Protestant denominations. Although the major churches are under local leadership, a large number of missionaries remain in the country. The non-Christian portion of the population, as well as a portion of the nominal Christians, practice a wide variety of religions that are an integral part of traditional culture, mainly animism (spirit worship) and ancestor cults.

Foreign residents comprise about 1% of the population. More than half are Australian; others are from the United Kingdom, New Zealand, the Philippines, and the United States, most of whom are missionaries. Since independence, about 900 foreigners have become naturalised citizens.

The United Nations Papua New Guinea Millenium Development Goals (UN, 2004) produced a list of gender-differentiated development indicators as of the year 2000. These data are presented in Table 11.2.

The population has been growing since 1980 at an average rate over the past 25 years of almost 3% per year. Fertility remains high, with an estimated 3.96 children born per woman. Approximately 40% of the population is under the age of 15.

The rapid decline in mortality during the 1970s did not continue after 1980. The level of infant, child and adult mortality remains high.

Table 11.2 PNG development indicators at 2000

Indicator	Total	Male	Female
Population size			
Total	5,171,548	2,679,769	2,491,779
Rural	4,496,145	3,314,236	2,181,909
Urban	675,403	365,533	309,870
Average population growth rate from 1980 to 2000 (% per year)	2.7	2.7	2.7
Crude population density (per km^2)	11.2		
Age Structure			
Population under 15 (%)	40	40.6	39.4
Population 15 to 59 (%)	55.9	55.1	56.8
Population 60 and over (%)	4.1	4.3	3.8
Adult (over 15) literacy rate	49.2	55.2	43.9
Infant mortality rate (per 1,000 live births)			
Total	64	67	61
Rural	69	72	65
Urban	29	31	26

Table 11.2 PNG development indicators at 2000 (cont'd)

Indicator	Total	Male	Female
Under age 5 mortality rate (per 1,000)	88	93	83
Life expectancy at birth (years)			
Total	54.2	53.7	54.8
Rural	53.0	52.5	53.6
Urban	59.6	59.0	60.3

Source: UN (2004).

The spectrum of PNG society ranges from traditional village-based life dependent on subsistence production (sago cultivation, fishing, hunting, gathering and agriculture) and small-scale cash cropping to modern urban life in the main cities of Port Moresby, Lae, Madang, Wewak, Goroka, Mt Hagen and Rabaul.

The three key elements of PNG's social environment are the traditional land tenure system, the 'wantok' system, and faith-based and community-based groups. The 'wantok' system is PNG's social safety net under which family and group members support each other under customary obligations defined by their shared language, culture, and kinship. The State relies heavily on faith-based and community groups in regard to social service delivery in rural areas. About 50% of all health and education services in the rural sector are provided by faith-based or community groups.

Papua New Guinea has vast natural resources, especially mineral, forest and marine resources, but the rugged terrain and lack of road transport make exploitation of these resources difficult. The main road network was estimated in 1999 to comprise approximately 20,000 km of road, of which only 686 km was paved. This sparse road network is reflected in the large number of 'airports' in the country, 21 of which have paved runways and a further 550 of which have unpaved runways.

Papua New Guinea's most important resource is its land. Almost 97% of the land is collectively owned via various forms of social organisation based on kinship and descent principles. Ownership is thus governed by traditional land tenure systems. Most people meet their basic needs through subsistence agriculture.

Because only 3% of all land is owned by the state, most forms of economic activity can only be sustained through partnerships with traditional landowners.

Papua New Guinea has a dual economy, comprising a formal, corporate-based economy and a large informal economy in which subsistence production accounts for the bulk of economic activity.

The formal sector provides a rather narrow employment base, consisting of workers engaged in mineral and oil or gas production, a relatively small manufacturing sector, the public sector, and service industries, including finance, construction, transportation and utilities.

The labour force is estimated to be 3.32 million, but the bulk of the population is engaged in the informal sector, which provides a subsistence livelihood for 85% of the population.

Major exports, estimated to be worth US$2.44 billion in 2004, include oil, gold, copper ore, logs, palm oil, coffee, cocoa, crayfish and prawns, mainly destined for Australia (28%), Japan (5.8%), Germany (4.7%) and China (4.6%). Imports of such items as machinery and transport equipment, manufactured goods, food, fuels, and chemicals cost the country US$1.35 billion in 2004 and are mainly sourced from Australia (46.4%), Singapore (21.6%), Japan (4.3%) and New Zealand (4.2%).

Debt growth continues to be higher than economic growth. Debt at the end of 2003 stood at K8.7 billion, which corresponded with a debt-to-GDP ratio of 80%. Because of the stagnation in per capita income growth and evidence of deterioration in some public services in rural areas, there is a view that living standards for a significant number of Papua New Guineans have declined since 1990. Most of the economically active people are engaged in subsistence activities (for household consumption). In the small urban sector and particularly in the National Capital District, unemployment rates are high.

The current GDP of Papua New Guinea is approximately US$12 billion (US$2,200 per capita), with an estimated 2004 growth rate of 0.7%. Figure 11.1 shows the importance of natural resource exploitation to the national economy. Existing natural resource projects are in decline, making the planned PNG Gas Project critically important with regard to sustaining export earnings.

11.3 Project Impact Area

For the purposes of determining landowner beneficiaries of royalty and equity benefits, the Oil and Gas Act defines ‘project area landowners’ as landowners whose land lies within the area of a project development licence or within a ‘buffer zone’ (determined by the Minister) of certain project facilities. Beneficiary local-level and provincial governments are determined under the Oil and Gas Act by reference to the presence in their jurisdiction of certain project facilities.

For the purposes of the Social Impact Assessment, however, the impact area for the PNG Gas Project has not been determined simply by reference to the area associated with landowners who are entitled to benefits under the Oil and Gas Act. In order to better capture the people and places likely to be directly or indirectly impacted by the project’s interventions and its associated benefit streams, the project impact area (Figure 11.2) is defined as being inclusive of some 98 census units, straddling Southern Highlands and Gulf provinces.

The concept of the project impact area is not necessarily absolute but rather is indicative of where the major impacts associated with the project are likely to be felt in the short to medium term and where the majority of the affected populace presently resides. The approach adopted to define the project impact area is consistent with Department of Environment and Conservation guidelines for the social impact assessment process (OEC, no date).

The project impact area contains an estimated 23,760 persons comprising 4,104 households. This population is distributed among five geographically based catchments: Hides (50%), Moran (7%), Kutubu (12%), Gobe (14%) and Kikori (17%).

Southern Highlands Province occupies approximately 25,700 km^2 in the central western part of Papua New Guinea. The total population of the province in 2000 was 546,265. Population densities are highest in the Tari Basin at approximately 190 persons/km^2; areas around Lake Kutubu support approximately 40 persons/km^2. In the western part of the Komo-Margarima district, the population density is less than 20 persons/km^2. More than half of Southern Highlands Province is unoccupied.

Gulf Province occupies approximately 13,500 km^2 on the south coast of mainland Papua New Guinea, where the estuaries of six major rivers converge into one large delta of islands, swamps and channels. The total population of the province in 2000 was 106,898. Population densities range from 25 to 35 persons/km^2 in the most densely settled areas to less than 10 persons/km^2 in other areas. Most of the province west of Kerema is unoccupied, with only small scattered settlements existing along rivers and the coast.

11.4 Project-Related Cultural Groups

11.4.1 Project Impact Area

The following linguo-cultural groups have been identified within the project impact area:

- The Fasu, who occupy the western and southeastern fringes of Lake Kutubu down to Tamidigi and who claim land on both the eastern and western borders of the Hegigio/Tagari River.
- The Huli, who inhabit the areas northwest from Yalenda through Baguale-Homa-Paua-Yarale-Tari-Koroba, and the area on the western side of the Hegigio/Tagari River from south of Komo through to Nogoli-Yaluba-Mogora-Pugua-Lebani and Tanggi.
- The Onabasulu, who inhabit the land west of the Hegigio River on the eastern edge of the Great Papuan Plateau. They are part of the population group of similar cultures that make up the 'Strickland-Bosavi Region'. They own land within PDL-2, but their residential villages are outside the immediate PNG Gas Project catchment area.
- The Foi, who inhabit the northeastern fringes of Lake Kutubu extending along the Pimaga to Poroma road.
- The Samberigi peoples, who variously speak Sau, Kewa and Polopa and who inhabit the northern Gobe area.
- The congeries of Kikori peoples frequently referred to as the Kairi (Rumu), who inhabit the Kopi and Ogomabu environs; the Ikobi (Kasere, Omati, Ikobi Kairi), a large group of Kasere speakers many of whom reside in Omati; the Porome (Kibiri), who are clustered in the vicinity of Veiru Creek and the villages of Doibo, Veiru and Babaio; and the Kerewo, who are originally from Goaribari Island but now also inhabit the eastern and western banks of the Omati River. Kerewo is divided into two distinct groups known as the Pai'a (located in Bisi) and the Otoia Kerewo (located at Goare, Dopima, Kemei, Mubagoa, Aidio, Samoa, Babaguina and Do'humo).

Figure 11.3 illustrates the various linguo-cultural groups both within and adjacent to the project impact area. Further ethnographic information regarding the project impact area linguo-cultural groups can be found in Supporting Study 10. No ethnic or linguo-cultural group within the project impact area is to be disadvantaged with regard to the development process.

11.4.2 Western Province

The proposed sales gas pipeline will traverse PNG sovereign seabed areas before entering the Torres Strait Protected Zone and then Australian waters.

The pipeline will not enter Western Province land territory. However, many Western Province communities have voiced opinions about the project.

Under the laws of Papua New Guinea, traditional owners of the seabed, waterways, or river beds where a pipeline is laid have no entitlement to benefits or compensation.

11.5 Social Organisation

All ethnic groups in and around the project impact area maintain their own cultural and social identity. This ethnic diversity constitutes the predominant social organisation throughout both the project impact area and PNG national society. However, as explained below, both community organisations associated with petroleum projects and non-governmental organisations now also play a part in social organisation in the project impact area.

11.5.1 Clans and Leadership

The social organisation of all project impact area cultures is based on patrilineal descent under which the people are distributed among named clan and subclan groups. Settlement patterns vary from scattered households to hamlets and long-house villages. Some clans are small (30 members), with a high rate of fission into separate primary landholding groups after a few generations. Most clans have representatives in more than one village, and so what is encountered in each village is, in effect, a local clan segment.

Leadership among the clan groupings is a mix of both ascribed (leaders are based on primogeniture in the direct male line from the founder) and achieved ('big men' ascend to power by virtue of entrepreneurial, oratorical and fighting prowess) in the project impact area.

11.5.2 Representative Community Organisations

One of the most significant effects of petroleum projects to date in Papua New Guinea has been the formation of formal entities by local groups.

The three most significant representative community organisations in the project impact area are incorporated land groups, landowner companies and landowner associations.

11.5.2.1 Incorporated Land Groups

Incorporated land groups are incorporated under the Land Groups Incorporation Act. There are some 700 to 800 incorporated land groups from Hides to Kikori, with highly variable levels of social groupings (individual, family, subclan, clan). Pursuant to the Oil and Gas Act, in the absence of other agreements between the State and project area landowners[1], the incorporated land groups receive distributions of royalty and equity benefits on behalf of the project area landowners.

11.5.2.2 Landowner Companies

Various landowner groups have established companies to undertake business ventures in and around customary clan property. The constitution of these companies varies from individual or small landowner group ownership to shareholding entities with ownership spread over a broader population segment.

There are more than 30 landowner companies in the project impact area, and they have worked in construction, catering, transport, security, sawmilling and other commercial activities. Many landowner companies currently have contracts with the existing petroleum operations.

Landowner companies have provided a measure of business development opportunity to landowners, but their performance has been uneven due to a combination of inadequate business knowledge, a perceived lack of transparency, and insufficient understanding of the roles of directors, management and shareholders.

11.5.2.3 Landowner Associations

Landowner associations are less formal entities formed under the Association Incorporation Act. Some landowner associations are parties to negotiations related to the distribution of petroleum revenues.

11.5.3 Non-Governmental Organisations

The Community Development Initiative Foundation (CDI) is the principal non-governmental organisation working to address the social needs of rural communities across Southern Highlands and Gulf provinces. CDI has entered into rolling 3-year agreements with the existing petroleum operations in the project impact area to undertake an assortment of social development initiatives.

CDI currently oversees initiatives in the areas of health and education and manages other programs across the catchment areas of Kutubu, Gobe and Kikori. CDI has facilities in Port Moresby, Moro, Samberigi and Kikori.

[1] Under the Act, 'project area landowners' means, in relation to a petroleum project, 'the persons who are customary landowners or who have registered title to: (a) any part of the licence area of a petroleum development licence the operations under which are part of that petroleum project; or (b) any land with the buffer zone of that petroleum project'.

CDI sees its mission as providing a legacy of sustainable development for the communities in the project impact area 'by fostering self-sufficiency and facilitating long-term improvements to the capacity of social service providers'.

CDI's funding is provided by the present-day petroleum operations, with minor contributions being received from outside agencies.

A variety of faith-based organisations are active at the community level in the project impact area. These organisations work within the communities to address an assortment of social, health, education and sustainable-agriculture challenges.

A limited number of international non-governmental organisations, such as the World Wide Fund for Nature (WWF), are also active in the project impact area.

11.6 Health

Health functions in the project impact area are under the jurisdiction of the Provincial Health Division of the Gulf and Southern Highlands provincial administrations. At the provincial level, the Health Division is headed by the Principal Health Adviser, who reports to the Provincial Administrator.

Each Provincial Health Division functions to determine service delivery and development in its area. Matters related to service provision and policy are to be referred to the Provincial Health Board, the membership of which is determined by the Provincial Executive Council and endorsed by the National Executive Council.

11.6.1 Project Impact Area Health Facilities

Figure 11.4 illustrates the distribution of health facilities within the project impact area.

11.6.2 Morbidity and Mortality Profiles in the Project Impact Area

Tables 11.3 and 11.4 provide key indices of community health, morbidity and mortality in the project impact area.

Table 11.3 Basic indices of community health (per 1,000 individuals) in developed countries versus Papua New Guinea and the project impact area

Index	Developed World*	PNG 1980**	Provinces 1994	
			Southern Highlands	Gulf
Crude mortality rate	under 10	13.2	26	45
Crude male mortality rate	under 10	NA	21	41
Crude female mortality rate	under 10	NA	31	49
Birth rate	under 15	34.2	38	36

Sources: * Derived from World Health statistics, WHO, Geneva.; ** PNG National Health Plan, 1991–95, p. 21; N. Anwar, 1996 Kutubu Health Report, Chevron, Moro, p. 58.

Table 11.4 Principal causes of morbidity and mortality in the project impact area (2002 to 2005)

Disease	Cause of Outpatient Visits	Cause of Inpatient Stays	Cause of Death
Malaria	Yes	Yes	Yes
Respiratory infections (including tuberculosis)	Yes	Yes	Yes
Anemia – Pimaga	Yes	Yes	Yes
Anemia - Kikori	No	No	Yes
Diarrhoeas	Yes	Yes	No
Neonatal sepsis	No	Yes	Yes
Meningitis	No	No	Yes
Skin infections	Yes	No	No

11.6.3 Disease Control Issues

11.6.3.1 Malaria

Malaria is endemic in Papua New Guinea and is among the top five causes of morbidity and mortality in the project impact area. It is also the leading cause of lost work hours among the oil industry workforce in the project area. Malaria is the most common cause of patients' visits to health facilities in the project impact area.

11.6.3.2 Tuberculosis

Tuberculosis is widespread in project impact area villages. Circumstances that contribute to the prevalence of tuberculosis in this region include:

- Malnutrition and living in long houses with inadequate ventilation.
- High incidence of incomplete tuberculosis treatments among infected cases.
- Insufficient access to X-ray facilities for proper diagnosis.
- Incomplete training of tuberculosis control officers.

11.6.3.3 Sexually Transmitted Diseases

The control and treatment of sexually transmitted diseases in Papua New Guinea are hindered by cultural resistance to both condom use and the reporting of symptoms.

In Papua New Guinea, 10,000 people have been recorded as being afflicted with HIV/AIDS. However, there are no reliable statistics related to infection rates, in part due to the remoteness of villages. The actual number of HIV/AIDS cases in Papua New Guinea is estimated to be approximately 50,000.

11.7 Education

The Education Branch of the respective provincial administrations has the responsibility for overseeing education services and is headed by the Principal Education Adviser, who reports to the Provincial Administrator.

The provincial management of education operates independently from the National Department of Education except for matters related to national standards and curriculum.

Each Education Branch reports all matters associated with service delivery and policy development to a Provincial Education Board, which ideally is constituted by community representatives, including members from the local-level governments and resident faith-based organisations. Provincial Education Board decisions are referred to the Provincial Executive for approval.

11.7.1 School System

Prior to the recommendations of the National Department of Education in 1991, the system depicted in Table 11.5 below was prevalent across the project impact area.

Table 11.5 Project impact area school systems before the 1991 education reform

Type	Grades	Age Group
Community school	Grades 1–6	6–12 years old
High school	Grades 7–10	
Senior high school	Grades 11–12	13–18 years old
College of Distance Education (CODE)	Grade 6 completed	Can complete up to Grade 10 by correspondence
Vocational school	Completed Grade 8	–

Under the 1991 education reforms, this structure was to be replaced by a uniform feeder system from elementary to primary to secondary (high school) school (Figure 11.5).

The slow implementation of these reforms has meant that the status of the school system in 2005 is in fact a mixture of both systems, with community schools remaining in many places.

Each village in the project impact area is intended to have a feeder elementary school, but the reality is that, although many villages have registered their elementary schools, many are inoperative. The type of school in a community is dependent on the numbers of children willing to go to school and the availability of trained teachers, supplies and buildings. Most people in the project impact area still refer to Preparatory to Grade 3 as ‘community/elementary’ schools, with Grades 4 to 8 referred to as ‘top-up elementary’ schools.

11.7.2 Educational Level and Enrolment

As shown in the Table 11.6, school attendance and literacy are low across the project impact area.

Table 11.6 Selected project impact area education data

Education Indicators (Age)	Project Impact Area Communities											
	Yarale		Atare		Ayegeiba		Walagu		Homa		Sisbia #3	
	M (%)	F (%)	M (%)	F (%)	M (%)	F (%)	M (%)	F (%)	M (%)	F (%)	M (%)	F (%)
Proportion never been to school (ages 5 to 29)	97.4	99.0	80.7	77.1	72.6	78.4	40.3	52.0	80.0	94.5	52.6	75.7
Illiteracy (age 10+)	55.0	73.4	70.0	75.0	63.9	70.6	50.0	50.0	18.1	21.6	17.8	25.4

Data collected since 1990 suggest that the retention rate (i.e., the per cent of children entering school who complete primary education) was 62.6% for boys and 60.3% for girls in the project impact area. These levels drop to just below 50% in the transition from Grade 6 to Grade 7. This indicates that very small percentages of children advance past the elementary/primary school level.

Table 11.7 presents statistics for preparatory and elementary school (elementary P, 1 and 2) enrolments in Southern Highlands and Gulf provinces for 2004.

Table 11.7 reveals a disparity between the provinces both in the teacher-to-student ratio (which in Southern Highlands Province averages 1:35, while in Gulf Province it is 1:22) and in the gender participation levels in the two provinces. In Southern Highlands Province, the percentage of females in classes from Grades 1 to 8 declines from an average 39% to less than 20% by Grade 8. By contrast, in Gulf Province, over the same grades, the percentage remains steady at 41%.

Table 11.7 2004 national statistics for elementary enrolments

Grade Level	Southern Highlands Province (No. of Schools: 275)		Gulf Province (No. of Schools: 125)	
	M	F	M	F
Preparatory (P)				
Enrolment	3,673	3,166	755	697
Teachers	113	72	53	29
Elementary 1				
Enrolment	2,801	2,432	822	624
Teachers	75	72	33	22
Elementary 2				
Enrolment	2,689	2,101	799	709
Teachers	96	53	36	28
Totals by Gender				
Enrolment	9,201	7,582	2,040	1,809
Teachers	284	197	103	71
Overall Totals				
Enrolment	16,603		3,849	
Teachers	481		174	

11.8 Agriculture and Fishing

For much of the last century, agriculture has been the backbone of PNG's economy. In Southern Highlands Province, swidden horticulture using a bush fallow approach predominates, with sweet potato being the principal crop. In the Kikori region, agriculture contributes less to subsistence production than does fishing, hunting and gathering.

With the advent of the resource developments, there has been no quantum change or development in agricultural activities in the project impact area. Commercialisation of agriculture has been unsustainable to date. Agricultural and livestock opportunities remain largely undeveloped due to a combination of a lack of communications and transport infrastructure, poor planning, and inefficient business practices. The only crops likely to offer a commercially viable basis for sustained agricultural business are coffee and sago.

Fish provide the main source of protein for the people living around Lake Kutubu. The lake contains at least 14 species of fish endemic to the lake and has high research and conservation value. However, reports indicate that the lake fish catches are in decline, due to increases in human population and the more widespread use of gill nets. Also, there is a threat from the recent introduction of European carp elsewhere in the province.

In the Kikori delta, fish, crab, and shellfish have traditionally been important sources of food and cash income. More than 60% of the households surveyed in the Kikori area reported cash income from fishing-related activities during the past year.

11.9 Transportation

Prior to the development of the Kutubu oil field, access to the project impact area was by foot, ship to Kikori, plane to Pimaga or Kutubu, or small aircraft to one of the grass airstrips serving various mission stations. The only roads in the project impact area were within and adjacent to the Kikori and Pimaga government stations, and these roads had no linkage with other centres in Papua New Guinea.

Since 1990, more than 800 km of roads have been constructed in the project impact area. This has increased the mobility of the population in the region and has facilitated their exposure to development services.

Figure 11.6 provides an overview of the existing and planned road system in the project impact area.

11.10 Project Impact Area Economic Activity

11.10.1 Local Businesses

Local business development in the project impact area is mainly through landowner companies.

Trade stores are the most common village-based economic venture, but their life cycle is intermittent due to the dissipation (rather than reinvestment) of profits and the uncertainty of supplies due to problematic logistics and high costs.

Other common small-scale business ventures in the project impact area include logging and sawmilling and a variety of agricultural cash cropping activities, such as growing chillies, coffee and vanilla and the rearing of poultry.

Business development is constrained by a number of cultural factors, including traditional dependence on subsistence agriculture, inadequate literacy and numeracy skills, customary redirection of profits to bride wealth and clan networks, and the lack of a maintenance culture (i.e., when goods deteriorate, they are replaced rather than repaired).

11.10.2 Personal Income

Compared with other rural areas in Papua New Guinea, the project impact area has relatively high employment levels, a relatively low dependency on agriculture as a source of cash income, and relatively diversified sources of income.

Listed below are the percentages of household survey respondents who reported receiving income from defined sources:

- Royalty payments: 33%.
- Cash crops: 35%.
- Employment: 11%.
- Sale of Livestock: 23%.
- Business Activities: 11%.

11.11 Archaeology and Cultural Heritage

Knowledge of cultural practices and historical trends and events in the project impact area is based on oral traditions, early colonial and anthropological observations, museum and other portable objects, and archaeological evidence (i.e., material traces of past cultural activity).

Landscapes and waterscapes signify ongoing relationships between people, their forms of social organisation, and the spirit world. The gulf region in the pre-contact era was a prolific ‘art’ producing area famous internationally for its skull-shrines and Gobe sacred carved boards. The archaeological ceramic finds indicate a rich history of maritime exchange and trade with eastern cultures. The Kikori-Omati environs are characterised by sacred sites associated with guardian spirits, old village sites, rock shelters containing ossuaries, mortuaries, and sites of archaeological significance.

The Huli area from Hides to Baguale contains a range of cultural heritage sites. Many of the sacred sites are marked by specific tree species, such as hoop pines (*Araucaria cunninghamii*), and still contain a variety of sacred stone representations of spirits. The extent to which landowners in the project impact area continue to retain knowledge of this heritage, and indeed imbue it with contemporary significance, suggests the importance of ensuring that a record of this heritage is made.

Cultural heritage sites are more than just a reminder of the ritual past; they indicate the spiritual tie between past generations and past ancestral deities and, in this context, serve to signify clan and subclan ownership of territory. Although the ritual practice associated with such shrines ceased some 30 years ago, children are taught about their importance.

11.12 Government

11.12.1 National Government

Papua New Guinea is a constitutional monarchy with a parliamentary democracy. The head of state is Her Majesty Queen Elizabeth II, represented in Papua New Guinea by a Governor-General, who is appointed by the National Executive Council (cabinet).

The head of the government is the Prime Minister, who is appointed and dismissed by the Governor-General on the proposal of Parliament. The Prime Minister is usually the leader of the majority party (or majority coalition) in Parliament. The National Executive Council is appointed by the Governor-General on the recommendation of the Prime Minister.

The nation is divided into 20 administrative units (19 provinces and the National Capital District of Port Moresby). Each province is subdivided into various districts, which have a number of local-level governments (LLGs), with councils having elected ward representatives.

The legislative branch is the unicameral National Parliament, which has 109 seats, 89 elected from open electorates (that is, within a specific geographic area) and 20 elected from 'provincial' electorates (that is, from each administrative unit as a whole). Members are elected by popular vote to serve five-year terms. The legal system is based on English common law.

The judicial branch is headed by the Supreme Court. The Chief Justice is appointed by the Governor-General on the recommendation of the National Executive Council after consultation with the minister responsible for justice. Other judges in the National Court and local or village courts are appointed by the Judicial and Legal Services Commission.

11.12.2 Provincial Government

The Department of Provincial and Local Government Affairs is charged with the responsibility for administering the *Organic Law on Provincial and Local-level Governments*, which establishes the political, planning and financial management relationships between the national government and the provinces.

The administrative, executive and political structures provided for in the Organic Law and their relationships to national institutions are set out in Figure 11.7.

The Provincial Assembly is the paramount decision-making body in a province. It is composed of members of the National Parliament (MPs), heads of local-level governments, and a limited number of appointed members representing women and other groups.

Each Provincial Assembly is chaired by a Provincial Governor, who is the member of the National Parliament representing the provincial seat. Provincial governors can be removed by a two-thirds majority vote of the Provincial Assembly.

The Provincial Executive Council is the executive arm of the provincial government and is composed of the Provincial Governor, the Deputy Governor and the chairmen of the Provincial Executive Council's permanent committees. While the Deputy Governor is elected by the local-government members of the Assembly, the heads of the permanent committees are chosen by the Governor.

Each Provincial Executive Council is required to establish a Joint Provincial Planning and Budget Priorities Committee (JPPBPC).

11.12.3 Local-Level Governments

Local-level governments are given certain legislative powers and, in principle, guaranteed funding. Their role in directing the budget priorities for their area is intended to be reflected in the activities of the Joint District Planning and Budget Priorities Committee (JDPBPC), which is responsible for incorporating local government plans and budgets into its larger district plan.

Local-level governments only function in some parts of PNG's provinces. The provincial governments have included local-level government administration costs in forecast budgets but have done little to assist in their inauguration or to arrange for accounts into which funds, such as development levies, might flow.

For much of the project impact area, this lack of local-level government implementation has meant that local development is driven by the provincial governments.

11.12.4 Provincial and Local-Level Government Financing

Provincial and local-level governments are financed by grants from the national government and by 'internal' revenue, which is made up mainly of transfers of national taxation funds and a small amount of revenue that is generated by investments or under their own tax laws.

For provinces having mining and petroleum resources, the national government revenue transfers include royalty payments and development levies. In Southern Highlands Province, oil-related revenues have amounted to about 40% of the province's annual budget.

11.13 Oil and Gas Governance

The governance of the distribution and expenditure of oil and gas income to host provinces and landowning communities is a relevant socioeconomic consideration for the PNG Gas Project. The oil and gas income streams associated with the project are described in Chapter 15. This section describes the key national government institutions involved in the administration of oil and gas income and the planned mechanism for the distribution of this income should the PNG Gas Project proceed.

11.13.1 Department of Petroleum and Energy

The Department of Petroleum and Energy (DPE) is charged with encouraging exploration for and development of hydrocarbon resources. Its role is to ensure that petroleum development projects comply with applicable safety, health and environmental regulations and that benefits arising from such projects are equitably and fairly distributed to stakeholders. The department administers the Oil and Gas Act.

11.13.2 Mineral Resource Development Corporation

Mineral Resource Development Corporation (MRDC) is a state-owned holding company that manages provincial government and landowner equity in mining and petroleum projects in Papua New Guinea. MRDC distributes the proceeds from royalty and equity benefits. Some of these dividends are distributed to landowner trusts[2] that are managed by MRDC.

11.13.3 Department of National Planning and Rural Development

The Department of National Planning and Rural Development acts as the key central agency advising the Independent State of Papua New Guinea on strategic development policy, development planning and programming, aid coordination and management, and the monitoring and evaluation of national development.

11.13.3.1 Development Planning and Programming Division

The Development Planning and Programming Division coordinates the implementation of the Medium Term Development Strategy and the review, appraisal and prioritisation of national and provincial government programs and project submissions for inclusion in the Public Investment Program.

This division also supervises the administration of the Infrastructure Tax Credit Scheme[3] and the Special Support Grant,[4] which directly affect resource-bearing provinces.

11.13.3.2 Monitoring and Evaluation Division

The Monitoring and Evaluation Division monitors and evaluates the effectiveness of the Medium Term Development Strategy, Public Investment Program activities, and the management of the Expenditure Implementation Committee.

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[2] Community Infrastructure Trust and Future Generation Trust.

[3] The Infrastructure Tax Credit Scheme allows the state, using mining and petroleum companies or their nominated contractors, to build infrastructure without the need for appropriation from the Treasury. The scheme was introduced in 1992 and currently is set at 0.75% of assessable income of mining and petroleum companies or their nominated contractors.

[4] The Special Support Grant is a special grant provided by the national government to support the development of priority infrastructure and services nominated by the provinces and approved by the Department of National Planning and Rural Development.

11.13.4 Expenditure Implementation Committee

The Expenditure Implementation Committee is a committee established, according to the Oil and Gas Act, to manage the expenditure of a project's income provided to affected provincial or local-level governments. Pursuant to the Oil and Gas Act, any such expenditure is to be made in accordance with provincial and local-level government development plans and with the approval of the Expenditure Implementation Committee.[5]

The Expenditure Implementation Committee contemplated by the Oil and Gas Act has not yet been fully implemented. In accordance with the Oil and Gas Act, the Expenditure Implementation Committee for the PNG Gas Project will have representation from the Departments of National Planning and Rural Development (Chair), Petroleum and Energy (Deputy Chair), Treasury, Works and Transport, and Provincial and Local Government Affairs, as well as provincial/district administrators of affected provinces and local-level governments, and the chief executive of the Operator of the PNG Gas Project.

11.13.5 Gas Project Co-operation and Sharing Agreement

In accordance with the requirements of the Oil and Gas Act, the allocation of the royalty and equity benefits granted under the Oil and Gas Act to project-area landowners, local-level governments, and provincial governments will be agreed to by those parties and the State and documented in a coordinated development agreement. The coordinated development agreement for the PNG Gas Project is referred to as the Gas Project Co-operation and Sharing Agreement (GPCSA). It is proposed to seek agreement of the affected parties to a benefit-sharing formula as the basis for the allocation of benefits under the GPCSA. The GPCSA may also contain provisions relating to other matters connected with the PNG Gas Project as these matters affect project-area landowners, local-level governments, and provincial governments.

In accordance with the requirements of the Oil and Gas Act, a development forum will be held to which will be invited persons or organisations (or representatives of those persons and organisations) who, in the view of the Minister, will be affected by the PNG Gas Project. One of the functions of the development forum will be for the parties to endeavour to reach agreement on the terms of the GPCSA. The development forum is likely to be preceded by a series of consultations with stakeholders. A model for representation for the GPCSA process and a draft GPCSA are being finalised.

11.14 Sociocultural Issues

This section highlights sociocultural issues with potential significance related to the PNG Gas Project.

[5] This type of expenditure is sometimes referred to as non-cash benefits to differentiate it from cash distributions made directly to landowners. The referenced expenditure is intended for community infrastructure development investments and not for cash subsidies to local governments.

11.14.1 Government Capacity and Alignment

Based on survey information, there is a perception among many residents of the project impact area that government fails to honour commitments or fails to engage with landowners.

Landowners expressed a desire to see changes in the way government revenues are expended in their areas. Appropriate practices that govern the sharing, use, and disbursement of revenue entitlements are seen as important contributions towards continued landowner support for the PNG Gas Project. Systems that manage intra-government processes regarding the control of project-related revenue streams are also important.

11.14.2 Unfulfilled Petroleum MOA, MOU, DA Obligations

Survey participants stated that there are recurrent shortcomings in the process and procedures related to the fulfilment of MoAs, MoUs and DAs[6] that engender anxiety, dissatisfaction and conflict. These include failure to communicate terms to affected constituencies, confusion between ‘wish-lists’ and firm commitments, and cultural miscommunication between signatories. Actions taken by dissatisfied landowners include legal challenges to the validity of the Oil and Gas Act.

11.14.3 Gas Project Co-operation and Sharing Agreement

The GPCSA (see Section 11.13.6 above) will provide for the sharing of PNG Gas Project benefits occurring during the operations phase. The following issues related to the GPCSA have been expressed by project impact area inhabitants: disagreement over landowner representation (in the negotiation or administration of benefit sharing), inability to come to an agreement on benefit sharing, resistance by provincial governors to the statutory role of the Expenditure Implementation Committee, and destabilisation of the GPCSA by factional or ethnic rivalries. For example, there is a movement to create a new province (Hela Province), the area of which would include land that is known to contain gold, oil and gas resources, including those associated with the PNG Gas Project.

11.14.4 Local Business Development (NECL)

It is proposed that a new landowner company (National Energy Company Limited, or NECL) will provide construction-related and other services to the PNG Gas Project, in particular, services in those areas outside the existing landowner companies’ areas of skill or operations. The proposed role of NECL is consistent with local business development that has as its goal the equitable distribution of employment and business opportunities among landowners in the project impact area.

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[6] These refer to Memorandums of Agreement (MoA), Memorandums of Understanding (MoU), and/or Development Agreements (DA) that have been negotiated for previous resource development projects. These negotiations have generally been between the national government and affected landowner parties and have focused on local infrastructure and public service needs. Sometimes, the developer also enters into such agreements with landowners as a corollary agreement to obtain the required license.

The conditions to accommodate NECL in the prevailing employment and business environment in the project impact area are being developed. Landowner support for NECL is variable, depending on the relative satisfaction with existing landowner companies. Implementing NECL may be somewhat problematic due to conflicting interests among the ethnic groups in the project impact area.

11.14.5 Other Issues

The following are findings on other issues specified in DEC (OEC, undated) guidelines for social impact assessment.

11.14.5.1 Cultural Heritage

There are no programs targeted towards cultural heritage in the project impact area. Communities appear not to be willing to invest part of their benefit stream to preserve their cultural heritage.

11.14.5.2 Social Structure

Regional developments appear to have accelerated clan fragmentation, evidenced by new organisational and representational structures in the project impact area.

11.14.5.3 Participation of Women

There is unwillingness on the part of many men to support the empowerment of women. With the lack of local-level government initiatives, women are, for the most part, disempowered in terms of having a voice in local community decision-making.

11.14.5.4 Stratification and Empowerment

There are large disparities related to project involvement and awareness between central and peripheral communities in the project impact area. This creates conditions for the potential unequal distribution of project-related benefits. Disempowerment is a major risk factor when landowners are subject to superimposed levels of decision-making.

11.14.5.5 Consumerism and Cultural Miscommunication

Consumer goods are, for the most part, readily available; but when these deteriorate, they are typically replaced rather than repaired. This trend means that a large part of the wealth devoted to immediate consumption of goods is being wasted.

The indigenous concepts of agreement, contract, responsibility, blame, and dispute processes can be radically different from those of resource development companies and their staff. Likewise, the cultures of the project impact area necessitate a flexible model of negotiation.

11.14.5.6 Migration, Law, and Order

At present, intending migrants to the project impact area are limited in their options because they cannot obtain land and residence without permission from the legitimate landowners. There is no evidence of squatter settlements in the region, and no violent conflicts between residents and landowners have arisen.

The completion of the Tari to Kikori public road will have a significant impact on the project impact area. Local business development opportunities will be stimulated. There may be gravitation to mini-townships and greater interactions with petroleum facility personnel. The potential also exists for higher crime and prostitution rates due to the influx of additional people into the relevant areas. These problems appear to have been reflected in the low support in Kikori for the public road (less 50%), compared to a substantial majority in the Gobe catchment and almost 100% support in the Kutubu, Hides, and Moran catchments.

Cumulative impacts associated with the road to be upgraded/built by the project are discussed in Chapter 16.

11.14.5.7 Post-Project Sustainability

There are no simple answers to the question of sustainable economic growth in the project impact area. Cash-crop agricultural projects will be difficult to sustain if the Tari to Kikori public road falls into disrepair. The three top-scoring suggestions in the household survey for long-term sustainability in the project impact area were investment, education, and the creation of a future generations trust fund.

11.14.5.8 Psychosocial Welfare

The majority of project impact area landowners surveyed have a favourable opinion regarding the impact of the recent petroleum developments on their lives, and 82.8% stated that they want the PNG Gas Project to proceed. Only a very small percentage of the region's society has experienced radical lifestyle transformations due to the current petroleum developments. For the vast majority, the land tenure system remains the bedrock of both their identity and their subsistence base. There is no evidence that the landowners have become dependent on the petroleum developments and, as a consequence, they have not suffered a loss of self-esteem.

12. Route Description

12.1 Introduction

This chapter describes significant features along the proposed onshore pipeline right of way (RoW) and the offshore pipeline route to the PNG—Australian border using a travelogue format. The travelogue provides an overview of features traversed and also includes information on features that are to be avoided either to pre-empt potential adverse environmental impacts or to avoid terrain where construction is not technically or economically feasible.

The onshore route has been divided into 13 sequential segments. The beginning and end of each segment have been selected on the basis of geographic features, such as villages, watercourses, as well as major project production facilities, which could serve as an identifiable beginning or end of the segment under consideration. Two separate segments are described for the Gobe and Agogo rich gas pipeline RoWs, namely, segments 14 and 15 respectively.

The proposed offshore pipeline route has been divided into 4 sequential sections from the Omati River landfall through the PNG—Australian border in Torres Strait to the landfall at Cape York, Australia. This complete coverage of the offshore route is necessary due to the common interests of the Papua New Guinean and Australian governments with regard to the fisheries and other customary and commercial uses of Torres Strait waters (see Section 4.1.5).

12.2 Hides Gas Field to Hides Production Facility

This section provides travelogues of the two pipeline RoW segments (i.e., Segments 1 and 2) between the Hides gas field and the Hides Production Facility.

A spine line and gathering system (flowlines) are proposed for the Hides gas field ridge, which will convey wellstream fluids from new and existing wellheads to the existing Hides 4 well. From the Hides 4 well, the spine line descends along a section of the existing Komo to Nogoli road to the proposed new Hides Production Facility adjacent to the Tagari River.

12.2.1 Segment 1: Hides Ridge to the Hides 4 Well

This 19-km-long segment encompasses the alignment of the Hides spine line, gathering system (flowlines), wellpads, and a proposed new access way associated with the development of the Hides gas field. Figure 12.1 shows the location of Segment 1.

The Hides spine line will be laid within a cleared RoW and will generally follow the ridge line between sinkholes (Plate 12.1) on either side, thus avoiding any significant side cuts and reducing the quantities of side-cast spoil potentially entering the sinkholes. A sinkhole management strategy will be developed and implemented to protect those shallow sinkholes (less than 50 m deep) that contain swamps. After pipeline installation, the Hides spine line RoW will become the access way to the new and existing wellpads. The new well pads will be located on hilltops of which Plate 12.2 shows an example.

For the first 17 km, the proposed new RoW and access way traverse rugged polygonal karst between elevations of 2,800 m ASL and 2,000 m ASL. The vegetation of the Hides ridge is lower montane small-crowned forest with *Nothofagus* (FIM type LN) (Plate 12.3) and very small crowned forest with *Nothofagus* (FIM LsN) (Plate 12.4). Above 1,800 m ASL on the Hides ridge, the high altitude *Nothofagus* forest on karst is recognised as a high-value conservation area (see Special Area 1 in Section 9.3.6.). Supporting Study 2 lists over 16 features of this forest type warranting its being classified as a noteworthy area. The epiphytes and ferns in this forest type are the major component of plant biodiversity, the trees being the structure upon which this is developed.

For the final 2 km to the existing Hides 4 wellpad, the RoW and access way descend through the polygonal karst to about 1,800 m ASL. There are numerous sinkholes along the Hides ridge and some have swamps (see Plate 9.32 in Chapter 9) at their bottoms. There are also numerous caves along the ridge and a survey will be undertaken to identify those caves that might contain endangered species. The spine line RoW will avoid these sinkhole swamp and cave habitats or implement mitigation and management measures to reduce potential impacts on them.

Figure 12.2 is a digital elevation model view of terrain in the vicinity of segments 1 and 2 from Hides ridge southwest to Lake Kutubu.

12.2.2 Segment 2: Hides 4 Well to Hides Production Facility

This 8-km-long segment commences at the Hides 4 well and terminates at the proposed Hides Production Facility, near the Tagari River. For most of this segment, the spine line will be installed within the easement of existing Koma to Nogoli public road, which will be upgraded. Figure 12.1 shows the location of Segment 2.

The area around the Hides 4 wellpad features human settlements, and most of the forest has been cleared (Plate 12.5). From the Hides 4 wellpad, the pipeline RoW leaves karst terrain and traverses an area of higher quality volcanic soils on a gently sloping plateau, and then follows the existing Koma to Nogoli road through regrowth and gardens to the Hides Production Facility, which is located on land adjacent to the Tagari River.

Drainage from the upgraded Komo to Nogoli road within Segment 2 is via small tributaries to the Tagari River.

12.3 Hides to Kutubu Pipeline RoW

This section provides travelogues of the five pipeline RoW segments (Segments 3 to 7a) between the Hides Production Facility and the Kutubu Central Gas Conditioning Plant.

12.3.1 Segment 3: Hides Production Facility to Maruba River

This 45-km long segment begins at the Hides Production Facility and terminates at the Maruba River crossing (Figure 12.3). The proposed Hides Production Facility is located in an area of regrowth, kunai grassland and remnant forest on raised land on the south bank of the Tagari River (Plate 12.6). From the Hides Production Facility, the pipeline RoW crosses the Tagari River (Plate 12.7) and traverses alluvial plains clothed in a complex of intact and disturbed small crowned forest (Plate 12.8) at about 1,200 m ASL near the Angore rest hut. From here, the pipeline ROW continues eastwards and then joins the proposed Idauwi to Homa access way at about 1 km west of the Dagia River. The terrain in this section is hilly, consisting of volcanic footslopes and plains, with hills rising to 1,400 m ASL and limestone outcrops occurring in the east. The forest is discontinuous along this section and is fragmented by gardens and clearing, but there are numerous emergent *Araucaria*. In the area where the pipeline RoW joins the proposed Idauwi to Homa access way, there is a large area of archaeological and cultural significance, known as the Honeanda Complex, which lies between 1 and 3 km west of the Dagia River. The pipeline RoW and access way alignment will negotiate the Honeanda Complex to avoid archaeological sites. After rejoining the Idauwi to Homa access way, the RoW/access way alignment crosses the Dagia River and traverses hilly terrain south of Tambaruma village.

From approximately 3 km south of Tambaruma village, the small crowned forest becomes more continuous with fewer clearings and fewer *Araucaria* as the RoW/access way alignment skirts to the west of the Pali Range, crossing rolling volcanic hills at altitudes between 1,200 and 1,400 m ASL, before it crosses the Benaria River. The RoW/access way alignment follows the old Tari road from Tambaruma to the Benaria River through a corridor of regrowth forest.

At the Benaria River, the RoW crosses directly over the river but the proposed Idauwi to Homa access way alignment runs for just over 1 km upstream, following the route of the old Tari road to cross the Benaria River on a new bridge close to the original bridge site (Plate 12.9). The access way alignment then crosses cow paddocks and secondary forest before rejoining the RoW alignment.

From the Benaria River, the RoW/access way alignment crosses the footslopes of the steep, rugged volcanic range between the Benaria and Bakari rivers. The forest is intact for most of the distance between these two swift-flowing rivers, except for the river approaches where there are clearings (Plate 12.10). At the Bakari River, the RoW alignment deviates from the access way alignment to cross the river about 1 km west of Tambera village and rejoins the access way alignment at about 1 km south of Tamera village. A bridge will be built across the Bakari River for the access way at Tambera village.

About 1 km south of the Bakari River bridge crossing, the RoW/access way alignment follows a small river valley past the villages of Pai and Hoia, and then runs downslope to the Maruba River. This small river valley is settled, and the vegetation is a mixture of intact forest, secondary growth and clearings.

12.3.2 Segment 4: Maruba River to Kondari River

This 12-km-long inter-river segment (Figure 12.4) traverses a steep, rugged volcanic range threading its way between four large volcanic peaks, one rising to 1,890 m ASL. Between the Maruba River and Pororo Creek, the RoW and access way alignments take separate routes, although they cross each other at several points. The RoW alignment crosses Pororo Creek, while the access way alignment crosses both the Pawgano River and Pororo Creek before rejoining the RoW alignment. The RoW alignment reaches its highest elevation at about 1,600 m ASL in this segment.

This segment is not settled, and the forest on the very steep ridges is undisturbed (Plate 12.11) until the Kondari River, where there is some riparian cultivation and gardening. From the steep ridges, the access way alignment heads north to Homa village to join up with the existing Homa to Kutubu public road, while the RoW alignment continues east across the river.

12.3.3 Segment 5: Kondari River to North of Lake Kutubu

This 29-km-long segment begins at the Kondari River crossing and terminates on a hilltop 1 km to the northwest of Lake Kutubu (see Figure 12.4). From Homa on the Kondari River, the RoW alignment follows the existing Homa to Moro road and traverses a densely forested pass north of Mt Barina and then to Pua'a village, which lies in the cultivated Aiu River valley. There is a concentration of archaeological sites centred on the area between Homa and Pua'a villages, and the RoW alignment and the upgrading of the existing Homa to Moro road will be planned to avoid significant archaeological, cultural heritage or spiritual sites within this area.

The RoW/existing road alignment then crosses the Humphries Range and descends to the upper valley of Kaimari Creek, where the RoW alignment deviates from the existing road to take a more direct crossing of the creek. This 1-km-long deviation avoids sharp bends along the existing road that the pipeline cannot negotiate because of its turning radius. The RoW alignment rejoins the existing road and continues through the upper valley of Kaimari Creek to the Mubi River valley at about 940 m ASL (Plate 12.12). Along the upper Kaimari Creek valley, the RoW alignment and existing road leave the volcanics terrain and enter polygonal karst again. The valleys of the Mubi and Aiu rivers are settled and cultivated, and the RoW alignment passes through intact, small crowned forest.

The RoW alignment follows the existing Homa to Moro road along the western side of the Mubi River valley, mostly through secondary growth forest along the road alignment. About 4 km north of Lake Kutubu and at an elevation of 1,000 m ASL, the RoW alignment deviates from the existing road and takes a direct 3-km-long route to rejoin the Homa to Moro road about 1 km north of Taga Creek and the northwest corner of Lake Kutubu.

12.3.4 Segment 6: North of Lake Kutubu to Moro

This 10-km-long segment of the RoW alignment follows the existing Homa to Moro road alignment and begins 1 km north of Lake Kutubu (Plate 12.13), traverses the swamp forests northwest of the lake and a section of karst terrain (Plate 12.14) and terminates at Moro airfield (see Figure 12.4). The RoW alignment then follows the existing road alignment across Kaimari Creek and continues on to Moro. The swamp forests in this section are skirted to the north except at Kaimari Creek. The buried pipelines will not influence the hydrology of these swamps any more than the existing road does (see Section 13.4.4).

A major portion of this segment lies within the catchment of Lake Kutubu, which is recognised as a wetland of international conservation importance under the Ramsar Convention (see Section 4.1.5), owing to the large number of endemic fish fauna (a total of 15 species). The project will apply mitigation measures to limit impacts from pipeline RoW construction and the upgrading of the existing road in the catchment area of this lake (see Section 13.3.3).

12.3.5 Segment 7a: Moro to Kutubu Central Gas Conditioning Plant[1]

From Moro, the RoW alignment climbs through polygonal karst terrain along the existing Moro to Kutubu road to the proposed Kutubu Central Gas Conditioning Plant at 1,050 m ASL (Figure 12.5). The high polygonal karst terrain is densely clothed with small crowned lower montane forest with *Nothofagus*. The RoW alignment continues through montane forest, passing the surrounding peaks, which reach 1,400 m ASL in the vicinity of Ridge Camp. The route then descends for 2 km to the Kutubu Central Production Facility at approximately 960 m ASL, which is located in small-crowned lowland hill forest with *Nothofagus*.

At the intersection with the existing road to the Agogo Production Facility, which is located about 8 km south of the Moro airfield, a 1.5-km section of the RoW alignment deviates from the existing Moro to Kutubu road to bypass the Ridge Camp area and then rejoin the existing road alignment. This is the only section between Moro and the Kutubu Central Gas Conditioning Plant where a new RoW will be constructed through karst country. The pipeline RoW alignment in this segment concludes at the Kutubu Central Gas Conditioning Plant.

The 24-km-long Agogo rich gas pipeline, which intersects this segment near Ridge Camp, is presented as a separate segment (i.e., Segment 14) and is described in Section 12.5 below.

Figure 12.6 is a digital elevation model view of terrain in the vicinity of segments 3 to 7a looking northwest from over Lake Kutubu towards Hides.

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[1] Note that segment 7a is combined with segment 7b for assessing impacts on the terrestrial biological environment in Chapter 13.

12.4 Kutubu to Omati River Landfall

Travelogues of the seven pipeline RoW segments (Segments 7b to 13) between the Kutubu Central Gas Conditioning Plant and the sales gas pipeline landfall on the Omati River are provided below.

12.4.1 Segment 7b: Kutubu Central Gas Conditioning Plant to the Ai'io River[2]

In this 11-km segment (see Figure 12.5), the pipeline RoW leaves the Kutubu Central Gas Conditioning Plant, follows the existing road alignment, and traverses a 3-km section of steep, mountainous karst terrain clothed in small crowned lowland hill forest with *Nothofagus* (Plate 12.15), which reaches an elevation of 1,040 m ASL. At about 6 km east of the Kutubu Central Gas Conditioning Plant, a 2.5-km section of the pipeline RoW deviates from the existing road alignment to follow the existing crude oil export pipeline easement to better negotiate the Iwa Range (Plate 12.16) before descending to the Ai'io River.

12.4.2 Segment 8: Ai'io River Valley

In this 15-km segment (see Figure 12.5), the pipeline RoW coincides with the crude oil export pipeline easement as it traverses the alluviums of the Ai'io River valley at an altitude of about 450 m ASL. The terra rossa soils overlie limestone and support swamp forest and swamp woodland with sago and other palms at the northwestern end of the valley. Towards the southeast, the forest grades into small crowned forest as the pipeline RoW ascends into polygonal karst country (Plate 12.17). The Ai'io River valley contains several villages, including one established on the crude oil export pipeline easement near the Ai'io River and Manu village (Plate 12.18).

12.4.3 Segment 9: Ai'io River Valley to Wassi Falls

In this 34-km segment (Figure 12.7), the pipeline RoW/existing road alignment leaves the Ai'io River valley and enters an uplifted area of polygonal karst clothed in medium crowned lowland hill forest and small-crowned lowland hill forest to a point 13 km from the Ai'io River (Plate 12.19). From here, the pipeline RoW/existing road alignment descends via a long, narrow valley into the Mubi River valley and overlooks Kantobo village (Plate 12.20). The karst terrain in this segment has many areas where the drainage is impeded. Sinkholes, small valleys and sections of the existing crude oil export pipeline easement retain water during periods of high or sustained rainfall. Plate 12.21 shows an example of flooding.

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[2] Note that segment 7b is combined with segment 7a for assessing impacts on the terrestrial biological environment in Chapter 13.

12.4.4 Segment 10: Wassi Falls to Mubi River Crossing

This short 5-km segment forms the second major descent of the pipeline RoW towards the Kikori lowlands (40 m ASL) via steep terrain approximately 1 km from west of the Wassi Falls (see Figure 12.7). After descending through an area of terra rossa clays, the pipeline RoW crosses the Mubi River 65 km from the Kutubu Central Production Facility near its junction with the Hegigio River, at which point the Kikori River begins. The access way alignment deviates from the pipeline RoW at a point southwest of Kantobo village to negotiate a southerly descent across the range and then follows the Hegigio River valley east to the Mubi River crossing, while the pipeline RoW follows the existing oil export pipeline easement down the range (Plate 12.22) to the Mubi River crossing (Plate 12.23).

12.4.5 Segment 11: Mubi River Crossing to Kikori River Crossing

In this 52-km long segment (Figure 12.8), the RoW/access way alignment follows the existing oil export pipeline easement. After crossing the Mubi River, the RoW/access way alignment runs along the northern side of the Kikori River and traverses mudstone overlain with terra rossa clays developed on karst plain for about 8 km. This section is vegetated by medium crowned lowland hill forest (Plate 12.24). From here, the soils become very thin and the vegetation is lowland open forest. The RoW/access way alignment then traverses polygonal karst terrain, which is vegetated by medium crowned lowland hill forest, as it approaches the Gobe airfield (Plate 12.25). This is a difficult section for construction, as the RoW/access way alignment traverses cockpit karst in places as well as areas of unstable terra rossa soils and mudstones. The proposed Gobe rich gas pipeline may tie-in to the sales gas pipeline near the Gobe airfield approximately 82 km from the Kutubu Central Production Facility. The Gobe gas pipeline is presented as a separate segment (i.e., Segment 15) and is described in Section 12.6.1 below.

The RoW/access way alignment continues across karst plain for a further 35 km before approaching the Kikori River upstream of the Kaiam ferry crossing (Plate 12.26). In this section, sinkholes and pinnacles occur frequently, particularly at the Kikori River crossing. As in the previous segment, the vegetation of the karst plains is lowland open forest and that of the polygonal karst is medium-crowned lowland hill forest. At about 1-km from the Kikori River, the access way alignment deviates from the pipeline RoW to take a westerly crossing over the Kikori River via a proposed new bridge upstream of the Kaiam ferry crossing.

12.4.6 Segment 12: Kikori River Crossing to Kopi

This 40-km-long segment begins at the Kikori River crossings and terminates at Kopi (Figure 12.9). After crossing the Kikori River, the RoW and access way rejoin about 1 km south of the river. The RoW/access way alignment then continues along the southern side of the Kikori River and along the western edge of the karst plain through dense lowland open forest on plains and fans. The RoW/access way alignment continues to the Ututu Creek, some 156 km southeast of the Kutubu Central Production Facility and about 2 km west of Kopi. Polygonal karst terrain occurs between the Ututu Creek bridge (Plate 12.27) and Kopi (Plate 12.28), and the karstic pinnacles present are clothed in medium crowned lowland hill forest. Caves and sites of archaeological and cultural heritage significance occur in this pinnacle area. The final route planning for the new access way will take the locations of these sites into consideration. The RoW/access way alignment diverges from the existing crude oil export easement just north of the Kopi Support Base and passes on the western side of the base before taking a southerly route to the Omati River landfall.

12.4.7 Segment 13: Kopi to Omati River Landfall

This 34-km-long segment begins at Kopi and terminates at the Omati River landfall for the sales gas pipeline (Figure 12.10). The gas pipeline RoW/access way alignment leaves Kopi and follows its own onshore alignment to the landfall location on the lower Omati River, which is located about 34 km to the south. After leaving Kopi, the RoW/access way alignment crosses Mati Creek (Plate 12.29) at about 3 km, and then tracks for a further 7 km southwest across karst plain with outcrops of pinnacles and small karst towers where polygonal karst encroaches. The vegetation on this plain is small crowned lowland open forest on very shallow to non-existent soils.

The RoW/access way alignment then crosses Veiru Creek (Plate 12.30) and an area of small rugged karst range (Plate 12.31), from where it turns due south. The RoW/access way alignment finally descends past isolated limestone pinnacles to enter a complex of medium crowned lowland hill forest and swamp forest 8 km further on. The pinnacles and the karst range support better-structured, medium crowned, lowland hill forest, but the karst range has been logged. From this point, the forest becomes wetter and swampy, and sago palms become predominant until the near the water's edge of the Omati River, which is lined with a thin fringe of nypa palm (*Nypa fruiticans*) (see Plate 9.16 in Chapter 9). The sands, silts and muds overlying the karst plain are not deep. Raised areas within the karst plain are dominated by broad-leaved trees and the lower areas are dominated by extensive stands of sago palms.

Plate 12.32 shows the east bank of the lower Omati River where the sales gas pipeline landfall will occur. In Plate 12.32, the area of cleared vegetation in the foreground represents the former proposed landfall site that has now been relocated southwards to near the junction of the Omati River and an unnamed tributary that links the Omati and Newberry rivers. This relocation allows the crossing of the river bank at right angles and maintains the straight section of the onshore pipeline as it heads offshore.

Figure 12.11 is a digital elevation model view looking north from the Omati River landfall over terrain in the vicinity of segments 7b to13.

12.5 Segment 14: Agogo Rich Gas Pipeline RoW

A 24-km-long rich gas pipeline will be installed from the Agogo Production Facility to the Kutubu Central Gas Conditioning Plant (see figures 12.5 and 12.6). This section presents a travelogue of the first 17 km of the Agogo rich gas pipeline to its intersection with the Hides to Kutubu pipeline RoW/access way alignment near Ridge Camp. The remaining 7 km of the Agogo rich gas pipeline to the Kutubu Central Gas Conditioning Plant are already described in the travelogue of Segment 7a (see Section 12.3.5).

From the Agogo Production Facility (see Plate 2.3 in Chapter 2) at about 800 m ASL, the RoW and existing access way traverse steep and rugged polygonal karst clothed in small-crowned lowland hill forest with *Nothofagus* for about 10 km, then descend to about 760 m ASL and into medium-crowned lowland hill forest with *Nothofagus* and areas of swamp forest with sago palms in a perched valley with mostly terra rossa soils. From this valley, the RoW and existing access way climb rapidly onto high, rugged karst terrain that is densely clothed with very small crowned, lower montane forest with *Nothofagus*. This segment terminates at the intersection of the existing Moro to Kutubu road.

12.6 Segment 15: Gobe Gas Pipeline RoW

The gas pipeline RoW from the Gobe Production Facility may follow the existing Gobe crude oil pipeline RoW for some 10 km to tie-in with the sales gas pipeline RoW at about 82 km east of the Kutubu Central Gas Conditioning Plant. In this 10-km section, the RoW traverses polygonal karst with small to medium crowned lowland hill forest. Figure 12.12 is a digital elevation model view of terrain in the vicinity of Gobe.

12.7 Offshore Pipeline Route

The offshore sales gas pipeline commences at the Omati River landfall and continues offshore through the Gulf of Papua and northern Torres Strait to the PNG—Australian border. From the border, the pipeline route continues across the Torres Strait to a landfall at Cable Bay on Cape York in Queensland; however, this section of the natural gas pipeline is beyond the scope of the PNG Gas Project and is not covered by this EIS but by a separate EIS (NSR, 1998a).

This section presents travelogues of the four sections of the offshore pipeline route within PNG jurisdiction (see Figure 12.10).

12.7.1 Offshore Section 1: Omati River Landfall to Omati River Mouth

The length of the pipeline route in this section is about 24 km, and the lower Omati River water depth varies between 5 m and 6 m. The alignment of the pipeline route within the lower Omati River will be mid-channel, thus keeping a fair distance away from riparian sociocultural heritage and archaeological sites (see Chapter 11) along the river banks and mid-river islands in this section.

The lower Omati River is characterised by mobile bedforms, such as ripples and megaripples, as well as sandbanks and sandbars. Bed topography is generally shallow and variable, with intermittent scour holes and occasional rock pinnacles. Scouring takes place due to the prevalence of high currents and river flows associated with flood flows, particularly during the wet season. Bed material is mainly soft silty muds and sand of variable thickness.

The fish fauna of the lower Omati River are characterised by the presence of sediment-tolerant freshwater and estuarine species, such as barramundi, sawfish, fork-tailed catfish, mangrove jack, and threadfin salmon. The lower Omati River may also be frequented by Irrawaddy, Indian Ocean bottlenose and Indo-Pacific humpbacked dolphins, which occur in the Omati-Kikori delta.

12.7.2 Offshore Section 2: Omati River Mouth to Bramble Cay

The length of the pipeline in this route section is about 150 km, and the water depth varies from 6 m to 70 m. Bramble Cay represents the northern boundary of the Torres Strait Protection Zone (see Figure 12.10).

After leaving the Omati River mouth the pipeline route heads due south then deviates around the area immediately offshore of the Fly River delta and below the 40-m isobath. This deviation is required since Fly River delta sediments are constantly reworked, and there exists a potential for seabed instability and mud slides. However, little deposition of Fly River sediments occurs beyond the 40-m isobath, hence the deviation. Other constraints along the pipeline route in this section are relict river channels of the ancient Fly River and the possible presence of submerged trees and logs. Three relict channels are present, namely, the Umuda, Purutu and Kiwai channels (see Figure 10.2 in Chapter 10). The presence of submerged trees and logs will be assessed during a marine geophysical survey, and minor route deviations may be required. The pipeline route will also take advantage of the stable seabed provided by the carbonate platform offshore of the Fly River delta at about the 50- to 70-m isobath. No other tactical routing constraints are currently evident in this part of the route section.

From the outer edge of the Fly River delta the pipeline route continues southwest and passes some 10 km north of Bramble Cay while avoiding the shipping lanes of the Great North East Channel. Bramble Cay is some 50 km from the centre of the mouth of the Fly River and features a narrow, fringing reef sloping down to a muddy-sand bottom (Babcock, 1988). It is the northernmost outlier of the Great Barrier Reef and the closest coral to the turbid waters of the Fly River delta. The water depth in this section is between 20 m and 30 m, and soft seabed conditions are again encountered in the form of coarse to fine carbonate sands, with mobile bedforms. The route enters the Torres Strait Protection Zone approximately 25 km west of Bramble Cay.

Most of the seabed along this pipeline route section is deltaic silty organic-rich muds of variable thickness (Figure 12.13), except for the more stable seabed of the carbonate platform offshore of the Fly River delta. Locally, these muds appear to be poorly consolidated and gas rich. There is a progression of sedimentary facies from unstable terrigenous prodelta muds with moderate infaunal densities in the Fly River delta, to stable highly bioturbated fluid muds with high infaunal densities away from the delta (Alongi et al., 1992). The pipeline route crosses the latter seabed type and infaunal habitat. Along the carbonate platform offshore of the Fly River delta, the more stable and hard substratum provides habitat for benthic algae of the genus *Halimeda*, which occurs as sparse patches in this area. The *Halimeda* beds of this carbonate platform habitat are extensive and are not expected to form a routing constraint, as the pipeline route skirts to the north of these beds (see Figure 10.7 in Chapter 10).

As the water column deepens away from the delta towards Bramble Cay, clearer water and better light penetration of the water column allows increased pelagic production and enhanced benthic production. Here demersal fauna, such as bivalves, crabs and sponges, become more abundant compared to closer to the Fly River delta where they are rare or absent.

12.7.3 Offshore Section 3: TSPZ—PNG

The sales gas pipeline enters the Torres Strait Protection Zone off Bramble Cay and runs west-southwest some 80 km to the Warrior Reefs in water depths of between 20 m and 30 m. Bramble Cay is some 50 km from the centre of the mouth of the Fly River and features a narrow, fringing reef sloping down to a muddy-sand bottom (Babcock, 1988).

Soft seabed conditions are again encountered in this section of the pipeline route in the form of coarse to fine carbonate sands, with mobile bedforms, including areas of silty muds and sands of variable thickness. In general, the pipeline route passes through areas where epibenthos density is sparse, very sparse or absent, owing to the influence of Fly River sediment loads and offshore sedimentation.

Approaching the Warrior Reefs, the pipeline turns south-southwest and runs in water depths between 10 m and 20 m along the eastern side of the reef complex. Southwest of Pearce Cay and some 6 km east of Moon Passage, the pipeline crosses the PNG—Australian border.

The seabed to the east of the Warrior Reefs is generally protected from strong current action and consists of smooth mud, with sand around the entrances to the passages through the reef. There is little seagrass along the proposed pipeline route and most seagrass east of the reef complex is restricted almost exclusively to shallow-water reef habitats (i.e., the tops and edges of reefs).

The presence of low current velocities (as would be expected in the lee of the Warrior Reefs complex) results in a depositional environment, dominated by a silt and mud substratum. In general, the pipeline route passes through areas where epibenthos density is sparse, very sparse or absent. Surveys of this area have found no epibenthic fauna and the seabed is largely devoid of sessile megabenthos (Long et al., 1997).

This section of the pipeline skirts the main prawn trawling grounds east of the Warrior Reefs, but with some overlap of the less intensively fished western margins.

12.7.4 Offshore Section 4: TSPZ—Australia

From the PNG–Australia border, the sales gas pipeline continues generally southwest along the eastern edge of the Warrior Reef for a further 70 km before turning west-southwest to run for some 40 km through the South Central Passage, a natural opening between Sassie Island and Bet Reef.

Fast currents flow through the passage under the influence of astronomic tides and the fluctuating hydrostatic levels of the Coral Sea to the east and the Arafura Sea to the west. The seabed in this area is rocky with a sparse to very sparse epibenthos. Seagrass is present as the pipeline exits the passage to the west. In the Torres Strait Protection Zone, the total area of seagrass disturbed is predicted to be very small — about 0.052% of the mapped area of seagrasses (see Section 14.3.4).

Passing north of Saddle Island, the pipeline again turns south-southwest to run some 30 km to the southern boundary of the Torres Strait Protection Zone over a sand and rubble seabed with seagrass present and epibenthos sparse or absent. The pipeline crosses a shipping channel and leaves the Torres Strait Protection Zone some 30 km west-northwest of Thursday island and some 40 km north-northwest of the landfall location on Cape York.

13. Environmental Impacts and Mitigation Measures - Onshore

This chapter identifies and assesses the direct and indirect impacts of the project on the onshore environment and evaluates the residual impacts (i.e., those remaining after appropriate mitigation and environmental management measures have been applied to the direct and indirect impacts).

The PNG Gas Project will be largely a ‘brownfield’ development (i.e., it will exist to a great extent within the footprint of the existing petroleum infrastructure), but with spatial extensions into ‘greenfield’ areas. Direct impacts will mostly occur during construction, primarily due to the land clearing and earthworks necessary to establish the pipeline installation RoWs and access roads.

Indirect impacts are those arising from the existence of project facilities but which are not caused by its construction or operations. Such impacts will occur mostly during operations, for example hunters using construction access ways and the creation of new settlements along project-improved roads.

The indirect impacts associated with oil and gas developments in Papua New Guinea over the past fifteen years have been moderated by access restrictions—that is, at present, there is no public road from Kutubu to Gobe. However, there are public roads from Hides to Kutubu (a circuitous route via Idauwi, Tari, Poroma and Pimaga), between the Hides 4 well and Idauwi, between Homa and Kantobo (downstream of Manu becomes more and more difficult) and between Gobe and Kopi.

Indirect impacts involve third parties and may also be overlain by other activities and developments. They cannot be readily quantified, but they can be characterised as the impacts from all foreseeable activities that will occur in a given place. This aggregation of the effects of direct, indirect and other possible cumulative and associated impacts not related to the PNG Gas Project is addressed in Chapter 16.

Where appropriate, the discussion of direct and indirect impacts in this chapter is presented according to the type of project activity, such as construction, commissioning or operations. The chapter begins with definitions (Section 13.1) and then addresses the resources or receptors that may be subject to impacts: landforms (Section 13.2), soils (Section 13.3), water resources and hydrology (Section 13.4), water quality (Section 13.5), aquatic ecology (Section 13.6), terrestrial biodiversity (Section 13.7), air quality (Section 13.8), greenhouse gases (Section 13.9) and noise (Section 13.10).

The RoW between Hides and Kutubu will be built almost entirely in the bench either of the existing roads at each end of this section or in the new section of road between Idauwi and Homa. Strictly speaking, the impacts of this road would be defined as ‘cumulative’, since the road is a separate initiative of the State, sections are currently under construction and it would be built regardless of whether the PNG Gas Project were to proceed or not. However, the sales gas pipeline RoW requires a wider bench than a road alone, and it is therefore difficult to separate the respective earthworks calculations without doing separate designs for the road alone and for the road and RoW combined.

In both cases, the nature of the impact is the same, and so the landform and ecological impacts of the road and RoW have been assessed together in this chapter.

13.1 Definitions

The definitions used to classify the spatial and temporal scale of impacts are given below. The classification of effects, nature of effects and impact assessment criteria are given in the individual sections of this chapter.

13.1.1 Spatial Classification of Residual Impacts

Definitions of the spatial scale of residual onshore environmental impacts are provided so that statements about the degree of an impact have a precise meaning. Environmental effects have been evaluated in different spatial contexts for the terrestrial and freshwater aquatic environments, and these contexts are described below.

13.1.1.1 Terrestrial Environment

Residual impacts (those remaining after appropriate mitigation and management measures have been implemented) on the terrestrial environment are evaluated at the following five spatial scales (see Supporting Study 2 for more detail):

- Very limited: Immediate environs of an impact location and extending to a radius of less than 200 m.
- Limited: Immediate environs of an impact location and extending to a radius of between 200 m and 2 km.
- Local: Generally occurring within a radius of between 2 and 10 km from an impact location.
- Regional: Generally occurring over a large area that extends to a radius of more than 10 km from the impact location or up to 10% of the Kikori Integrated Conservation Development Program (KICDP) area.
- Widespread: Generally occurring over a large area that extends from more than 10% of the KICDP area to the national scale.

13.1.1.2 Aquatic Environment

The onshore freshwater or estuarine environment presents a different environmental domain from that of the terrestrial environment, and residual environmental impacts have therefore been evaluated in a longitudinal spatial context and relate mainly to the watercourses of the project area, which are the aquatic environments most likely to be influenced by construction activities and operations. Potential impacts on the few lacustrine environments present in the project area (e.g., Lake Kutubu) will be avoided by the implementation of appropriate site-specific mitigation and management measures (see Section 13.4.3).

Residual impacts on the freshwater and estuarine aquatic environments have been evaluated at three spatial scales:

- Site scale: Immediate watercourse within 2 km downstream of a project impact location.

- Local scale: Extending between 2 km and 10 km downstream from ‘site scale’ waters and generally includes larger streams and the tributaries (e.g., Dagia, Wada, Maruba, Pawgano and Kondari rivers) of major rivers.
- Regional scale: Extending more than 10 km downstream from ‘local scale’ waters and principally includes the mainstems of the major rivers of the project area, such as the Tagari, Hegigio, Mubi and Kikori rivers.

13.1.2 Temporal Classification of Residual Impacts

Definitions of the temporal scale of residual onshore environmental impacts are provided so that statements about the degree of an impact have a precise meaning. Environmental effects have been evaluated in different temporal contexts for the terrestrial and freshwater aquatic environments, and these contexts are described below.

13.1.2.1 Terrestrial Environment

Residual impacts on the terrestrial environment have been evaluated at the following three temporal scales (see Supporting Study 2 for more details):

- Short term: Residual impacts lasting less than 7 years.
- Medium term: Residual impacts lasting between 7 years and 25 years.
- Long term: Residual impacts lasting more than 25 years.

13.1.2.2 Aquatic Environment

Residual impacts on the onshore freshwater and estuarine aquatic environments have been evaluated at the following three temporal scales:

- Short term: Residual impacts lasting less than 1 year.
- Medium term: Residual impacts lasting between 1 year and 5 years.
- Long term: Residual impacts lasting more than 5 years.

13.2 Landforms

This section addresses the impact assessment criteria (Section 13.2.1), principal issues (Section 13.2.2), proposed mitigation and management measures (Section 13.2.3) and then discusses the residual environmental impacts of project construction and operations activities (Section 13.2.4) relating to landforms and the geomorphological processes that affect landforms.

13.2.1 Residual Impact Assessment Criteria

The spatial and temporal classifications of residual impacts on landforms follow those for the terrestrial environment outlined in Sections 13.1.1 and 13.1.2 above.

Operational definitions of significance criteria for assessing the residual impacts on the landforms of the project area have not been made, owing to the aesthetic nature of potential impacts. Therefore, assessment in this section is based on qualitative judgements taking into account the sensitivities of the sites concerned and the magnitude and duration of the construction works proposed.

13.2.2 Issues to be Addressed

13.2.2.1 Construction

Landform impacts will take place primarily where new ground disturbances occur as follows:

- New wellpads and the spine line RoW/access way along the Hides Ridge.
- The Homa to Idauwi access way. Large cut and fill volumes will be required, notably in the section along valley walls and ridgelines between the Maruba and Pawgano river valleys.
- The section of new road up the escarpment from the Mubi River to Kantobo required to be built by the project.
- New quarries and borrow pits.

For most of the project area, advantage will be taken to the maximum extent practicable of existing pipeline RoWs, with little major additional earthworks.

Landform impacts will take two forms: the excavation and placement of fill as part of the earthworks design and the subsequent deposition of material from active construction sites and areas under regrowth.

13.2.2.2 Operations

There are no major excavations or bulk earthworks proposed during operations. Therefore, there are no issues relating to residual impacts on local landforms.

13.2.3 Mitigation and Management Measures

Civil works can generally be accomplished more quickly and at less cost by limiting landform changes, and this is the project's primary pipeline and access way route selection and design objective. For the PNG Gas Project, the main proposed mitigation measures related to landforms are as follows (see also Section 3.3.3):

- Use of existing RoW and access ways for pipelines, roads and wellpads to the maximum extent practicable.
- Routing pipelines and access ways along ridgelines in preference to side slopes.
- Where practicable, avoiding steep slopes.
- Where practicable, avoiding swamps and wetlands.
- Where practicable, avoiding high erosion- or landslide-prone areas.

13.2.3.1 Construction

Many of the standard operating practices involved in pipeline RoW and road works construction activities include the implementation of mitigation measures that can reduce impacts on landforms and other areas (e.g., soil and water quality), including:

- Implementation of appropriate drainage control measures (e.g., ditch drains and culverts), where required.
- Implementation of appropriate site-specific erosion control measures along the pipeline RoW/access ways, such as terracing or grading of slopes, and at facilities sites, where required.

In addition, the following mitigation and management measures that reduce landform impacts have been included in the project design:

- In general, limestone in the project area makes for good road-base material and will be used in lieu of quarried material within reasonable haulage distances.
- Facility sites. The new Hides Production Facility and the Kutubu Central Gas Conditioning Plant will require a level site, but both sites will be designed to reduce earthwork volumes and hence overall landform impacts.
- Quarries. Some new quarries will be needed, but for most of the length of the construction access way, existing quarries set up for the Kutubu Petroleum Development Project will be able to be extended to supply road-making material and concrete aggregate.
- Drilling sites and wellpads:
  - Wellpads will be individually located and designed to provide for safe, efficient and economic operations. This generally has the effect of reducing the extent of vegetation clearing and earthworks. The need for individual wellpads for each well will be avoided where practicable by enlarging wellpads to accommodate two or more wells.
  - Wellpads require a level area paved with limestone. The area cleared will be the minimum extent practicable as required to safely and efficiently drill and complete the wells.
  - Like roads and access ways, the landform impacts of wellpads depend entirely on the terrain in the area, which in turn depends on the location. Some flexibility exists in the siting of individual pads, but within the overall constraints imposed by the requirement to efficiently develop the reservoir. (See also the discussion in Section 3.4.3 regarding the feasibility of developing the Hides gas field by drilling from adjacent valleys rather than the ridge).
- Rehabilitation in selected parts of the unstable volcanic terrain between the Maruba and Pawgano rivers in order to accelerate ground stabilisation.
- Providing a new construction access way that by-passes the steep section of the existing crude oil pipeline RoW/access way between the Mubi River and Kantobo.

13.2.3.2 Operations

There are no major excavations or bulk earthworks proposed during operations. Therefore, no mitigation or management measures are proposed.

13.2.4 Residual Impact Assessment

13.2.4.1 Construction

The landform impacts associated with the construction earthworks will be locally very high, but within the site spatial scale classified as 'very limited' (i.e., less than 200 m radius). The total volume of excavated material is estimated to be approximately 9 million m^3.

The project's estimate for construction phase earthworks is provided in Table 13.1.

Table 13.1 Estimated bulk earthworks and batter gradients along sections of the pipeline RoW/access way alignments in the project area

Section	Km	Earthworks (million m^3)		Batters H:V	Comments
Hides 1 to Hides 4 well	20	1.40	Cut	0.5:1 and 1:1	Spine line RoW/access way.
Hides 4 well to Hides Production Facility	6	0.41	Cut	1:1	Spine line RoW/access way.
Pipeline RoW from Hides Production Facility to Angore	13.2	0.37	Cut	1:1	New section.
Road from Hides Production Facility to Idauwi	20.0	0.20	—	1:1	Uses existing road.
Pipeline short cuts Angore to Homa	3.6	0.30	Cut	1:1	Avoids gradient constraints of a future public road.
Idauwi to Homa	54	2.98	Cut	1:1 and 0.5:1	Gas Agreement public road under construction.
Homa to Moro	38	0.27	Cut	1:1	Uses existing road.
Moro to Ridge Camp	12	0.09	Cut	1:1 and 0.5:1	Uses existing road.
Ridge Camp bypass	2	0.14	Cut	0.5:1	Gas Agreement public road.
Central Production Facility bypass	1.5	0.14	Cut	0.5:1	Gas Agreement public road.
Central Production Facility to Kantobo (KP55)	55	0.81	Cut	0.5:1 and 1:1	Uses existing road bench.
Kantobo (KP55) to Mubi River crossing	14.6	0.67	Cut	0.5:1 and 1:1	New gas pipeline follows existing crude oil pipeline RoW. A separate new Gas Agreement public road.
Mubi River crossing to Gobe intersection	18	0.20	Fill	2:1	Follows existing crude oil export pipeline RoW
Gobe intersection to Kopi	77	0.78	Fill	2:1	Uses existing crude oil export pipeline RoW.
Kopi to Omati landfall	33	0.15	Fill	2:1	New section of pipeline RoW.

Notes: H = horizontal. V = vertical.

The implementation of appropriate mitigation measures can reduce construction impacts, but landform change is in fact the objective, and hence the inevitable consequence, of the earthworks. The single most important mitigation measure is the same as the project's overall engineering objective — that is, limiting bulk earthworks.

The effects that follow earthworks themselves – slope failures, erosion and sedimentation – will occur on some areas, but with decreasing frequency as time passes and disturbed areas revegetate, consolidate and stabilise. All of these effects mimic natural geomorphological processes occurring in the area to a degree:

- Landslides are a feature of the steeper parts of the project area.
- Landslides, in turn, create a source of unconsolidated material in most catchments, with erosion and fluvial sediment transport in overland flow during rainstorms, and sediment delivery to watercourses and sediment deposition as flow rates fall.

Earthworks locally and temporarily accelerate these geomorphic processes that influence local landforms. The water quality, aquatic ecology and biodiversity implications of these landform impacts are discussed in Sections 13.5.4, 13.6.4 and 13.7.4, respectively. Residual impacts on local landforms are assessed for three areas of major earthworks, which are discussed below.

Hides Ridge Spine Line

The spine line RoW/access way along the Hides Ridge requires the removal of limestone pinnacles, cutting about 1.4 million m^3 of which 1.2 million m^3 is expected to be sidecast and 0.2 million m^3 used for fill. The ridgeline route of the spine line RoW/access way reduces the amount of cut and fill required compared to a route along the side slopes.

Construction areas and spoil along the spine line RoW/access way are unlikely to be exposed to extensive erosion or landslides: areas of fill will be compacted, and the limestone rubble will form a blocky scree slope. Some spoil (mainly limestone scree mixed with soil) may be sidecast into sinkholes that are greater than 50 m vertical depth, where most of the material is expected to hang up on the side-slopes with little material reaching the base. Potential sidecast spoil impacts are difficult to mitigate safely and effectively and construction earthworks will damage a limited number of shallow (less than 50 m deep) sinkholes. An examination of LIDAR topographic imagery indicates there may be up to 46 sinkholes or dolines near the proposed route of the Hides spine line that may be affected by sidecast spoil (see Section 13.7.4). Not all the sinkholes potentially affected by earthworks will be, and so some 90% of the sinkholes either side of the spine line on the Hides Ridge should remain intact. Not all of these potentially affected will contain sinkhole swamps.

In summary, the landform impact of spine line RoW/access way construction on the Hides Ridge meets the impact assessment criterion of ‘very limited’ for spatial scale but ‘long term’ for temporal scale.

Homa to Idauwi Public Road Alignment

The Homa to Idauwi public road crosses areas of active landslides and erosion, particularly when crossing the southward-flowing rivers that drain the Doma Peaks. The proposed 14-km-long road section between the Pawgano and Maruba rivers requires large cuts through the readily erodible soils of the Kerewa volcanics and the management of large volumes of spoil (about 1.6 million m^3 as cut to spoil). The road and gas pipeline RoW cuts will be restricted to a 15 m maximum height consisting of a maximum of two benches, and these sections will constitute the most obvious landform impact.

As far as spoil sidecast areas are concerned, the angle of repose of the sidecast material will parallel that of the original slope, which has a gradient of about 45%. The residual impact on this landform meets the residual impact assessment criteria of 'limited' for the spatial scale and 'long term' for the temporal scale.

The remaining 40-km-long section of the access way alignment from the Maruba River to Idauwi crosses gentler terrain with fewer cuts and lower sidecast spoil volumes (about 0.4 million m^3 as cut to spoil).

Mubi River to Kantobo

The landform impact in this section will be mainly in the cut required to create the access way bench, with major losses of mainly competent limestone rubble to sidecasting, but only minor erosion. The residual impact on landforms in this area meets the impact assessment criteria of 'very limited' for the spatial scale (within 200 m) and 'long term' for the temporal scale.

Recovery Potential

The physical alteration of landforms will be long term in nature but the perceptions of landform impacts will be reduced as disturbed soils and sidecast spoil material stabilise and vegetation re-establishes itself (see Section 13.3.3).

13.2.4.2 Operations

During operations there are no major excavations, bulk earthworks or quarrying proposed. Therefore, the project will not have any direct impacts on landforms or indirect impacts on geomorphological processes that influence landforms during operations.

13.3 Soils

This section presents impact assessment criteria (Section 13.3.1) and addresses the principal issues (Section 13.3.2), proposed mitigation and management measures (Section 13.3.3) and residual environmental impacts of project construction and operations activities (Section 13.3.4) on the soils of the project area. Various references to rehabilitation, revegetation and regeneration are made. These terms are clarified as follows (see also Chapter 19, Glossary):

- Revegetation: The re-establishment and development of a plant cover by either natural or artificial means. *Natural revegetation* (also called passive revegetation) takes place without intervention and *active revegetation* takes place with intervention using artificial means, such as ground preparation, fertilisation, seeding or seedling planting.

- Rehabilitation: The measures and actions used to repair land disturbed by project construction or operations activities. Repairing does not necessarily imply restoring project-disturbed areas to their original states, which is seldom possible and not necessarily desirable.

- Regeneration: The natural process by which plants within vegetation communities reproduce (either by seed or vegetatively) so that new individuals grow to replace the older plants when they die.

13.3.1 Residual Impact Assessment Criteria

The spatial and temporal classification of project-related residual impacts on soils follows those for the terrestrial environment outlined in Sections 13.1.1 and 13.1.2.

Operational definitions of the intensity of residual impacts on soils are as follows:

- Negligible: Soil disturbance and displacement are highly localised to construction sites. Sidecast spoil volumes are very low. The propensity for surface erosion is very low and revegetation can occur by natural processes without intervention.
- Minor: Soil disturbance and displacement are localised to within 50 m of construction sites. Sidecast spoil volumes and the propensity for surface erosion are low and revegetation can occur by natural processes without intervention.
- Moderate: Soil disturbance and displacement may occur up to 100 m from construction sites. Sidecast spoil volumes are moderate. The propensity for surface erosion is moderate and revegetation can occur by natural processes, but may require some intervention (i.e., rehabilitation) to control and limit surface erosion.
- Major: Soil disturbance and displacement may occur up to 200 m from construction sites. Sidecast spoil volumes are high. The propensity for surface erosion is high and rehabilitation is required to expedite the establishment of a suitable vegetation cover to control and limit surface erosion.

13.3.2 Issues to be Addressed

13.3.2.1 Construction

The principal soil issues associated with the construction of pipeline RoWs/access ways and project facilities relate to:

- Soil disturbance or displacement (including spoil sidecasting).
- Erosion of disturbed soil either by surface runoff or mass movement.
- Efficacy of natural and active revegetation of completed works areas, including sidecast materials, to consolidate and stabilise soils to limit surface erosion.
- Increased risk of soil contamination from fuels, oils and chemicals due to increased transport, storage and handling of these materials during construction, and from small-volume drilling fluid releases.

13.3.2.2 Operations

During operations, construction-disturbed soils and sidecast materials are expected to continue to stabilise progressively as vegetation is re-established naturally or by active intervention (see below). Land disturbances during operations are anticipated to be infrequent and limited in extent and, therefore, residual impacts to soils will be negligible (not significant) to minor.

The main issues relating to soils during operations are anticipated to be limited to the mass movement of construction-generated sidecast material by earthquakes. Impacts to soils during operations could also occur as a result of small leaks or spills of liquid hydrocarbons, fuels, lubricants, and chemicals, as well as releases caused by (highly unlikely) accidents (e.g., liquid hydrocarbons pipeline rupture, fuel tank failure, fuel tanker rollover).

13.3.3 Mitigation and Management Measures

13.3.3.1 Construction

Mitigation to limit soil erosion and soil loss is inherent in many of the pipelines, roadworks and facilities design features, which are summarised below:

Pipeline RoW/Access Way Route Selection and Alignment

- Where practicable, pipeline RoW/access way alignments will avoid erosion-prone areas.
- Where practicable, the pipeline RoW/access way alignments will be routed to avoid midslope locations in favour of higher, flatter areas, such as ridge tops and spurs, which reduce cut and fill requirements and the volume of spoil requiring sidecasting.
- Where practicable, ridgetop pipeline RoW/access way alignments will be located to avoid headwalls at the source of tributary drainages. Headwall areas are prone to erosion.
- Where practicable, the routing of pipeline RoW/access way alignments will avoid inner valley gorges (the very steep slopes adjacent to streams), as these are areas of high landsliding incidence.
- Where practicable, valley-bottom access way alignments will be located so as to provide a buffer strip of natural vegetation between the access ways and streams.
- The number of watercourse crossings will be reduced, consistent with the above considerations, to limit riparian soil erosion and sediment delivery (i.e., soil loss) to watercourses.

Watercourse Crossings

- Where practicable, the pipeline RoW/access way alignment approaches to watercourses will be kept as close to right angles as possible to limit soil disturbance on the banks of watercourses.
- Watercourse crossings will be designed and constructed so that they will not divert flow out of the watercourse channel and into the pipeline RoW/access way alignments.
- Provisions for vegetative or mechanical stabilisation will be made in areas where cut and fill erosion could cause elevated soil loss or sediment delivery to land and water.

Facility Construction Sites

- The area of land (and therefore soil resource alienated) required for constructing facilities will be reduced to the extent practicable. Plant-type facilities associated with the project will be constructed on existing facility sites for the most part. Therefore new soil disturbances associated with project facilities will be limited.

- Construction facilities will be designed to limit soil erosion. Runoff will be diverted to undisturbed vegetated land to encourage infiltration and reduce soil loss (sediment delivery) to watercourses.

- Where practicable, uncontaminated surface runoff will be intercepted by installing diversion drains to route such runoff around facilities and away from construction areas.

In addition to the design mitigation measures outlined above, the project will implement appropriate soil erosion and soil loss prevention mitigation and management measures where required, which are summarised below for different project construction areas and sites.

Pipeline RoW/Access Way Construction

- Erosion-prone areas will be protected by intercepting and redirecting rainfall runoff to stable, vegetated land for natural infiltration.

- Where practicable, soil, mulch and discarded vegetation debris (including natural seed stock) will be spread on reclaimed or rehabilitated disturbed land surfaces to facilitate natural revegetation.

- The pipeline RoW/access way alignments will be periodically inspected and erosion and sediment control structures will be maintained until adequate soil stabilisation has been achieved.

Facility Construction Sites

- Where practicable, topsoil will be stripped and stockpiled separately in designated topsoil stockpile areas at facility construction sites for later reuse.

- Vegetation will be re-established on earth batter slopes (where present) surrounding construction facility sites as soon as is practical after reinstatement earthworks in order to stabilise exposed soils.

- Retaining walls, where required, will be designed with to ensure sufficient drainage and distribution of stormwater to reduce erosion.

Watercourse Crossings

- Specific plans will be developed for watercourse-crossing construction sites that address watercourse diversions, disturbance limits, equipment limitations and erosion control measures.

Access Way Maintenance

The project's responsibility for access way maintenance is defined under the Gas Agreement. Subsequent maintenance will be undertaken by the PNG Department of Public Works for those access ways that will become public roads.

- Access way surfaces will be graded and shaped to conserve existing surface materials, without compromising the design drainage of the access way.

- During the construction period, access way maintenance checks will be conducted and problem sites will be corrected promptly.

- Access way surface drainage structures and culverts will be periodically checked for integrity.
- Access ways will be periodically graded during the construction period to maintain stable surfaces, and ditches, drains and culverts will be kept free of materials sidecast by surface graders.

Production Facility Site Maintenance

- Periodic site maintenance checks of earth batters will be conducted, especially after prolonged periods of rain or exceptionally high rainfall events.
- Surface water runoff controls and diversions will be checked periodically to assess their integrity and stability.

Soil Contamination Mitigation

- Procedures will be developed and implemented for the safe handling, transport, storage and disposal of fuels, oils, drilling fluids, chemicals and special wastes, which will include:
  - Design measures including impervious bases and bunds.
  - Measures for the control of refuelling activities to guard against spillages.
  - Site-specific plans and procedures for emergency planning and response.
  - Drilling fluids handling systems at drill sites to prevent spillages onto adjacent land and soils as described in Section 6.5.2.
  - Provision of appropriate spill response equipment at construction sites, and at fuel storage and handling facilities.

Rehabilitation

Following the completion of the pipeline RoW/access way construction activities, most areas of disturbed and displaced soils are expected to stabilise through natural revegetation, which generally occurs rapidly in the project area (see Section 9.6). The re-establishment of vegetation will reduce the rate of soil loss to background levels at a pace principally determined by whether the disturbed surface is soil- or limestone-dominated (see Tables 9.20 and 9.21 in Section 9.6).

Natural revegetation on soil-dominated surfaces (e.g., disturbed soil, limestone scree mixed with soil, and sidecast spoil material) was found to be rapid and comprehensive following construction of the crude oil export pipeline RoW and the access ways for the Kutubu Petroleum Development Project (Rogers, 2005; Hartley, 1991; Gillison, 1990; NSR, 1990a). Table 9.20 in Section 9.6 summarises natural revegetation times on soil-dominated surfaces. Plate 13.1 presents a series of photographs taken between 1991 and 2005 where the existing Kutubu crude oil export pipeline RoW/access way descends the Iwa Range down to the Ai'io River valley. This section required a long bench cut established by spoil sidecasting. By 1996, pioneer and primary forest trees up to 8 m high had naturally established themselves on the sidecast material downslope of the bench, with forest regrowth being well established after fourteen years (May 2005). Plates 13.2 to 13.5 show similar regrowth sequences at other locations along the crude oil export pipeline RoW.

In general, natural revegetation on limestone-dominated surfaces, including limestone rubble, has been found to be slow and less successful. Disturbed areas of this type had little or no vegetation on them or were revegetating very slowly in comparison with soil-dominated surfaces. Plate 13.6 and Table 9.21 in Section 9.6 show poor natural revegetation on hard limestone pavement after about 10 years following excavation. Similarly, Plate 13.7 shows poor natural revegetation on limestone rubble along the existing road to the Moran oil field.

The following management implications may be drawn from the above findings:

- Sections of completed pipeline RoWs that are not required for access ways will be allowed to revegetate naturally and will do so vigorously where soil-dominated surfaces are present.
- Sections of completed pipeline RoWs that are not required for roads will be decommissioned and, if needed, their surfaces will be ripped and/or soil added to facilitate natural revegetation where limestone-dominated surfaces are present.
- The pattern of natural revegetation after disturbances associated with existing petroleum developments in the project area suggests that — apart from exposed compacted or pavement limestone — special topsoil or subsoil handling measures are not generally required and that the same construction earthworks methods used to build the earlier Kutubu crude oil export pipeline, including the sidecasting of spoil, are appropriate (see 'Topsoil Management' below).
- Sections of compacted or pavement limestone that are not required for the access way itself, or for the stability of access ways or the buried pipelines, will be ripped and/or mixed with soil or unconsolidated spoil material to facilitate natural vegetation re-establishment.
- The completed works areas on the Hides Ridge will be inspected and areas of limestone-dominated surface will be considered for active revegetation.
- To accelerate ground consolidation and stabilisation downslope of spoil sidecast areas in steep and unstable volcanic terrain, the completed works areas between Idauwi and Homa will be inspected and locations will be selected for active revegetation.

The analogue of the existing oilfield developments suggests that all other areas of the pipeline RoW will adequately revegetate naturally. Active revegetation measures will be implemented where necessary.

Topsoil Management

In general, the temporary stockpiling of topsoil separately from subsoil and its subsequent respreading on reclaimed or rehabilitated construction-disturbed surfaces is a standard operating procedure to facilitate natural vegetation re-establishment. For the PNG Gas Project, topsoil management will occur at watercourse crossings and at the construction sites of the production facilities and potentially on other construction-disturbed areas on flat or shallow-gradient land. However, along the pipeline RoW/access way alignments, topsoil will not be separated from subsoil for the following reasons:

- If topsoil were to be separated from the subsoil, an extra 3-m width must be cleared on the pipeline RoW to accommodate the area required for the temporary stockpiling of topsoil. All trees, shrubs and other vegetation would be required to be cut down in the area designated for topsoil stockpiling. Over the entire route of the proposed pipeline RoW/access way alignments, this would require the additional clear cutting of an extra 1 million m^2 of terrain for the temporary stockpiling of topsoil, which presents an unnecessary removal of vegetation, and an additional source of soil erosion.

- Supporting Study 11 indicates that the top 40 cm of soil provides a soil seed bank that will facilitate natural revegetation of construction-disturbed and cleared sites. Where it is not practicable to temporarily store topsoil, subsoil spread over reclaimed construction-disturbed land surfaces can provide a suitable substratum for vegetation re-establishment.

In those cases where topsoil and subsoil are intermixed, the seed bank will still be present. Given the high propensity for natural revegetation on soil-dominated surfaces (see above) in the project area, the mixing of topsoil and subsoil is not regarded as a hindrance to successful natural revegetation.

Overall, the segregation of the topsoil cleared from the pipeline RoW/access way alignments from subsoil is not required to achieve successful natural revegetation of construction–disturbed or displaced soils, including sidecast spoil material. Topsoil mixed with subsoil, as a rehabilitation medium, is expected to foster and allow rapid natural revegetation.

13.3.3.2 Operations

There will be less potential for soil impacts during the operations phase, save for the potential for soil contamination through minor operational spillages of fuels, oils and chemicals. The mitigation and management measures outlined above for the construction phase are also applicable during the operations phase.

Potential soil contamination by larger accidental spillages of fuels, oils and chemicals through traffic accidents or a rupture of the Hides natural gas liquids pipeline between the Hides Production Facility and the Kutubu Central Gas Conditioning Plant would be managed in accordance with the project's spill response procedures, that which will be developed before the commencement of operations and which will be detailed outlined in the Operations Phase Environmental Management Plan (see Chapter 18).

13.3.4 Residual Impact Assessment

13.3.4.1 Construction

The assessment of residual impacts on soils during and after construction has the advantage of the known situation related to the construction earthworks associated with the existing oil and gas developments in the project area and, therefore, the areas of impact and recovery times can be estimated with some confidence.

The temporal classification of residual impacts on the terrestrial environment outlined in Section 13.1.2 does not suit an assessment of the impacts on soils, which rapidly revegetate naturally nor does it suit the fact that implementation of appropriate mitigation measures will accelerate vegetation re-establishment where this is naturally slow. For soil impact and recovery periods only, the temporal classification of residual impacts is as follows: short term (pre-vegetation re-establishment), medium term (post-vegetation re-establishment) and long term (regeneration).

During land clearing and construction activities, soil will be disturbed, displaced or compacted and there will be fugitive soil losses downslope and to watercourses at most construction works areas. Residual impacts related to soils after post-disturbance mitigation and management measures have been implemented are assessed below.

- *Shallow-gradient sections of pipeline RoW/access way alignments.* Ground disturbances and soil impacts will be limited to construction areas, and immediate areas and completed works areas will naturally revegetate. Residual impacts on soils, soil erosion and soil loss are therefore expected to be minor in the short term and negligible (not significant) in the medium to long term.

- *Steep-gradient karst terrain sections of pipeline RoW/access way alignments.* Along these portions of the alignments (steep descent from the Iwa Range to the Ai'io River and the section between KP55 and the Mubi River), residual impacts on soils, soil erosion and soil loss are predicted to be major in the short term. In the medium term, soil impacts will progressively decline through natural revegetation processes to become minor, then negligible (not significant) as natural revegetation and regeneration takes hold in the longer term.

- *Steep-gradient sections of pipeline RoW/access way alignments with readily erodible volcanic soils.* Along these portions of the alignments (sections between the Pawgano and Maruba rivers), residual impacts on soils, soil erosion and soil loss are predicted to be major in the short term. In the medium term, soil impacts will progressively decline through active revegetation processes to become minor, then negligible (not significant) as natural revegetation and regeneration takes hold in the longer term.

- *Pipeline RoW/access way alignments along the existing crude oil export easement.* Between the Kutubu Central Gas Conditioning Plant and Kopi, much of the sales gas pipeline RoW will follow the existing crude oil export pipeline easement and/or the existing Kutubu to Kopi road. These works will be in or adjacent to the footprint of existing facilities. Therefore, residual impacts on soils are expected to be minor in the short term, falling quickly to negligible (not significant) in the medium to long term.

- *Hides Ridge Area.* The Hides spine line RoW/access way alignment will follow the ridgeline of the Hides Range, where the predominant terra rossa soils are very thin. Construction of the RoW/access way will involve highly localised ground disturbances in this high-altitude, steep karst terrain. The project will implement site-specific mitigation and management measures to limit the amount of sidecast material entering shallow sinkholes (especially those that are permanently water-filled), and sidecast limestone rubble or scree will be mixed with soil to re-establish vegetation and ground cover. After the application of these mitigation measures, the residual impacts on soil erosion and soil loss are expected to be moderate in the short term, falling to negligible (not significant) in the medium term or longer.

- *Pipeline RoW/access way alignments across swamps and wetlands.* Portions of the alignments will traverse coastal swamplands between Kopi and the Omati River landfall location for the sales gas pipeline and alluvial swamps in the floodplains of the Kikori and Mubi rivers. Residual impacts on soils in these depositional environments are expected to be minor in the short term, falling quickly to negligible (not significant) in the medium to long term.

- *Other project construction works areas and quarries.* Like the Kutubu to Kopi section of the sales gas pipeline RoW, these works will be in or adjacent to the footprint of existing facilities. Residual impacts on soils are therefore expected to be minor in the short term, falling quickly to negligible (not significant) in the medium to long term. For new quarries, the short-term residual impacts will be moderate, again falling to negligible (not significant) in the medium to long term. In the case of the proposed new Hides Production Facility, which is located on shallow-gradient terrain, residual impacts on soils are predicted to be minor in the short term, falling quickly to negligible (not significant) in the medium to long term.

- *Soil contamination by fuels, hydrocarbons, drilling fluids or chemicals.* Residual impacts of minor operational spillages after appropriate mitigation measures have been implemented are expected to be negligible (not significant) in the short term and longer, given the small volumes of liquids likely to be involved and the immediate post-spill application of appropriate clean-up procedures. Similarly, the residual impacts on soils associated with drilling fluid spillages at drilling sites are expected to be negligible (not significant) in the short term or longer given the mitigation and management measures that would be implemented.

13.3.4.2 Operations

No major excavations or bulk earthworks are proposed during operations.

Construction areas will be progressively revegetated either by natural or active revegetation (where required), and so impacts on soils during the operations phase will be limited to potential small operational spillages of fuels, hydrocarbons or chemicals. Procedures to prevent such spillages are intended to ensure that residual soil contamination impacts will be negligible (not significant) in the short to long term.

Pipelines and facility safety and security systems (see Section 2.5.4) will be implemented to isolate the occurrence of larger spills of fuels (e.g., fuel tanker accidents) or the accidental release of liquid hydrocarbons. Soil impacts from such incidents will be managed by the implementation of spill response procedures, which will be a component of the project's Operations Phase Environmental Management Plan (see Chapter 18).

13.4 Water Resources and Hydrology

This section addresses the impact assessment criteria (Section 13.4.1), principal issues (Section 13.4.2) and proposed mitigation and management measures (Section 13.4.3), and discusses residual environmental impacts of project construction and operations activities (Section 13.4.4) relating to water resources and hydrology.

13.4.1 Residual Impact Assessment Criteria

The spatial and temporal classifications of project-related residual impacts on water resources and hydrology follow those for the onshore aquatic environment outlined in Sections 13.1.1 and 13.1.2 above.

Definitions of significance criteria for assessing the residual impacts on water resources and hydrology of the project area are provided below so that statements regarding the nature of an impact have a precise meaning.

13.4.1.1 Significance Criteria for Residual Impacts on Water Yield

Water yield is the amount of surface runoff and groundwater flows that enter a watercourse or water body. Four residual impact assessment criteria have been defined to assess project-related residual impacts on water yield:

- Negligible: Basically unchanged water yields (less than 10% deviation); indistinguishable from the pre-disturbance range of fluctuations in surface runoff and/or groundwater flows.
- Minor: Deviation in water yields between 10% and 25% of the pre-disturbance range of fluctuations in surface runoff and/or groundwater flows.
- Moderate: Deviation in water yields between 25% and 50% of the pre-disturbance range of fluctuations in surface runoff and/or groundwater flows.
- Major: Deviation in water yields greater than 50% of the pre-disturbance range of fluctuations in surface runoff and/or groundwater flows.

13.4.1.2 Significance Criteria for Residual Impacts on Stream Flow

Stream flow is defined as the volume of water over time present in a flowing watercourse. Four residual impact assessment criteria have been defined to assess project-related streamflow impacts:

- Negligible: Basically unchanged flow volumes (less than 10% deviation); indistinguishable from the pre-disturbance range of flows or hydrological conditions.
- Minor: Deviation in flow volumes between 10% and 25% of the pre-disturbance range of flows or hydrological conditions.
- Moderate: Deviation in flow volumes between 25% and 50% of the pre-disturbance range of flows or hydrological conditions.
- Major: Deviation in flow volumes greater than 50% of the pre-disturbance range of flows or hydrological conditions.

13.4.1.3 Significance Criteria for Residual Impacts on Bed Sediment Loading

Bed sediment loading is the amount of coarse-grained sediment material that travels along the bed of a watercourse. Four impact assessment criteria have been used to assess project-related residual impacts on bed sediment loading:

- Negligible: Basically unchanged bed sediment loading; indistinguishable from the pre-disturbance range of bed sediment loading, where the sediment-carrying capacity of the receiving watercourse is able to transport all delivered coarse sediments downstream.
- Minor: Deviation in bed sediment loading not greater than 10% of the pre-disturbance range of bed sediment loading, where the sediment-carrying capacity of the receiving watercourse is able to transport 90% of delivered coarse sediments downstream.
- Moderate: Deviation in bed sediment loading between 10% and 50% of the pre-disturbance range of bed sediment loading, where the sediment-carrying capacity of the receiving watercourse is able to transport between 50% and 90% of delivered coarse sediments downstream.
- Major: Deviation in bed sediment loading greater than 50% of the pre-disturbance range of bed sediment loading, where the sediment-carrying capacity of the receiving watercourse is able to transport less than 50% of delivered coarse sediments downstream.

13.4.1.4 Significance Criteria for Residual Impacts on Suspended Sediment Loading

Suspended sediment loading refers to the amount of fine sediments carried in suspension in the water column of a watercourse or water body. Residual impact assessment criteria are not presented for suspended sediment loading as this situation, by its nature, cannot exceed the sediment-carrying capacity of the watercourse or waterbody. However, residual impact assessment criteria for suspended sediment concentrations (rather than loads) are presented in Section 13.6.1 (Aquatic Ecology), since increased suspended sediment concentrations in watercourses or water bodies can affect the well-being of aquatic organisms.

13.4.2 Issues to be Addressed

13.4.2.1 Construction

Construction activities can generally lead to the following effects on water resources and hydrology:

- The clearing of vegetation from land required for construction activities may lead to changes in the local pattern of runoff and water yield, which may affect water availability and streamflow regimes.
- Water abstraction for project requirements, such as camp water supplies, civil engineering works, production facility process waters and hydrotest waters, which may affect water availability and streamflow regimes.
- The discharge of treated hydrotest waters, which will transfer large quantities of water from one location to another, has the potential to affect the streamflow regimes of local watercourses, depending on their size.

- Construction activities may expose readily-erodible surficial materials to rainfall-based erosion and scour, resulting in coarse and fine sediment delivery via overland flow (i.e., surface runoff) to watercourses and water bodies, which may change the magnitude, timing, or duration of sediment transport through changes in bed and suspended sediment loads.
- Changes in channel morphology via the construction of the Omati River landfall for the sales gas pipeline and watercourse crossings for pipelines and access ways may disturb river or stream beds and cause changes in aggradation by in-stream sedimentation or degradation caused by scouring.

13.4.2.2 Operations

During operations, the only major issue associated with water resources and hydrology is the need to confirm that water abstraction and wastewater discharges do not adversely affect water resource volumes and water availability to other users. This will be determined via the proposed environmental management, monitoring and reporting program (see Chapter 18). All wastewater discharges will need to conform to the requirements of waste discharge permits.

13.4.3 Mitigation and Management Measures

13.4.3.1 Construction

Water Yield

No specific mitigation or environmental management measures are considered necessary to reduce impacts on water yields during the construction period, owing to the small project footprint and the anticipated limited impacts on surface runoff and groundwater flows.

Water Abstraction

The abstraction of water from watercourses or groundwater sources for project purposes will be governed by the conditions included the relevant water abstraction permits, which are intended to ensure that an adequate water supply is available both for project purposes and local people. Therefore, no additional mitigation or management measures related to water abstraction are proposed.

Hydrotest Water Discharges

The discharge of hydrotest waters during pipeline integrity testing may augment flow volumes in small streams, if they were to receive such flows directly or via their catchments. However, the discharge of hydrotest waters will be either to retention ponds for treatment (if required) and then to land surfaces via dissipators or directly to land surfaces via dissipators. The receiving watercourses will be the mainstems of the larger rivers in the project area or the process water system of the Kutubu Central Production Facility for one or two test pipeline sections. The disposal of hydrotest waters will be carried out in accordance with an engineering code of practice for system gauging, hydrotesting and disposal (ExxonMobil, 1998) and will need to meet all conditions set out in the relevant water discharge permits.

Channel Morphology

Appropriate channel morphology mitigation and management measures will be incorporated into the design of watercourse crossings, the Kopi wharf development and the Omati River landfall for the sales gas pipeline. Currently proposed mitigation and management measures are described below.

Watercourse Crossings

- At some watercourse crossings, where the watercourse is considered too large and fast-flowing for the use of conventional open-cut trenching methods, horizontal directional drilling methods will be used. This will avoid the direct disturbance of these watercourse beds and their channel morphologies.
- The construction of bridges, abutments and in-river bridge supports (where needed) will take into account the hydraulics of the watercourse in question in their design to ensure their long term stability. Such mitigation by design will limit localised scouring and aggradation.

Kopi Wharf Development

- The modified and new wharfs will be designed to parallel the existing frontage of the Kikori River, so that no interruptions to the direction of flow of the Kikori River are created.
- The design of the wharfs will take account of channel hydraulics and other physical and hydrodynamic characteristics of the Lower Kikori River that may affect the long-term stability of the river frontage.

Omati River Landfall

- Fluvial processes in the Omati River will be considered in the sales gas pipeline design to minimise the likelihood of pipeline exposure.
- At the completion of sales gas pipeline installation activities, the sheet piling of the temporary coffer dam that will be constructed into the lower Omati River may be removed or buried or cut off at river bed level to prevent the long term interruption of bed sediment transport processes and to reduce potential impacts on channel morphology due to aggradation (sedimentation) or degradation (scouring).
- The sales gas pipeline will be buried in the bed of the lower Omati River to protect the pipeline and limit interruptions to bed sediment transport processes that may alter channel morphology.
- If the sales gas pipeline becomes exposed in the Omati River, it will be reburied by jetting or other resources methods as appropriate.
- Inspections of physical conditions in the lower Omati River will be undertaken to monitor geomorphic processes and identify areas which that require maintenance.

Limiting Sediment Delivery to Watercourses

Appropriate mitigation and management measures will be implemented where necessary to limit soil erosion and sediment delivery to watercourses. In this regard, the mitigation and management measures outlined in Sections 13.2.3 (Landforms) and

13.3.3 (Soils) aimed at reducing soil erosion and downslope soil loss to land and water are pertinent since they would also serve to limit sediment delivery to watercourses. However, supplementary site-specific mitigation and management measures to further reduce sediment delivery to watercourses or water bodies have been identified to be warranted in three areas:

- The Hides Ridge Area. This includes the swamp habitats of permanently water-filled sinkholes.
- Lake Kutubu Catchment. Lake Kutubu is listed as a Ramsar wetland system due to its high level of fish endemism.
- Pawgano and Maruba Rivers. The proposed Homa to Idauwi public road alignment and twin rich gas and liquids pipelines RoW traverses steep terrain with readily-erodible volcanic soils in these river valleys.

Site-specific mitigation and management measures to limit hydrological and sedimentation impacts in these sensitive project areas are discussed below.

Hides Ridge Area

There are small pools or swamps at the bottom of some sinkholes along the Hides Ridge (see Plate 9.32 in Chapter 9). Sinkholes of this type are the only microhabitats where tree frogs and other water-dependent frogs can breed in high-latitude karst areas, which are characterised by few surface-flowing streams. These small pool and swamp microhabitats are recognised as high-value conservation areas (see Section 9.3.4).

The Hides spine line generally seeks to thread a ridgetop alignment between sinkholes and pinnacles, so as to limit bulk earthworks. However, the topography requires sidecuts and the sidecasting of spoil. The landform impacts on sinkholes will therefore depend in part on their depth. The evidence from existing earthworks on Hides (drillpads) suggests that sidecast limestone scree mixed with soil hangs up on the concave slopes of sinkholes and that spoil is unlikely to reach the bottom of sinkholes that are deeper than 50 m (Crome, pers. com., 2005). Natural revegetation of the settled scree and soil mix (Plate 13.8) has stabilised the scree slope and has helped to prevent further downslope migration of the sidecast materials (see Section 13.7.4.3).

Lake Kutubu Catchment

The Ramsar-listed Lake Kutubu has high water clarity and dependent high-value conservation resources (i.e., endemic fish species). The project proposes to implement the following site-specific mitigation and management measures (in addition to those described in Sections 13.2.3 and 13.3.3) to reduce sediment delivery to the lake's principal inflow streams:

- Active revegetation of exposed soil surfaces along certain sections of the existing Moro to Homa public road during road upgrading, especially within riparian areas, at watercourse crossings and along steeper sections (i.e., greater than 10% grade). Note that active revegetation will accelerate the re-establishment of natural vegetation on construction-disturbed, displaced or compacted soils and sidecast spoil more rapidly than the process of (unassisted) natural revegetation, even though the latter can stabilise soils in less than six months to one year (see Section 9.6).

- Periodic post-construction site inspections along the upgraded road/pipeline RoW within the catchment of Lake Kutubu, including:
  - Checking for problematic erosion sites and taking appropriate remedial action.
  - Inspections of ditches and culverts to remove accumulated debris.
- Reviewing feedback from water quality monitoring for advance warning of deteriorated water quality due to increased suspended sediment loading.

In general, regular inspection and maintenance will keep the pipeline RoW and road alignments in good condition and help identify and correct problems as they arise. Identification of problematic erosion sites along the pipeline RoW/access way alignments and undertaking appropriate remedial actions will serve to reduce coarse and fine sediment delivery to those streams in the catchment of Lake Kutubu. This process seeks to assure the protection of the aquatic habitats and water quality of Lake Kutubu in the long term.

Pawgano and Maruba Rivers Section of the Homa to Idauwi Public Road

Site-specific mitigation and management measures to limit surface erosion associated with sidecast spoil in the Pawgano and Maruba river valleys have already been described in Section 13.2.3 for landforms and geomorphological processes (e.g., erosion, soil loss and downslope sedimentation). In summary, the limitation of impacts to water resources and hydrology in this area is to be achieved by active revegetation of sidecast spoil as needed along this steep section of the public road to accelerate the re-establishment of natural vegetation.

13.4.3.2 Operations

No additional mitigation and management measures are proposed during operations related to water resources and hydrology, save for measures to ensure the integrity, security and maintenance of village water supplies, which will be included in the relevant permits for water abstraction and treated wastewater discharges.

13.4.4 Residual Impact Assessment

This section assesses the residual impacts of project construction and operations activities on water resources and hydrology, after the proposed mitigation and management measures described above have been implemented.

13.4.4.1 Construction

This section addresses project-related residual impacts on water yield, streamflow regimes, bed sediment loading, and suspended sediment loading attributable to construction activities.

Water Resources

Residual impacts on water yield at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer, owing to the very small area of land affected. Therefore, no significant changes in water availability or streamflow volumes are anticipated.

Individual environment (water abstraction) permits will be issued to the project for each water abstraction point and will contain conditions to ensure that an adequate water supply is available both for the intended project purposes and other beneficial uses of local villagers. Therefore, residual impacts related to water abstraction, water availability or streamflow volume at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer.

Hydrotest Water Discharges

Water for onshore hydrotesting will generally be drawn locally from nearby large rivers. The following abstraction and likely release points have been provisionally identified by the project: the Kikori River at the Kikori bridge crossing, the Wah River at the Wah bridge crossing, the Mubi River at the Mubi bridge crossing, and the Ai'io River at the pipeline crossing location. The Kutubu Central Production Facility may also provide a source of water for hydrotesting.

Table 6.2 in Section 6.4.4.2 presents the anticipated volumes of hydrotest water that may be discharged from the individual segments of the various pipelines to be pressure tested. The largest volumes are from the rich gas pipeline between the Hides Production Facility and the Kutubu Central Gas Conditioning Plant (25.3 million litres) and the section of the sales gas pipeline between the Central Gas Conditioning Plant and the Kopi Scraper Station (56.9 million litres). The reuse of hydrotest water from pipeline section to pipeline section will be investigated; if this is feasible, most of the volume will travel from the Hides Gas Field to the Kikori River at Kopi. The mean natural flow of the Kikori River at Kopi is estimated to be 2,378 m^3/s and, therefore, the discharge of hydrotest water is predicted to produce a 0.01% incremental increase in the river flow over a period of two and a half days.

The residual impacts of hydrotest water discharges on the flows of the major receiving rivers at the site scale or further afield are predicted to be negligible (not significant) in the short term and longer.

Watercourse Sediment Transport and Bed Sediment Loads

For predictive impact assessment purposes and based on empirical evidence from other road construction projects and subsequent impact assessment monitoring in Papua New Guinea (e.g., NSR, 1990a, 1999), soil and sediment particle sizes greater than 125 μm in diameter are assumed to report to watercourses as bed sediment load. Impacts on bed sediment loading will derive from the increased sediment delivery of coarse-grained sediments to watercourses.

During rainfall periods or significant storm events, coarse sediments from construction-disturbed sites are predicted to enter the natural drainage systems via overland flow following moderate to high rainfall events. These sediments will have been supplied largely from sidecast spoil materials and disturbed areas on catchment slopes. Additionally, coarse sediments are also expected to enter watercourses directly and report as bed load at locations immediately downstream of water-crossing and bridge construction sites, where riparian bank and watercourse bed disturbance will take place.

In general, where the sediment-carrying capacity of a stream is exceeded, deposition of coarse material is expected. This will tend to be characterised by highly localised but temporary sedimentation of the watercourse bed in close proximity to the sources of sediment production. However, subsequent rising flows and flood flows are expected to move and disperse most of these temporary deposits further downstream. This pattern of temporary sediment deposition followed by scouring and downstream sediment transport during flood flows is typical of road construction sites in tropical, high-rainfall climates.

Residual impacts on bed sediment loading at the site scale or further afield are predicted to be negligible (not significant) in the short term and longer for pipeline RoW/access way alignments on flat or shallow-gradient karst terrain, swamplands, floodplains, and at the construction sites of the production facilities, laydown areas, quarries and borrow pits, the Kopi wharf development and at the lower Omati River landfall location. However, sedimentation-related residual impacts are expected in those rivers draining steep terrain with readily erodible volcanic soils, which are discussed below.

Pawgano to Maruba Rivers Section Sediment Loading Residual Impacts

Estimates of the total areas disturbed and volumes of excavation, fill or sidecast spoil material likely to arise from the construction of the proposed new Homa to Idauwi public road are given in Table 13.2

Table 13.2 Areas disturbed and estimated volumes of material to be excavated or moved along the Homa to Idauwi public road alignment

Construction Activity	Unit	Proposed Homa to Idauwi Public Road Alignment
Clearing and grubbing	ha	150
Shredding timber	t	250
Embankment compaction	m^2	750,000
Cut to fill	m^3	900,000
Cut to spoil	m^3	2,000,000
Rock excavation	m^3	250,000*
Subgrade preparation	m^2	550,000
Embankment toe protection	m^2	55,000
Excavation of off-shoot drains	m^3	3,000

* Included in cut to spoil.

Table 13.2 indicates that construction of the Homa to Idauwi public road is expected to generate about 2.9 million m^3 of cut of which about 900,000 m^3 will be used for fill and the balance of about 2 million m^3 will be sidecast as spoil. However, most bulk earthworks (about 80%) along the proposed Homa to Idauwi public road will occur in steep terrain between the Pawgano and Maruba rivers (i.e., 1.6 million m^3 of cut to spoil material), while the Maruba River to Idauwi section is located in less steep terrain and will require much less extensive earthworks. Therefore, the residual impact assessment has been undertaken on the steep Pawgano to Maruba rivers section of the Homa to Idauwi access way, owing to the large amounts of cut required, the anticipated sidecasting of spoil, the presence of erodible volcanic soils, and a history of recent small landslides in this area.

Sediment Production and Delivery to the Pawgano and Maruba Rivers

Table 13.3 presents first-pass estimates of coarse- and fine-grained sediment delivery to the Pawgano and Maruba river systems from soil displacement and erosion of sidecast spoil in the first year following construction. More detailed analysis and information on assumptions and data limitations can be found in Supporting Study 12.

Table 13.3 Estimates of sediment production and delivery to the Pawgano and Maruba river mainstems during the first year following construction of the Homa to Idauwi public road

Access Way Segment	Access Way Statistics			Sediment Delivery*		
	Length (km)	Total Cut to Spoil (m3)	Spoil to River (%)	Total (Mt)**	>125 μm (Mt)	<125 μm (Mt)
Pawgano River catchment	10.5	1,200,000	20	0.40	0.25	0.15
Maruba River catchment	3.5	400,000	20	0.14	0.09	0.05

Notes: * Production in first year following construction. ** Conversion from volume to weight using a composite density factor of 1.75. Mt = million tonnes.

The total volumes of cut to spoil in the Pawgano and Maruba river catchments are 1.2 million m^3 and 0.4 million m^3, respectively. Approximately 20% of the sidecast spoil is predicted to enter the river systems during the first year following construction. This amount of material is less than the 50% value that was typically observed for the sidecast spoil on steep slopes produced during the construction phase of the Ok Tedi Gold Project, where the rainfall is about 8,000 mm per year; this is more than twice the annual rainfall amount in the Pawgano and Maruba rivers area (i.e., about 3,000 mm per year).

Particle size distributions of the anticipated side-cast spoil material to be produced are based on a borehole stratigraphic log (see Supporting Study 12). Side-cast spoil will be comprised mainly of volcanic soils, with a typical composition makeup of gravels (17%), sands (50%), silts (27%) and clays (6%).

During the first year following construction, the estimate of total sediment delivery to the Pawgano River system is 0.4 million tonnes, of which 0.25 million tonnes (65%) is expected to report as bed load material and 0.15 million tonnes (35%) as suspended sediment load material. The fate of the coarse sediments delivered to the watercourses is discussed below.

Fate of Coarse Sediments from Increased Bed Loading

The sediment transport capacities of the Pawgano and Maruba river mainstems is expected to far exceed the project's maximum initial construction and sidecast spoil-derived sediment inputs, owing to the steep gradients of these two rivers and their high water velocities.

Unless there is a significant landslip-induced load, it is expected the Pawgano and Maruba river mainstems will be able to readily carry all of the public road construction and sidecast spoil-derived sediment loads with only small and temporary zones of aggradation during flood recessions. Residual impacts on bed sediment loading in the Pawgano and Maruba river mainstems at the site scale (see spatial scales in Section 13.1.1) are predicted to be moderate in the short term and negligible (not significant) in the medium to long term. At the local scale, residual impacts are predicted to be minor in the short term and negligible (not significant) in the medium to long term. Residual impacts on the Hegigio River at the regional scale are predicted to be negligible (not significant) in the short term and longer, owing to the large sediment-carrying capacity of this receiving river.

Increased bed sediment loading may have consequential impacts on the aquatic habitats and aquatic flora and fauna of the project area (see Section 13.6.4).

Watercourse Sediment Transport and Suspended Sediment Loading

For predictive impact assessment purposes, soil and sediment particle sizes less than 125 μm in diameter are assumed to report as suspended sediment load. Residual project-related impacts on suspended sediment loading will derive from the increased sediment delivery of these fine-grained sediments to watercourses.

During periods of significant rainfall or storm events, fine sediments mobilised from construction-disturbed sites and sidecast spoil are predicted to enter the natural drainage systems either directly or via overland flow. These suspended sediments will augment resuspended sediments from the river bed due to the higher transport energy associated with increased stream flows. In addition, direct but highly localised project-related disturbances of riparian banks and stream beds will occur during the construction of watercourse crossings for access ways and pipeline RoWs, which will temporarily increase suspended sediment loads by mobilising fine sediments.

Most of the rivers and streams draining the upland catchment areas where new access ways are proposed to be built are steep and fast-flowing, and they are expected to transport all fine suspended sediments further downstream. Subsequent deposition in the lower reaches of the larger rivers, where gradients and water velocities are reduced, will augment bed load, with the finer particle sizes (e.g., less 20 μm) being transported to the Gulf of Papua as wash load.

In general, the strong trend based on previous studies of total suspended sediment loading in watercourses draining catchments affected by new road construction works (e.g., NSR 1991, 1992, 1993a, 1993b, 1994, 1995, 1997a) is that when appropriate erosion mitigation measures are employed where needed, increases in suspended sediment concentrations in receiving watercourses or water bodies are either small and non-persistent or difficult to detect because of natural variation in water quality data. Section 13.5.4 addresses residual impacts on water quality of increased fine-grained sediment loading.

Changes in Channel Morphology

Potential impacts on channel morphology mainly relate to the potential for scouring and resedimentation associated with landfall site construction activities, such as may occur at the Kopi wharf development and the Omati River landfall location.

Kopi Wharf Development

Section 2.3.5.2 outlines the modifications and new construction required to upgrade the existing wharf facilities at Kopi on the lower Kikori River. In summary, it is proposed to construct a new 30-m-long, steel and concrete barge wharf upstream of the existing main wharf (see Figure 2.13 in Chapter 2). This new wharf will be centrally located along the base's river frontage and will become the main wharf at Kopi. Additionally, the existing barge landing will be upgraded at the downstream end of the laydown area and will include in-river dolphins (mooring piles) for barge stationing.

Since the above-mentioned modifications and new construction works are to be located parallel or nearly parallel to the existing frontage of the Kikori River, no interruptions to the direction of the flow of the Kikori River are envisaged. Therefore, the residual impacts of wharf development at Kopi on river processes, such as flow modification, sedimentation, scouring and resedimentation, that can affect channel morphology at the site scale or further afield are predicted to be negligible (not significant) in the short term and longer. The design of the wharfs and the roll-on, roll-off barge ramp will take into account channel hydraulics and other physical characteristics that may affect the stability of the wharf's river frontage infrastructure.

Omati River Landfall Construction Activities

The residual impacts associated with the construction of a temporary coffer dam and the installation and burial of the sales gas pipeline within the bed of the lower Omati River on channel morphology have been assessed. Supporting Study 13 (Erosion and Sedimentation in the lower Omati River) provides a detailed impact analysis. Summaries of the likely residual impacts appear below.

- *Coffer Dam Construction.* The incursion of temporary sheet piling into the river channel will cause disruption of the flow pattern of the lower Omati River at the landfall site, leading to localised scour of the river bed and possible changes to the flow distribution of the adjacent tributary channel between the Omati and Newberry rivers. However, potential impacts on river processes that affect channel morphology will be limited by the short duration of the construction activities. Overall, residual impacts related to coffer dam construction on the channel morphology of the lower Omati River at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer.

- *Gas Pipeline Installation and Burial.* As indicated in Supporting Study 13, the buried gas pipeline is not likely to aggravate the Omati River's natural processes of aggradation, scour or flooding provided the pipeline remains buried in the river bed. Large scale, long-term processes of channel development and abandonment are ongoing in the lower Omati River and the Omati-Kikori delta, and these processes are unlikely to impact the buried pipeline. However, monitoring of the pipeline during operations will be undertaken to confirm that the pipeline remains buried. If the pipeline becomes exposed or spanning (caused by the removal of underlying unconsolidated sediments) occurs, the placement of grout bags, localised rock dumping or other means will be used to weigh down the pipeline. Overall, residual impacts of the buried gas pipeline on channel morphology in the lower Omati River at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer.

13.4.4.2 Operations

This section discusses residual impacts on water yield, streamflow regimes, and ongoing soil erosion and sediment production during operations.

During operations, residual impacts on water resources and hydrology will be significantly less than during construction.

Water Resources

No significant changes in surface runoff and water yields are expected in the catchments of the project area during operations, given the limited footprint of the constructed pipeline RoW/access way network and the small areas of plant site drainage. Water abstraction monitoring (predicted to be included in the conditions set out in water abstraction permits) will ensure that water resources used by local villagers are safeguarded. Therefore, residual impacts on water resources at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer.

Streamflow

No significant changes in the flow regimes of rivers and streams in the project area are expected during operations beyond that of natural variability. Altered streamflow regimes are not expected, given the absence of significant activities that could cause changes in surface runoff and water yield. However, consideration has been given (see below) to the volumes of operational wastewater discharges to the natural drainage systems.

Treated Sewage Effluent Discharges

Operational discharges of treated sewage effluent from existing sources (i.e., existing crude oil and natural gas projects) will continue for the long term, and new discharges will be associated with the Hides Production Facility. These existing and projected small volumes of discharged treated sewage effluent are expected to have a negligible (not significant) residual impact on the flow regimes of receiving watercourses. Such discharges will need to conform with to the requirements of waste discharge permits.

Produced Water

There will be no produced water discharges to surface waters attributable to the PNG Gas Project. All produced water from the processing facilities at Hides, Kutubu, Gobe, Moran and Agogo is or will be collected, handled and reinjected into produced water injection wells for reservoir pressure maintenance purposes.

Ongoing Soil Erosion and Sediment Production

After construction, natural or active revegetation of disturbed, displaced or compacted soils and areas of side-cast spoil is expected to stabilise soils and reduce their erosion potential. This will progressively reduce sediment delivery to watercourses to pre-disturbance levels. In general, rehabilitation of land cleared or disturbed by construction works has not been a significant issue with previous petroleum developments in the project area because of the vigorous natural regrowth processes. This recovery has been documented in this EIS (see Sections 9.6 and 13.2.3) and in the Environmental Plans prepared for the Kutubu Petroleum Development Project (NSR, 1990a) and the Gobe Petroleum Development Project (NSR, 1996). While small areas of problematic erosion may arise after intense storms or protracted heavy rainfall periods, such sites will be identified and appropriate remedial actions will be implemented to control and limit this erosion.

Overall, residual impacts associated with continuing coarse and fine sediment delivery to watercourses at the site scale or further afield attributable to the project are predicted to be negligible (not significant) in the short term and longer. This is substantiated by the results of the long-term water quality monitoring program that has been implemented for the Kutubu Petroleum Development Project (NSR, 1991, 1992, 1993a, 1993b, 1994, 1995, 1997a). This monitoring has revealed that there has been a general absence of elevated suspended sediment concentrations (and therefore suspended sediment loading) in monitored watercourses and Lake Kutubu during the operations phase of that project.

13.4.5 Residual Impacts Summary

Table 13.4 presents a summary of the residual impacts associated with the project on the hydrology of watercourses and water bodies in the project area during construction. The table highlights the fact that significant impacts on hydrology mainly relate to increased bed sediment loading and sedimentation of watercourses draining areas with steep terrain and readily erodible volcanic soils, particularly related to the construction of the Homa to Idauwi public road. Watercourses draining all other terrain types and construction sites are predicted to be subjected to negligible (not significant) impacts in the short term or longer. No significant residual impacts due to the project are predicted on the watercourses of the project area during the operations.

Table 13.4 Summary of residual impacts on the hydrology of watercourses in the project area during construction

Spatial Scale	**Site Scale (up to 2 km downstream)**			**Local Scale (between 2 km and 10 km downstream)**			**Regional Scale (greater than 10 km downstream)**		
Temporal Scale	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**
Bed sediment loading and sedimentation in watercourses draining:									
Shallow-gradient karst.	N	N	N	N	N	N	N	N	N
Steep-gradient karst.	N	N	N	N	N	N	N	N	N
Steep-gradient terrain with volcanic soils*.	Moderate	N	N	Minor	N	N	N	N	N
Lake Kutubu catchment.	N	N	N	N	N	N	N	N	N
Swamplands and wetlands.	N	N	N	N	N	N	N	N	N
Kopi wharf development.	N	N	N	N	N	N	N	N	N
Omati River landfall.	N	N	N	N	N	N	N	N	N
Changes in channel morphology of watercourses draining:									
Shallow-gradient karst.	N	N	N	N	N	N	N	N	N
Steep-gradient karst.	N	N	N	N	N	N	N	N	N
Steep-gradient terrain with volcanic soils*.	N	N	N	N	N	N	N	N	N
Lake Kutubu catchment.	N	N	N	N	N	N	N	N	N
Swampland and wetlands.	N	N	N	N	N	N	N	N	N

13.5 Water Quality

This section addresses the impact assessment criteria (Section 13.5.1) and addresses the principal issues (Section 13.5.2), proposed mitigation and management measures (Section 13.5.3) and discusses the residual environmental impacts of project construction and operations activities (Section 13.5.4) related to the water quality of rivers, streams, lakes and groundwater resources in the project area.

13.5.1 Residual Impact Assessment Criteria

The spatial and temporal classifications of project-related residual impacts on water quality follow those for the aquatic environment outlined in Sections 13.1.1 and 13.1.2 above.

Operational definitions of significance criteria for assessing the residual impacts on water quality in the project area have been provided so that statements regarding the nature of such impacts have a precise meaning. Residual impact assessment criteria that have applicability to water quality are presented below.

13.5.1.1 Criteria for Assessing Suspended Sediment Concentration Residual Impacts on Water Quality

Four assessment criteria have been used to assess the residual impacts of suspended sediment concentrations on the water quality of receiving waters in the project area:

Negligible: Concentrations of total suspended sediments at median flows (i.e., 50% exceedence flow duration) in receiving waters are less than 10% of background concentrations at median flows.

Minor: Concentrations of total suspended sediments at median flows in receiving waters are greater than 10% and less than or equal to 50% of background concentrations at median flows.

Moderate: Concentrations of total suspended sediments at median flows in receiving waters are greater than 50% and less than or equal to 100% of background concentrations at median flows.

Major: Concentrations of total suspended sediments at median flows in receiving waters are greater than 100% of background concentrations at median flows.

Note that the above residual impact assessment criteria are arbitrary but are useful in comparing suspended sediment concentration impacts on water quality at different project locations.

13.5.1.2 Receiving Water Quality Criteria

In Papua New Guinea, discharges to receiving waters must not cause a lowering of receiving water quality below the Prescribed Water Quality Guidelines outlined in Schedule 1 of the *Environment Act 2000*. These guidelines present water quality criteria for the protection of aquatic ecosystems. Table 13.5 presents the current ambient water quality criteria for the protection of freshwater and marine aquatic ecosystems in Papua

New Guinea. The seawater criteria are included, since residual impacts on the lower Omati River will be assessed and, at this location, freshwater, brackish and marine waters may be present.

Table 13.5 PNG prescribed water quality guidelines*

Parameter	Freshwater	Seawater
pH (pH units)	No alteration to natural pH	—
Temperature	No alteration greater than 2°C	—
Colour	No alteration to natural colour	—
Turbidity NTU‡	No alteration greater than 25 NTU	—
Insoluble residues	No insoluble residues or sludge formation to occur	—
Odour	No alteration to natural odour	—
Taste	No alteration to natural taste	—
Dissolved oxygen	Not less than 6.0 mg/L	Not less than 5.0 mg/L
Sulphate as SO_4^{2-}	400.0 mg/L	—
Sulphide as HS^-	0.002 mg/L	0.002 mg/L
Ammonia-nitrogen (NH_3-N)	Dependent on pH and temperature‡	—
Nitrates (NO_3^- + NO_2^-)	45.0 mg/L	45.0 mg/L
Chlorine (Total residual)	0.005 mg/L at pH 6	0.005 mg/L
Fluoride	1.5 mg/L	1.5 mg/L
Cyanide, free as HCN	0.005 mg/L	0.01 mg/L
Potassium	5.0 mg/L	450.0 mg/L
Arsenic	0.05 mg/L	0.05 mg/L
Barium	1.0 mg/L	1.0 mg/L
Boron	1.0 mg/L	2.0 mg/L
Cadmium, dissolved	0.01 mg/L	0.001 mg/L
Chromium (as hexavalent)	0.05 mg/L	0.01 mg/L
Cobalt	Limit of detection#	—
Copper	1.0 mg/L	0.03 mg/L
Iron, dissolved	1.0 mg/L	1.0 mg/L
Lead	0.001 mg/L	0.004 mg/L
Manganese, dissolved	0.5 mg/L	2.0 mg/L
Mercury	0.0002 mg/L	0.002 mg/L
Nickel	1.0 mg/L	1.0 mg/L
Selenium	0.01 mg/L	0.01 mg/L
Silver	0.05 mg/L	0.05 mg/L
Tin	0.05 mg/L	0.05 mg/L
Zinc	5.0 mg/L	5.0 mg/L
Radioactivity (radioisotopes)	None	None
Pesticides	None	None
Toxicants (miscellaneous)	None	None
Fats	None	None
Grease	None	None
Oil	None	None
Tars	None	None
Phenols	0.002 mg/L	0.002 mg/L
Faecal coliforms**	Not to exceed 200 colonies	Not to exceed 200 colonies

Source: Environment (Water Quality Guidelines) Regulation 2000. A dash ('—') denotes that no criteria are given in the Regulation. * The Environment (Water Quality Guidelines) Regulation 2000 [Section 2(4)] provides that an environment permit (e.g., waste discharge permit) may authorise a discharge or use that reduces water quality below these guidelines. ‡ NTU = nephelometric turbidity unit. ‡ Ammonia as nitrogen, ranges from 0.04 mg/L at pH 9 (35°C) to 16.1 mg/L at pH 7 (5°C). ** The criterion for faecal coliform bacteria (colonies per 100 mL) is based on not fewer than five water samples collected over not more than a 30-day period. # Note that the standard for cobalt (as 'limit of detectability') was established in Schedule 4 of the Water Resources Regulation of the *Water Resources Act 1982*. The routine method for metal analyses at that time was flame atomic absorption spectrometry (FAAS), which has a typical detection limit of 0.03 mg/L (APHA/AWWA, 1992). Graphite furnace atomic absorption spectrometry (GFAAS) was less commonly used during that period to achieve lower detection limits (typically 0.001 mg/L (APHA/AWWA, 1992)).

During construction and operations, all treated wastewater discharges will need to comply with the requirements of waste discharge permits.

13.5.2 Issues to be Addressed

13.5.2.1 Construction

The principal water quality issues arising during pipeline RoW/access way and project facilities construction and well drilling relate to:

- The delivery of fine sediments in overland flow to watercourses and water bodies as a result of the surface erosion of construction-disturbed and displaced soils and sidecast spoil materials, resulting in increased suspended sediment concentrations and turbidity.
- The discharge of treated sewage effluent, wastewater and other liquid wastes from the proposed construction camps.
- The disposal of hydrotest waters from pipeline integrity testing.
- The disposal of spent drilling fluids.
- The inadvertent loss of very limited quantities of foam drilling fluids during the drilling of fractured upper limestones.
- Increased risk of watercourse contamination from fuels, lubricating oils, and chemicals due to the transport, storage and handling of these materials during construction.

13.5.2.2 Operations

During operations, previously construction-disturbed soils and sidecast spoil materials are expected to stabilise progressively as vegetation is re-established naturally or by active revegetation. Therefore, there should be little or very limited (similar to background natural erosion rates) fine sediment delivery to watercourses, and suspended sediment concentrations and turbidity-type residual impacts on water quality are not anticipated.

The principal water quality issues during operations relate to:

- The discharge of treated process wastewaters and treated runoff waters from the production facilities.
- The disposal of treated sewage effluent, wastewater and other liquid wastes from the permanent camps.
- Increased risk of watercourse contamination from fuels, lubricating oils, and chemicals due to the transport, storage and handling of these materials during construction.

13.5.3 Mitigation and Management Measures

13.5.3.1 Construction

The project will implement appropriate mitigation and management measures to limit soil erosion and sediment production (see Sections 13.2.3, 13.3.3, 13.4.3 and 13.4.3), which will limit fine sediment delivery to watercourses and water bodies and, therefore, will also serve to protect water quality.

Mitigation measures that will limit impacts on watercourses and water quality are inherent in many of the pipelines, roadworks and facilities design features. The design mitigation measures include:

- The clearing of riparian vegetation will be limited to the width required to safely accommodate pipeline RoW/access way watercourse crossings.
- The banks of watercourses through which a temporary vehicle crossing will be installed will not be cleared until such time as the need for the crossing is imminent.
- Watercourse crossings will be designed to avoid adverse impacts on channel morphology and watercourse hydraulics.

In addition to the above 'mitigation by design', the project will implement appropriate additional mitigation and management measures to reduce impacts on water quality. The mitigation measures that are currently proposed are summarised below.

Clearing and Grading

- Large riparian trees may be chain sawed within the riparian buffer zone but root grubbing will not occur until the pipeline/access way crossing is imminent.
- Riparian trees will be trimmed using chainsaws rather than by whole tree removal, where practicable.
- Trees will be felled away from watercourses and any substantial vegetation debris that falls into the watercourses will be removed.
- Where grading of the pipeline RoW/access way alignment adjacent to streams is required, the soil will be graded away from the watercourse.
- Subsoil stockpiles will be located away from watercourse banks (a minimum of 10 m from the waterline).
- Before equipment is allowed onto riparian sites, checks will be made to ensure that it is in good working order and has no coolant, lubricating oil or hydraulic fluid leaks.
- Appropriate erosion and sediment control measures will be implemented, as necessary, during rehabilitation.

Watercourse Crossings – Open Dry- and Wet-Cut Construction

- Construction-disturbed watercourse banks will be reclaimed after the completion of access way construction/pipeline backfilling and prior to dismantling any flow diversion measures.

- The duration of construction activities at watercourse crossings will be as short as practicable.
- Watercourse crossings will be designed and constructed so that they will not divert flow out of the watercourse channel and into the pipeline RoW/access way alignments (e.g., use of trench plugs).
- Identified sites of problematic erosion at reclaimed watercourse crossings will be appropriately rectified.

Watercourse Crossings — Horizontal Directional Drilling

- For watercourse crossings at which horizontal directional drilling techniques are used to install the pipeline, a drilling fluids and cuttings management system, including drill cuttings settlement and slurry containment pits (see Figure 6.13 in Chapter 6), will be implemented.

Spill Containment

- Construction vehicles and equipment will be refuelled at sites away from watercourses. Appropriate spill containment equipment will be available at refuelling sites.
- Fuel storage areas will be located well away from watercourses.
- The washing of equipment, vehicles or machinery near or within watercourses will be prohibited.

Permitted Wastewater Discharges (In General)

- During construction, all water and wastewater discharges will be treated to enable compliance with conditions for discharge quality specified in the relevant waste discharge permits.

Treated Sewage Effluent Discharges

- Construction camp sewage treatment plants will be operated in accordance with conditions for discharge quality (including disinfection) specified in the relevant waste discharge permits.

Treated Drilling Fluid Discharges

- Appropriate practices related to drilling fluid discharges will be implemented in order to comply with permit requirements.
- Typical wastewater streams associated with drilling, such as water-based, non-toxic whole drilling fluids and completion fluids, will be diluted and discharged to vegetated land surfaces for natural infiltration.
- Oily water, which will be collected in water sumps, will have the oil skimmed and removed and transported off-site to an approved facility.

Untreated Drilling Fluid Discharges

- The use of foam drilling fluids on Hides Ridge to drill the upper portions of wells is expected to result in the release of very limited quantities of untreated foaming agents, corrosion inhibitors, and possibly bentonite clay and polymers when the drill string passes through the fractured upper Darai Limestone of Hides Ridge. Channels connecting subsurface limestone aquifers to surface waters have been confirmed for the Hides 4 well, where tracers applied to the drilling foam reappeared several days later at a surface location distant from and downslope of the well site.

- There are currently no feasible mitigation measures able to prevent the escape of these very limited quantities of foam drilling medium to subsurface aquifers (and eventually surface waters) via fissures and vugs in the Darai Limestone.
- Appropriate monitoring for the presence of untreated foam drilling fluids in emergent watercourses and surface waters will be undertaken.

Hydrotest Waters

- Hydrotest waters associated with onshore pipelines will be discharged to grade or to a temporary holding dam. If the discharge is to land for infiltration, the outflow energies will be dissipated (e.g., via sprinkler or T-bar arrangements) to prevent soil erosion.
- Pre-discharge sampling and analysis of hydrotest water will be undertaken as necessary in order to comply with the conditions attached to the relevant waste discharge permit.

Minor Fuel, Oil and Chemical Spillages

- Minor fuel, lubricating oil, and chemical spillages will be contained and cleaned up as soon as they are identified.

13.5.3.2 Operations

During operations, appropriate mitigation and management measures to limit the generation of wastes and appropriately treat wastewaters prior to their discharge will be implemented to protect the water quality of receiving watercourses. The following measures are proposed specifically to protect the quality of surface and subsurface waters in the project area.

Production Facilities Waste and Wastewater Management

Process Areas

- All equipment areas at facility sites will be concreted, kerbed and sloped to drain catchpits. The catchpits will feed to interception pits for separation of oil and water and the de-oiled water will be transferred to retention ponds. Oil that is collected from the interception pits and other facility sumps will be pumped to closed drain drums and any residual surface oil in retention ponds will be recovered by skimmers.

Drain System – Uncontaminated Runoff and Stormwater

- Non-equipment areas at plant facilities will be gravelled and sloped to allow uncontaminated storm water to drain naturally via the stormwater drains prior to routing offsite.

Sewage Treatment Plants

- Sewage treatment plants will be operated in accordance with the manufacturer's specifications and in order to comply with the conditions for discharge quality (including disinfection) specified in the relevant waste discharge permits.

13.5.4 Residual Impact Assessment

This section assesses the residual environmental impacts of the project on water quality after the proposed mitigation and management measures have been applied.

13.5.4.1 Construction

Residual impacts on water quality of receiving watercourses or water bodies will arise from increased suspended sediment concentrations and turbidity and the discharge of treated wastewaters.

Increased Suspended Sediment Concentrations and Turbidity

The project will temporarily increase the amount of sediment entering the project area's surface water system during construction. The residual impact severity on a particular watercourse will depend on the type of terrain in the locale.

Flat and Shallow-gradient Karst Terrain

Sections of the pipeline RoW/access way alignments traverse relatively flat karst terrain, where bulk earthworks, disturbed and displaced soils, and the side-casting of spoil will be of minimal quantity. The limestone component of the construction spoil comprises generally competent material and will tend to remain at an angle of repose close to the point of sidecasting, with minimal erosion and fine sediment delivery to watercourses occurring after the time of deposition. Residual suspended sediment impacts on the water quality of watercourses on flat karst terrain at the site scale or beyond are predicted to be negligible (not significant) in the short term or longer.

Steep-Gradient Karst Terrain

Sections of the pipeline RoW/access way alignments traverse relatively steep karst terrain, where bulk earthworks, disturbed and displaced soils, and the side-casting of spoil will be of a moderate quantity. Fine sediments eroded from construction spoil will likely reach surface drainage pathways, many of which travel only a short distance before flowing underground via sinkholes and sinkhole swamps to join the large subterranean flows that characterise this landform type. Since the limestone component of the construction spoil comprises generally competent material, this material will tend to remain at the angle of repose close to the point of sidecasting, with limited erosion and fine sediment delivery to watercourses and subterranean waters occurring after the time of deposition.

Overall, residual suspended sediment impacts on the quality of surface and subterranean watercourses in steep karst terrain at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer.

Swamp Terrain

Sections of the pipeline RoW/access way alignments traverse swamp terrain, where fine sediment production and delivery to watercourses will be of a limited quantity.

Construction across swamp terrain is likely to displace soils only a short distance from the pipeline RoW/access way alignments, owing to the presence of flat terrain with little or no hydraulic flow to disperse construction-derived suspended sediments. Residual impacts on the water quality of watercourses on swamp terrain at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer.

Steep Terrain with Volcanic Soils

The movement of unconsolidated material generated during pipeline and access way construction is most likely to occur in steep terrain with volcanic soils. Therefore, a focus has been placed on assessing the impacts of the pipeline RoW/access way construction activities between Homa and Idauwi, which have the greatest potential for fine sediment delivery to watercourses (see Section 13.4.4), potentially leading to increased suspended sediment concentrations and turbidity. Table 13.3 in Section 13.4.4 indicated about 1.6 million m^3 of side cast spoil (about 80% of the total of 2.0 million m^3 for the entire Homa to Idauwi pipeline RoW/access way alignment) will be generated between the Pawgano and Maruba rivers. This section has been used to illustrate the likely maximum impacts of increased suspended sediment concentrations on receiving watercourse quality in areas of steep terrain that possess volcanic soils.

Table 13.3 in Section 13.4.4 gives fine sediment (less than 125 μm size fraction) delivery estimates of 0.15 million tonnes and 0.05 million tonnes for the Pawgano and Maruba rivers, respectively. Assuming that the whole of these tonnages enter these two rivers, respectively, during the first year following construction, then suspended sediment concentrations can be predicted on the basis of dilution. Table 13.6 gives the predicted suspended sediment concentrations in the lower Maruba and Pawgano rivers and the receiving Hegigio and Kikori Rivers during the first year following construction.

During the first year of pipeline RoW/access way construction, suspended sediment concentrations in the lower Pawgano River are predicted to increase by 15 mg/L from a background value of 40 mg/L to 55 mg/L (about a 40% increase) at median flows and to increase by 70 mg/L at high flows (10% exceedence flow) from a background value of 80 mg/L to 150 mg/L (about a 90% increase). No increases in suspended sediment concentrations are predicted at base or very low flows (90% exceedence flow), when overland flows and sediment-laden runoff from construction sites and side-cast spoil are predicted to be extremely low to non-existent.

Table 13.6 Predicted suspended sediment concentrations in the lower Maruba and Pawgano rivers and the Hegigio and Kikori rivers

Station	Parameter	Predicted Suspended Sediment Concentrations at Different Exceedence Flow Durations		
		90% Exceedence (low flow)	50% Exceedence (median flow)	10% Exceedence (high flow)
Maruba River u/s Hegigio River	Flow (m^3/s)	3.0	16.0	21.0
	BSS‡ (mg/L)	5	40	80
	CSS (mg/L)	0	10	65
	TSS (mg/L)	5	50	145

Table 13.6 Predicted suspended sediment concentrations in the lower Maruba and Pawgano rivers and the Hegigio and Kikori rivers (cont'd)

Station	Parameter	Predicted Suspended Sediment Concentrations at Different Exceedence Flow Durations		
		90% Exceedence (low flow)	50% Exceedence (median flow)	10% Exceedence (high flow)
Hegigio River d/s Maruba River	Flow (m^3/s)	91.0	355.0	570.0
	BSS (mg/L)	49	78	120
	CSS (mg/L)	0	1	2
	TSS (mg/L)	49	79	122
Pawgano River u/s Hegigio River	Flow (m^3/s)	10.0	33.0	57.0
	BSS‡ (mg/L)	5	40	80
	CSS (mg/L)	0	15	70
	TSS (mg/L)	5	55	150
Hegigio River d/s Pawgano River	Flow (m^3/s)	128.0	502.0	809.0
	BSS* (mg/L)	49	79	122
	CSS (mg/L)	0	1	5
	TSS (mg/L)	49	80	127
Kikori River at Kaiam Gauging Station	Flow (m^3/s)	670.0	2,531.0	4,414.0
	BSS (mg/L)	15	82	400
	CSS (mg/L)	0	0	1
	TSS (mg/L)	15	82	401

Source: Flow data (Wright, pers. com.)
BSS = Background suspended sediments
CSS = Construction-derived suspended sediments.
TSS = Total suspended sediment (BSS+CSS)
‡ Estimated BSS. * BSS includes CSS increment from Maruba River, which is located upstream.

A similar pattern is predicted for the lower Maruba River, where suspended sediment concentrations are expected to increase by 10 mg/L from a background suspended sediment concentration of 40 mg/L to 50 mg/L (about a 25% increase) at median flows, and increase by 65 mg/L at high flows (10% exceedence flow) from a background suspended sediment concentration of 80 mg/L to 145 mg/L (about an 80% increase).

The above increases in the suspended sediment concentrations in the lower Pawgano and Maruba river mainstems will occur at the local scale, and are predicted to be minor in the short term and negligible (not significant) in the medium to long term. At the site scale, that is in the mainstems of the middle Pawgano and Maruba rivers and the various small tributaries within 2 km of the pipeline RoW/access way construction alignment, residual suspended sediment impacts are predicted to be major in the short term and negligible (not significant) in the medium to long term. Predicted suspended sediment concentrations at the site scale do not appear in Table 13.6 above, since flow durations for the middle Pawgano and Maruba rivers immediately downstream of the pipeline RoW/public road alignment are not available. However, suspended sediment concentrations would be expected to be greater than 100% of the background concentrations at median flows, and this reflects the 'major' criterion for assessing residual suspended sediment concentration impacts on water quality (see Section 13.5.1.1).

Residual impacts of suspended sediment impacts at the regional scale are predicted to be negligible (not significant) in the short term or longer, owing to the large dilution afforded by the Hegigio River downstream of the Maruba and Pawgano river confluences. For example, the predicted construction-derived suspended sediment increment in the Hegigio River downstream of the Pawgano River is 1 mg/L at median flows compared to a background suspended sediment concentration of about 80 mg/L (see Table 13.6 above).

Considering water quality recovery potential, the construction-related increases in suspended sediment concentrations will diminish as sidecast spoil and sites of erosion stabilise through a combination of natural vegetation and site-specific active revegetation, thus reducing the sources of fine sediment production. This general pattern of initial post-construction increases in suspended sediment concentrations and reduction during and following the year of construction is corroborated by the results of the long-term water quality monitoring program for the Kutubu Petroleum Development Project (NSR, 1991, 1992, 1993a, 1993b, 1994, 1995, 1997a), which confirms short-term elevations in suspended sediment concentrations associated with pipeline RoW/access way construction and watercourse crossings.

The predicted increases in suspended sediment concentrations have consequential impacts on aquatic life, water use and subsistence fisheries (see Section 13.6.4).

Kopi Wharf Development

Section 2.3.5.2 outlines the modifications and new construction required to upgrade the existing wharf facilities at Kopi on the lower Kikori River. In summary, it is proposed to construct a new 30-m-long, steel and concrete barge wharf upstream of the existing main wharf. This new wharf will be centrally located along the base's river frontage and will become the main wharf at Kopi. Additionally, modifications are proposed to the existing wharf at the downstream end of the laydown area.

The above-mentioned modifications and new construction works will be limited to the existing frontage of the Kikori River, and short-term increases in suspended sediment concentrations and turbidity are expected, but will be limited to the areas of active construction along the river frontage. Direct riverbank and riverbed disturbance will result in the resuspension of settled sediments, which will be transported downstream. While it is difficult to predict suspended sediment concentrations likely to arise from the Kopi wharf construction activities, concentrations may be expected to reach several hundred parts per million (mg/L) in the very short term while construction activities are occurring. Table 9.2 in Chapter 9 indicates that background median suspended sediment concentrations in the Kikori River at Kaiam (about 20 km upriver from Kopi) and near Kikori town (about 15 km south of Kopi) are 82 mg/L and 43 mg/L, respectively. Therefore, an estimated median background median suspended sediment concentration of 60 mg/L is assumed for the Kikori River at Kopi.

Overall, residual impacts of wharf development-induced increases in suspended sediment concentrations at the site scale or further afield are predicted to be negligible (not significant) in the short term and longer. Suspend sediment effects will be tempered by the high natural suspended sediment loads carried by the turbid Kikori River.

Omati River Landfall

The proposed cofferdam shore construction method for the landfall on the Omati River includes excavating the shoreline and extending a coffer dam up to 60 m offshore with a width of approximately 4 m. Construction-related suspended sediment loading is expected to create high suspended sediment concentrations in the lower Omati River mainstem in the vicinity of the construction site. Predictions of suspended sediment concentrations cannot be made at this juncture but are expected to exceed several hundred parts per million (mg/L). However, increased suspended sediment impacts on the water quality of the lower Omati River are expected to only last as long as active construction is taking place at the landfall site. Potential impacts on the water quality of the lower Omati River will be tempered by the existing high background suspended sediment concentrations and turbidity, due mainly to catchment disturbance by logging operations and an associated extensive logging road network (see Figure 16.1 in Chapter 16). Elevated suspended sediment concentrations are expected to be significantly reduced during the twice-daily tidal cycle, when estuarine saltwater intrusion enhances the settlement of fine suspended sediments (mainly silts and clays) by coagulation.

Overall, residual impacts on water quality of the lower Omati River at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer.

Treated Sewage Effluent Discharges

Since sewage effluents will be treated to comply with the requirements included in waste discharge permits, elevated suspended sediment concentrations in receiving waters are unlikely, given the anticipated high dilution factors. However, elevated (but still very low) concentrations of nutrients may occur in the receiving waters immediately downstream of treated sewage effluent discharge locations.

Treated sewage effluent will likely be discharged onto vegetated land to encourage infiltration rather than being discharged directly to watercourses. Using this approach, the mobilisation of nutrients will be tempered by their adsorption onto soil particles and by their uptake by soil micro-organisms and by aquatic micro-organisms that decompose detritus in the receiving watercourses.

In general, nutrients that undergo transformations, such as nitrogen, will be mobilised more readily than nutrients that are normally strongly retained in soils, such as phosphorus. However, given the low volumes of treated sewage effluent anticipated to be generated by the construction camps (up to 20,000 L per day), the fact that the discharge will likely be to land and will be followed by infiltration, and the high dilution factors associated with the receiving watercourses, no significant nutrient loading of project area watercourses is predicted during construction. Therefore, residual nutrient impacts on water quality at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer. This conclusion is corroborated by the findings of previous water quality monitoring programs in the project area. For example, monitoring of the streams in the area of the Kutubu Petroleum Development Project (NSR, 1991, 1992, 1993a, 1993b, 1994, 1995, 1997a) indicated that no significant changes in nutrient concentrations were observed in water samples collected both upstream and downstream of the Kutubu Central Production Facility, where treated sewage effluent is discharged.

Treated Drilling Fluid Discharges

During construction, treated drilling fluid discharges will be temporary and are expected to occur only for short periods of time. The residual impacts on receiving water quality at the site and further afield from the discharge of treated drilling fluids are predicted to be negligible (not significant) in the short term or longer.

Untreated Drilling Fluid Discharges

During construction, the inadvertent escape of small amounts of untreated foam drilling fluids from the fractured upper limestones of Hides Ridge is expected to occur only for short periods of time.

As the subsurface hydrogeology of Hides Ridge is largely unknown, it is very difficult to predict how drilling fluid constituents, such as foaming agents, corrosion inhibitors, bentonite clay (if used) and polymers, will present themselves in surface waters at locations distant from the proposed drill sites. It is anticipated that there will be ample dilution of the untreated foam drilling fluids, such that residual concentrations of drilling fluid constituents would be reduced to the very low levels. The toxicity characteristics of the foam drilling additives are low (see Appendix F of Supporting Study 12). The use of foam drilling fluids for surface drilling in limestone terrain in Papua New Guinea is widely practised.

Treated Hydrotest Water Discharges

The integrity of the onshore pipeline will be assessed by filling individual sections of the pipeline with hydrotest water, to which may be added a small amount of a biocide (to inhibit the growth of bacteria, algae or fungi in the pipe) and a small amount of an oxygen scavenger.

The preferred choice of biocide is a tetrakis-hydroxymethyl phosphonium sulphate $[(CH_2OH)4P]_2SO_4]$- (or THPS-) based product. This product is generally considered to be less of a human health risk as compared to alternative gluteraldehyde-based products and is also more effective at inhibiting bacterial growth. The THPS-based biocide is readily degradable, hydrolyses in 7 days at pH 9, and does not bioaccumulate (BTC, 2004).

The oxygen scavenger that is typically used for treating hydrotest water (sodium sulphite ($NaHSO_3$) or ammonium bisulphite (NH_4HSO_3)) will oxidise to sulphate (SO_4), which is a common and benign compound found in nature. However, if ammonium bisulphite is used, the hydrotest water may require additional treatment to ensure that any excess or unreacted oxygen scavenger is removed. For example, at the completion of a test, hydrotest water discharged to land via T-bar sprays or dissipators will enhance reaction with atmospheric oxygen and allow further degradation within the overland flow prior to its entering watercourses. Table 6.2 in Section 6.4.4.2 provides estimates of hydrotest water discharges, which range from 48 kL for the test section of the glycol return line (between the proposed Hides Production Facility and the Kutubu Central Gas Conditioning Plant) to 56,998 kL for the test section of the sales gas pipeline between the Kutubu Central Gas Conditioning Plant and the Kopi Scraper Station. Discharge locations for the hydrotest water are anticipated to be the mainstems of the larger rivers of the project area, such as the Tagari, Hegigio, Mubi, Kikori and Omati rivers. The large flow regimes of these rivers will greatly dilute the hydrotest water discharges and are expected to reduce any residual biocide and oxygen scavenger concentrations to very low non-toxicological levels.

Overall, residual impacts on receiving water quality at the site scale and further afield from the discharge of any residual, low concentrations of biocide and oxygen scavenger chemicals remaining in hydrotest waters are predicted to be negligible (not significant) in the short term or longer. The high dilution afforded by the large flows in the major river mainstems, where the treated hydrotest waters may be discharged, should reduce any residual concentrations of these materials to non-toxicological levels. Predischarge sampling and analysis of hydrotest water will be undertaken in order to comply with the relevant waste discharge permits.

Contamination of Watercourses by Fuel, Oil or Chemical Spillages

Residual impacts of minor spillages after mitigation (e.g., implementation of fuel handing procedures and emergency spill response and clean-up strategies) at the site scale or further afield are predicted to be negligible (not significant) in the short term and longer, given the small volumes of liquids likely to be involved and the immediate post-spill application of appropriate clean-up procedures. Minor fuel, lubricating oil and chemical spills are unlikely to reach watercourses, owing to the mitigation and management procedures outlined above in Section 13.5.3.1. Major accidental spillages and a rupture of the Hides liquids pipeline would be addressed by spill response procedures to be developed by the project.

13.5.4.2 Operations

Earthworks are not anticipated to be required during operations; therefore, soil erosion and fine sediment delivery to natural drainage systems having subsequent impacts on water quality are not expected. Existing waste and wastewater treatment systems at the Kutubu Central Production Facility as well as other production facilities in the project area will accommodate any increased wastewater inflows. New waste and wastewater treatment systems will be installed at the proposed Hides Production Facility.

Potential wastewater sources that may impact water quality include wastewater discharges associated with:

- Production facility site runoff.
- Sewage treatment plants.

Production Facility Site Runoff

The principal additional source of treated wastewater discharges during normal operations attributable to the project will be discharges from the Kutubu Central Gas Conditioning Plant. Rainfall from areas of the plant that have no potential for contamination will be segregated and drained separately through stormwater drains and sumps to the open drain system.

Rainfall from areas of the plant that have the potential for contamination will be intercepted in the closed drain system and transferred to the existing central detention pond, where oil and suspended solids will be removed before the water is discharged (after testing) to the natural drainage system. Discharges from the central detention pond are currently monitored on a monthly basis for permit compliance, and test data are reported on a quarterly basis. This procedure will continue. Similar, but smaller-scale systems are in operation at the other existing facilities, and such a system will also be installed at the new Hides Production Facility. Measures to contain and manage any unscheduled major discharges (spills) that may occur at the various sites will be described in spill response procedures to be developed by the project.

Overall, residual impacts on receiving water quality at the site scale and further afield due to the discharge of treated production facility site runoff are predicted to be negligible (not significant) in the short term or longer.

Treated Sewage Effluent Discharges

Existing sewage treatment plants will accommodate the small increase in the operations workforce. If required, the treatment plants will be expanded to ensure that treated sewage effluent discharges are in compliance with the applicable waste discharge permits. All treated sewage effluent discharges are currently monitored on a monthly basis for permit compliance, and test data are reported on a quarterly basis. Currently, the following wastewater discharges are monitored: Iagifu Ridge, Moro, Gobe Ridge, Gobe Airport, and Kopi sewage treatment plants. A sewage treatment plant will also be installed at the new Hides Production Facility.

Overall, residual impacts of treated sewage effluent discharges on receiving water quality at the site scale and further afield are predicted to be negligible (not significant) in the short term or longer.

13.5.5 Residual Impact Summary

13.5.5.1 Construction

Table 13.7 presents a summary of residual impacts on the water quality of watercourses and water bodies in the project area during construction. The table highlights the fact that significant impacts on water quality mainly relate to increased suspended sediment concentrations in areas with steep terrain and readily erodible volcanic soils.

13.5.5.2 Operations

No significant residual impacts on the water quality in watercourses or water bodies in the project area are predicted during operations.

13.6 Aquatic Ecology

This section presents impact assessment criteria (Section 13.6.1) and addresses the principal issues (Section 13.6.2), proposed mitigation and management measures (Section 13.6.3) and residual environmental impacts of project construction and operations activities (Section 13.6.4) on the flora and fauna of rivers, streams and lakes in the project area.

13.6.1 Residual Impact Assessment Criteria

The spatial classification of project-related residual impacts on aquatic habitats, flora and fauna follows that for the aquatic environment outlined in Section 13.1.1 above.

Table 13.7 Summary of residual impacts on the water quality of watercourses in the project area during construction

Spatial Scale	**Site Scale (up to 2 km downstream)**			**Local Scale (between 2 km and 10 km downstream)**			**Regional Scale (greater than 10 km downstream)**		
Temporal Scale	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**
Increased suspended sediment concentrations in watercourses draining:									
Shallow-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient terrain with erodible volcanic soils*	Major	N	N	Minor	N	N	N	N	N
Lake Kutubu catchment	N	N	N	N	N	N	N	N	N
Swamplands and wetlands	N	N	N	N	N	N	N	N	N
Kopi wharf development	N	N	N	N	N	N	N	N	N
Omati River landfall	N	N	N	N	N	N	N	N	N
Residual impacts on water quality by treated wastewater discharges:									
Sewage effluent	N	N	N	N	N	N	N	N	N
Drilling fluids	N	N	N	N	N	N	N	N	N
Hydrotest waters	N	N	N	N	N	N	N	N	N

Note: N = Negligible (not significant). * Pawgano and Maruba rivers section of the proposed Homa to Idauwi pipeline RoW/public road alignment.

Operational definitions of significance criteria for assessing the residual impacts on the aquatic habitats and biological communities of the project area are provided so that statements regarding the nature of impacts have a precise meaning. Residual impact assessment criteria in the form of water quality criteria that have applicability to the protection of aquatic ecosystems are presented in Table 13.5 in Section 13.5.1.

The nature and temporal scope of project-related environmental residual impacts on the aquatic habitats and biological communities in the project area are defined below in the form of impact criteria. Four categories of residual impacts are defined:

- Negligible: Habitat alteration or changes in water quality cause no measurable changes in aquatic community structure or function and are indistinguishable from existing natural variability.
- Minor: Habitat alteration or changes in water quality cause a measurable change in aquatic community structure or function that will persist in the short term (less than 1 year).
- Moderate: Habitat alteration or changes in water quality cause a measurable change in aquatic community structure or function that will persist in the medium term (more than 1 year but less than 5 years).
- Major: Habitat alteration or changes in water quality cause a measurable change in aquatic community structure or function that will persist in the long term (more than 5 years).

Note that the above impact assessment criteria for evaluating the significance of residual impacts are all-embracing in that habitat alterations can arise from individual physical, hydrological and water quality effects or from some combination of these.

13.6.2 Issues to be Addressed

13.6.2.1 Construction

The principal project-related aquatic ecological issues during construction relate to:

- Potential effects of sedimentation on aquatic habitats of watercourses and other water bodies.
- Potential effects of increased suspended sediment concentrations and turbidity on aquatic flora and fauna and water-associated fauna.

Discharges of treated wastewaters during the construction period, such as treated sewage effluent and hydrotest waters, were assessed in Sections 13.4.4 and 13.5.4 and were predicted to have negligible (no significant) residual impacts on streamflow and water quality. Therefore, the residual impact of treated wastewater and other discharges on aquatic ecology is similarly anticipated to be negligible (not significant).

13.6.2.2 Operations

The main issues arising during commissioning and operations related to aquatic ecology are:

- Increased suspended sediment concentrations and turbidity impacts on aquatic ecology due to ongoing soil erosion and access way use and maintenance.

Discharges of treated sewage and other effluents during operations were assessed in Sections 13.4.4 and 13.5.4 and were predicted to have negligible (not significant) residual impacts on water quality. Therefore, the residual impact of treated sewage and other discharges on aquatic ecology is similarly anticipated to be negligible (not significant).

13.6.3 Mitigation and Management Measures

13.6.3.1 Construction

The proposed construction-related mitigation and management measures outlined in previous sections of this chapter serve to significantly reduce potential impacts on aquatic habitats, flora and fauna. These include:

- Drainage control and site-specific erosion control mitigation and management measures (see Section 13.2.3).
- Soil erosion and sediment control mitigation and management measures (see Section 13.3.3).
- Water resources and hydrology mitigation and management measures (see Section 13.4.3).
- Water quality mitigation and management measures (see Section 13.5.3).

In addition, an environmental management framework will be part of the project's Environmental Management Plan (see Chapter 18).

No additional mitigation and management measures are proposed to reduce impacts on aquatic ecology.

13.6.3.2 Operations

During operations, the principal mitigation and management measure to limit impacts on the aquatic biological communities of the project area is compliance with effluent discharge limits and water quality criteria (see Table 13.5 above) that will be included in waste discharge permits.

Feedback from the hydrological, water quality and aquatic biological components of the Environmental Management Plan (Chapter 18) will confirm whether operational discharges are in compliance with effluent discharge quality standards contained in the relevant waste discharge permits. Corrective actions will be undertaken where non-compliance is indicated.

13.6.4 Residual Impact Assessment

13.6.4.1 Construction

Residual impacts related to the project's construction activities on aquatic habitats, flora, macroinvertebrates, fish, crocodiles, freshwater turtles and aquatic mammals are assessed below.

Aquatic Habitats

Residual impacts on aquatic habitats are assessed below for the range of aquatic habitats in the project area and in accordance with the impact assessment criteria defined in Section 13.6.1.

Surface Riverine Habitats

In Section 13.4.4, residual impacts on watercourse bed sediment loading at the site scale were predicted to be negligible (not significant) in the short term and longer for pipeline RoW/access way alignments on flat or low-lying karst terrain, in swamplands and floodplains and for the construction sites of production facilities, laydown areas, quarries, the Kopi wharf development and the Omati River landfall location. However, more significant bed sediment loading of watercourses is predicted along the pipeline RoW/public road alignments in steep terrain with readily erodible volcanic soils, such as the Pawgano to Maruba rivers section of the proposed Homa to Idauwi public road. The following residual impact assessment is for the Pawgano to Maruba rivers section and thus represents a worst-case scenario.

Section 13.4.4 indicated that residual impacts on bed sediment loading of the mainstems of the middle Pawgano and Maruba rivers at the site scale are predicted to be moderate in the short term and negligible (not significant) in the medium to long term. At the local scale, residual impacts on bed sediment loading are predicted to be minor in the short term and negligible (not significant) in the medium to long term. These predicted increases in bed sediment loading are expected to cause in-stream sedimentation resulting in some smothering of river bed habitats and some infilling of stony substrata with a consequent loss of some void spaces. Furthermore, the increased bed load causes a constantly mobile and shifting substratum that is not conducive to recolonisation and population re-establishment by aquatic flora or fauna.

Residual impacts on aquatic habitats of the middle Pawgano and Maruba river mainstems are predicted to be moderate at the site scale. Residual impacts on the aquatic habitats of the lower Pawgano and Maruba river mainstems are predicted to be minor at the local scale. At the regional scale, in the mainstem of the Hegigio River, residual impacts on aquatic habitats are predicted to be negligible (not significant).

Surface riverine habitat recovery potential is considered to be high as coarse sediment delivery diminishes rapidly once sidecast spoil and other soil-dominated surfaces become stabilised through a combination of natural and active revegetation (see Section 13.3.3). Accumulated bed load will be transported downstream during high rainfall and runoff events and subsequent flood flow regimes, which will clear the river mainstem habitats of coarse sediments and increase their structural diversity (e.g., return of a stony substratum with void spaces). In the medium to long term, residual impacts on aquatic habitats at the site scale and further afield are expected to be negligible (not significant). Aquatic habitat alteration has consequential impacts on aquatic flora and fauna (see below).

Subsurface Riverine Habitats

While much of the proposed pipeline RoW/access way alignments are located on karst terrain, some sections are located on flat or shallow gradients where coarse-sediment delivery and bed sediment loading of surface and subsurface watercourses is anticipated to be limited. However, higher coarse sediment deliveries to watercourses may be expected in steep karst terrain traversed by sections of the proposed pipeline RoW/access way alignments. These steep areas are in the Hides Ridge area and the Heartbreak Hill area, which is located to the west of Wassi Falls on the lower Mubi River.

- *Hides Ridge Area.* The project will implement appropriate site-specific mitigation and management measures along the spine line RoW proposed on Hides Ridge (see Section 13.4.3). This is proposed to include the development and implementation of a sinkhole management strategy. These measures, including avoiding large-volume side cuts and reducing the quantities of spoil sidecast to the extent practicable, and site-specific active revegetation measures, are all designed to limit sedimentation impacts on the swamps located at the bottoms of some of the sinkholes on either side of the spine line RoW alignment. Therefore, these same mitigation and management measures will also serve to limit coarse sediment delivery to ponds or swamps in permanently water-filled sinkholes and to insurgent streams (i.e., streams that flow for a short distance on the surface before flowing underground) and receiving subterranean streams and cave systems. Residual impacts on the subsurface riverine habitats at the site scale or further afield are predicted to be negligible (not significant), owing to the implementation of the site-specific mitigation and management measures that will limit sediment entry to the Hides karst surface and subsurface watercourses.
- *Heartbreak Hill (Kantobo to Mubi River).* The steep karst terrain in this area will be traversed by the sales gas pipeline RoW only (the proposed access way deviates about 5 km to the west on less steep terrain). Section 13.4.3 indicated that site-specific mitigation and management measures proposed to be applied to the extent practicable to limit the entry of coarse sediments to insurgent streams and sinkholes and thereby protect the aquatic habitats of subterranean streams and cave systems. One species of cave-dwelling fish, a blind gudgeon (*Oxyeleotris caeca*), inhabits sinkholes and subterranean streams of the karst terrain in the eastern catchment of the Mubi River. The proposed sales gas pipeline RoW and the new access way bypass alignment are located in the western catchment of the Mubi River and are therefore outside the known habitat area of this fish species. Note that no impacts were observed on the cave habitats of this cave-dwelling gudgeon, which, if present, survived the construction and installation of the existing crude oil export pipeline in this same location. Overall, no adverse sedimentation effects are envisaged on the habitat of this fish species from the currently proposed project-related construction activities in the Heartbreak Hill area. A monitoring component to assess the distribution of the cave-dwelling gudgeon and its habitat will be included of the Environmental Management Plan (see Chapter 18).

Lacustrine Habitats (Lake Kutubu)

The proposed upgrading of an approximately 19-km-long section of the existing Kutubu to Homa public road within the northwestern catchment of Lake Kutubu, is not expected to result in any significant bed or suspended sediment loading of the inflow streams that will be crossed, owing to the implementation of appropriate site-specific mitigation and management measures (see Section 13.4.3). These measures will be designed specifically to limit soil erosion and sediment delivery to the lake's primary inflow streams (i.e., the Kaimari and Taga creeks). Therefore, since no significant bed or suspended sediment loading of Lake Kutubu via its inflow streams is predicted and, therefore, residual impacts on Lake Kutubu habitats at the site scale or further afield are expected to be negligible (not significant) in the short term and longer.

Swampland and Floodplain Habitats

Section 13.4.4 indicated that floodplain and swampland habitats are the least likely to be impacted by construction-derived coarse and fine sediments or sedimentation, owing to the lack of water flow to disperse the delivered sediments. Residual impacts due to sedimentation on swampland and floodplain aquatic habitats at the site scale or further afield are predicted to be negligible (not significant) in the short term and longer.

Estuarine Habitats

Estuarine habitats that may be affected by the project are those associated with the Kopi wharf development on the lower Kikori River and the construction of the landfall site on the lower Omati River. Residual impacts on these estuarine aquatic habitats are assessed below.

- *Kopi Wharf Development.* In Sections 13.4.4 and 13.5.4 respectively, the residual impacts of bed and suspended sediment loading on estuarine habitats and water quality at the site scale or further afield were predicted to be negligible (not significant) in the short term and longer for the Kopi wharf development. Additionally, construction-related bed and suspended sediment loading will be masked and tempered by the very large, natural bed and suspended sediment loads carried by the lower Kikori River. Therefore, residual impacts on the estuarine aquatic habitats of the lower Kikori River at Kopi at the site scale or further afield are predicted to be negligible (not significant).

- *Omati River Landfall.* The proposed cofferdam shore construction at the Omati River landfall site includes excavating the shoreline and extending the cofferdam up to 60 m offshore with a width of approximately 4 m. This represents an area of 240 m^2 of riverbed habitat that will be directly disturbed. Construction activities are also expected to displace disturbed riverbed sediments to either side of the cofferdam construction area with additional coarse sediment loading resulting from riverbank construction activities. However, the total area of disturbance on the bed of the lower Omati River is anticipated to be small (less than 0.1 ha), and residual impacts on the estuarine aquatic habitats of the lower Omati River at the site scale or further afield are therefore predicted to be negligible (not significant). Construction-related bed and suspended sediment loading will be tempered by the very large, background bed and suspended sediment loads carried by the lower Omati River. In addition, the removal of a 30-m-long section of riverbank vegetation, such as the thin fringe of nypa palms at the landfall site, represents a small, direct loss of estuarine fish and macroinvertebrate habitat compared to extensive similar habitat that will remain unaffected by project construction activities. Therefore, residual impacts on estuarine aquatic habitats associated with the fringing nypa palm vegetation at the site scale or further afield are predicted to be negligible (not significant).

Aquatic Flora

Residual impacts on the aquatic flora of project-area watercourses and water bodies have been assessed, since the aquatic flora represent a food resource to herbivorous benthic macroinvertebrates (e.g., grazers and scrapers). Most of the watercourses in the project area have a very low aquatic primary production compared to external inputs of terrestrial organic matter that form the basis of the food chain, as reflected in the predominance of shredders and detritivores among the resident macroinvertebrate fauna. On the other hand, aquatic primary production is high in Lake Kutubu and also in the permanent swamps and wetlands of the project area.

The principal environmental effects related to project construction on aquatic flora will arise from aquatic habitat alteration (see above) via sedimentation and increased suspended sediment concentrations and turbidity in the water column. The following assessment of residual impacts on aquatic flora is undertaken in accordance with the impact assessment criteria defined in Section 13.6.1.

Increased Bed Sediment Loading and Sedimentation

Sediment deposition in construction–impacted watercourses is expected to affect benthic algae, diatoms and periphyton attached to the surfaces of boulders, stones and woody debris by causing a loss or reduction of habitat diversity through infilling and covering of habitat surfaces with sands and silt, which will reduce attachment and anchoring points for certain species. Benthic algae, diatoms and periphyton in sediment-impacted stream reaches are expected to show a temporary reduction in species diversity and density, with concomitant temporary reductions in mainstream primary production brought about by biomass reduction and depressed growth rates.

Section 13.4.4 predicted that residual impacts on bed sediment loading at the site scale or further afield would be negligible (not significant) in the short term or longer for pipeline RoW/access way alignments on flat or shallow-gradient karst terrain, in the Lake Kutubu catchment, and in swamps, floodplains and wetlands, as well as for construction sites at the production facilities, laydown areas, quarries, the Kopi wharf development and the Omati River landfall site. Therefore, residual impacts of increased bed sediment loads and in-stream sedimentation on aquatic flora at the site scale or further afield within these aforementioned areas are predicted to be negligible (not significant). However, significant sedimentation impacts are anticipated in those rivers draining steep terrain with readily erodible volcanic soils, and these are discussed below.

Section 13.4.4 predicted that sedimentation impacts in the Pawgano and Maruba rivers at the site scale would be moderate in the short term and negligible (not significant) in the medium to long term and, at the local scale, to be minor in the short term and negligible (not significant) in the medium to long term. Therefore, residual impacts associated with increased bed sediment loading on the aquatic flora of these two rivers at the site and local scales are predicted to be moderate and negligible (not significant), respectively. The environmental significance of these site-scale and local-scale residual impacts on aquatic flora will be limited by the fact that aquatic primary production in project-area watercourses is very low compared to the external inputs of terrestrial organic matter, which forms the basis of the aquatic food chain.

Increased Suspended Sediment Concentrations and Turbidity

Long-term increases in suspended sediment concentrations and turbidity are known to impact the aquatic flora of watercourses and water bodies by reducing the penetration of photosynthetically active light, which suppresses growth and primary productivity. As noted above, the key areas of primary productivity in the project area are Lake Kutubu and swamps and wetlands in which residual impacts on water quality at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer. Therefore, no significant residual impacts on the aquatic flora of these areas are predicted. However, Section 13.5.4 highlighted that increased suspended sediment loading in the Pawgano and Maruba rivers due to construction activities is expected in the steep terrain locales with readily erodible volcanic soils and in spoil sidecasting locations within their catchments. Residual impacts associated with project construction activities on the aquatic flora of these rivers are discussed below.

Table 13.6 in Section 13.5.4 indicates that the estimated background suspended sediment concentration at median flows in both the Pawgano and Maruba river mainstems immediately upstream of their confluences with the Hegigio River is about 40 mg/L. This suspended sediment regime is not conducive to the establishment of viable, reproducing populations of benthic algae, periphyton or diatoms. Therefore, potential suspended sediment and turbidity impacts attributable to project construction activities must be considered in the light of a prevailing low biomass and low diversity of aquatic flora.

Overall, the main project-related residual impact on the sparse aquatic flora in the Pawgano and Maruba river mainstems is expected to be due to habitat alteration caused by increased sedimentation (see sedimentation impacts on aquatic flora above), which is expected to predominate over and mask any residual impacts that may arise due to increased suspended sediment concentrations and turbidity in the same sediment-impacted watercourse reaches. Therefore, residual impacts on the aquatic flora of the Pawgano and Maruba rivers at the site and local scales are predicted to be moderate and minor, respectively.

Macroinvertebrates

Construction-derived direct impacts on benthic macroinvertebrates are likely to arise due to benthic habitat alteration caused by increased bed sediment loading and sedimentation and by increased suspended sediment concentrations in the water column. Indirect impacts on herbivorous benthic macroinvertebrates are expected to arise due to the loss or reduction of food resources from in-stream primary production sources, where present (see aquatic flora impacts above). The following assessment of residual impacts on aquatic macroinvertebrates is undertaken in accordance with the impact assessment criteria defined in Section 13.6.1.

Increased Bed Sediment Loading and Sedimentation

Supporting Study 12 provides a review of the generalised effects of increased bed sediment loading and sedimentation on benthic macroinvertebrates. In summary, construction-derived sediments, upon deposition, may temporarily bury benthic macroinvertebrates and/or their food sources (e.g., benthic algae and detritus), and may cause a temporary loss or degradation of bottom habitat through void space infilling. Interstitial filling of the stony substratum of riffle reaches in sediment-impacted watercourses is expected to reduce the structural diversity of riffle habitats by reducing voids and covering stone surfaces with coarse and fine sands and silts, which will reduce the number of attachment and anchoring points for some macroinvertebrate fauna. A reduction in the numbers and kinds of riffle-associated macroinvertebrate species is normally evidenced, especially since more than 70% of stream macroinvertebrates live in the top 10 cm of the stream bed (Hynes, 1972).

In most instances related to heavy sedimentation influxes, there is a change in macroinvertebrate community structure rather than a total loss of the fauna (Ryan, 1991). In addition, a significant proportion of the total sediment moved is present as bed load, and the presence of a continually shifting substratum is not conducive to macroinvertebrate colonisation or re-establishment. However, subsequent rising and high flows are expected to scour coarse sediment deposits and transport the resuspended sediments downstream, where redeposition of coarse sediments in shallower gradients may result.

In Section 13.4.4, it was predicted that residual impacts on bed sediment loading at the site scale or further afield would be negligible (not significant) in the short term or longer for pipeline RoW/access way alignments on flat or shallow-gradient karst terrain, in the Lake Kutubu catchment, and in swamps, floodplains and wetlands, as well as for construction sites at the production facilities, laydown areas, quarries, the Kopi wharf development and the Omati River landfall. Therefore, residual impacts of increased bed sediment loads and in-stream sedimentation on benthic macroinvertebrates at the site scale or further afield within these aforementioned areas are predicted to be negligible (not significant). However, significant sedimentation impacts may occur in those rivers draining steep terrain with readily erodible volcanic soils, and these are discussed below.

In Section 13.4.4, it was predicted that residual bed sediment loading and sedimentation impacts in the middle Pawgano and Maruba river mainstems at the site scale would be moderate in the short term and negligible (not significant) in the medium to long term. At the local scale, residual bed sediment loading and sedimentation impacts in the lower Pawgano and Maruba river mainstems were predicted to be minor in the short term and negligible (not significant) in the medium to long term. Therefore, residual impacts of increased bed sediment loading on the resident macroinvertebrate fauna and their benthic habitats of these two rivers at the site and local scales are predicted to be moderate and minor, respectively. These moderate to minor residual impacts at the site scale will result in a temporary reduction in the biomass and diversity of benthic macroinvertebrate species. Recovery by macroinvertebrate recolonisation will be rapid as the benthic habitats clear of settled sediments and as water quality improves (see suspended sediments below).

Note that reductions in the macroinvertebrate densities and biomass in construction-sediment–impacted watercourse reaches are expected to have temporary consequential effects on fish (see below), since aquatic macroinvertebrates form an important component of the diet of many project area riverine fish species, such as river gobies, gudgeons, rainbowfish and tandans.

Increased Suspended Sediment Concentrations

Supporting Study 12 provides a review of the generalised effects of increased suspended sediment concentrations in the water column on benthic macroinvertebrates. In summary, suspended sediment impacts may be considered both directly and indirectly at the individual, population and community level of organisation. These include direct lethal effects (mortality of adult, larval, nymphal or egg stages) and sublethal effects (suppression of growth or productivity). The direct effects of high suspended sediment concentrations include abrasion to body integuments or clogging of respiratory organs, particularly the gills of the lower macroinvertebrates (e.g., mayfly and dragonfly nymphs) and higher macroinvertebrates (e.g., crayfish and freshwater prawns), and interference with feeding mechanisms (e.g., filter-feeding apparatus). Indirect effects include the loss or reduction of food items for herbivorous macroinvertebrates, such as benthic algae, diatoms and periphyton (see aquatic flora impacts above).

In Section 13.5.4, it was predicted that residual water quality impacts at the site scale or further afield would be negligible (not significant) in the short term or longer within those watercourses draining pipeline RoW/access way alignment construction areas traversing shallow- and steep-gradient karst terrain, in the Lake Kutubu catchment, and in swamps, floodplains and wetlands, as well as at construction sites at the production facilities, laydown areas, quarries, the Kopi wharf development and the Omati River landfall. Therefore, residual impacts due to increased suspended sediment concentrations on macroinvertebrates inhabiting watercourses within these terrain types at the site scale or further afield are predicted to be negligible (not significant). However, significant increased suspend sediment concentrations due to project construction activities are expected in those rivers draining steep terrain with readily erodible volcanic soils, and these are discussed below.

Table 13.6 in Section 13.5.4 indicates that the predicted suspended sediment concentrations at high flows (represented by the 10% exceedence flow duration) in the lower Pawgano and Maruba river mainstems will increase during construction by 70 mg/L from an estimated background value of 80 mg/L to a total of 150 mg/L (about a 90% increase) and by 65 mg/L from an estimated background value of 80 mg/L to a total of 145 mg/L (about an 80% increase), respectively. Since high flows in the Pawgano and Maruba rivers are intermittent, occurring over 36.5 days per year for the 10% exceedence flow duration, the benthic macroinvertebrate populations will also be exposed intermittently to these elevated suspended sediment concentrations.

The effects of suspended sediments on benthic macroinvertebrates are time-concentration dependent, and the suspended sediment concentrations occurring at median flows (represented by the 50% exceedence flow duration) are those to which macroinvertebrates are exposed for the longest period of the time. Table 13.6 in Section 13.5.4 indicates that the predicted suspended sediment concentrations at median flows (represented by the 50% exceedence flow duration) in the lower Pawgano and Maruba river mainstems will increase during construction by 15 mg/L from an estimated background value of 40 mg/L to a total of 55 mg/L (about a 40% increase) and by 10 mg/L from an estimated background value of 40 mg/L to a total of 50 mg/L (25% increase), respectively. Since median flows in the Pawgano and Maruba rivers occur over a longer period (about 183 days per year) for the 50% exceedence flow duration, macroinvertebrates will also be exposed more frequently to those levels.

Note that there are no predicted increases in suspended sediment concentrations at low flows (represented by the 90% exceedence flow duration), owing to the absence of significant overland flow and little or no fine sediment delivery from surface erosion of construction-disturbed soils or sidecast spoil to the rivers.

Supporting Study 12 presents data to demonstrate that many benthic macroinvertebrate species tolerate much higher suspended sediment concentrations than those predicted above for high and median flows in the Pawgano and Maruba rivers. Therefore, most benthic macroinvertebrates inhabiting the mainstems of the Pawgano and Maruba rivers would be expected to tolerate intermittent but prolonged exposure to these predicted short-term increases in suspended sediment concentrations at high flows during the first year following construction. However, the in-river sedimentation impacts outlined above are expected to already have impacted the benthic macroinvertebrates of the mainstream habitats affected by construction, and those that survive and remain would be exposed to ongoing elevated suspended sediment concentrations.

In conclusion, the primary physical impact of construction-derived sediments on the benthic macroinvertebrate fauna of the Pawgano and Muruba river mainstems is expected to arise from in-stream sedimentation of macroinvertebrate habitats, which is expected to predominate over and mask the potential impacts of increased suspended sediment concentrations. Overall, residual impacts on the macroinvertebrate fauna of the Pawgano and Maruba rivers at the site and local scales are predicted to be moderate and minor, respectively. Residual impacts at the regional scale (i.e., the receiving Hegigio River) are predicted to be negligible (not significant). The recovery potential is expected to be high and will occur progressively as benthic habitat quality improves through scouring and the clearing of bed sediments by flood flows and as the construction-derived increased suspended sediment concentrations diminish with time as construction-disturbed soil surfaces and sidecast spoil stabilise through revegetation.

Fish

Supporting Study 12 provides a review of the generalised effects of increased suspended sediment concentrations on fish. In summary, the generalised effects of project construction activities on fish populations are due to the physical alteration of fish habitats (sediment deposition), changes in water quality (increased suspended sediment concentrations), and indirect impacts on fish food sources (decreases in macroinvertebrate, algae and detritus availability).

The principal impacts of sedimentation and increased suspended sediment concentrations on fish are discussed below. The assessment of residual impacts on fish is undertaken in accordance with the impact assessment criteria defined in Section 13.6.1.

Increased Bed Sediment Loading and Sedimentation

Construction-related sedimentation is expected to cause localised changes in the structural diversity and quality of fish habitats in watercourses in the vicinity of sediment production sources along the pipeline RoW/access way alignments and other construction areas. Indirect impacts are expected to arise from the loss or reduction of fish food resources, such as benthic algae and macroinvertebrates (see above). The response of fish populations to these changes varies with species, life stage, season, and habitat requirements.

In Section 13.4.4, it was predicted that residual impacts on bed sediment loading at the site scale and further afield would be negligible (not significant) in the short term or longer for pipeline RoW/access way alignments on flat or shallow-gradient karst terrain, in the Lake Kutubu catchment, or in swamps, floodplains and wetlands, as well as for construction sites at the production facilities, laydown areas, quarries, the Kopi wharf development and the Omati River landfall. Therefore, residual impacts of increased bed sediment loads and in-stream sedimentation impacts on fish and their habitats at the site scale and further afield within these aforementioned areas are predicted to be negligible (not significant). However, significant sedimentation impacts are expected in those rivers draining steep terrain with readily erodible volcanic soils, and these are discussed below.

In Section 13.4.4, it was predicted that residual bed sediment loading and sedimentation impacts in the middle Pawgano and Maruba river mainstems at the site scale would be moderate in the short term and negligible (not significant) in the medium to long term. At the local scale, residual bed sediment loading and sedimentation impacts in the lower Pawgano and Maruba river mainstems are predicted to be minor in the short term and negligible (not significant) in the medium to long term. Therefore, residual impacts of increased bed sediment loading on the resident fish fauna and their habitats of these two rivers at the site and local scales are predicted to be moderate and minor, respectively. The moderate residual impacts at the site scale will result in a reduction in the biomass and diversity of fish species in the short term. In the medium term and longer, fish recolonisation will be rapid as riverine habitats clear of settled sediments, as water quality improves (see suspended sediments discussion below), and as fish food resources, such as macroinvertebrates, recover.

In those river reaches experiencing localised heavy deposits of sediment, the change from a stones-in-current or cobble substratum to one where gravels and sands having a reduced number of void spaces predominate is expected to temporarily reduce the structural diversity of stream-bottom fish habitats. The obliterative and sub-obliterative impacts of sediment deposition are expected to temporarily reduce the survival of the eggs, larvae and juvenile stages in the life cycle of those fish species, such as river gobies, gudgeons and tandans, that depend on such habitat types for breeding.

The primary impacts of sediment deposition on the mainstream fish populations of the Pawgano and Maruba river mainstems are expected to be manifested as a temporary reduction in rather than a total loss of fish density and biomass, which can be attributed to alteration to mainstream fish habitats and spawning sites and to a reduction of fish food organisms, such as benthic macroinvertebrates. Tributaries unaffected by construction will continue to provide a source of fish food, such as benthic macroinvertebrates (drift), terrestrial organic materials (e.g., fruits and seeds) and terrestrial invertebrates, which are expected to be utilised by those fish species in the Pawgano and Maruba river mainstems capable of maintaining populations (albeit temporarily reduced) at the mouths and immediately downstream of these tributaries.

Recovery from the effects of sedimentation on fish habitats is expected to be rapid once the source of sediment supply is removed, as rising or flood flows scour and resuspend deposited sediments and transport them further downstream with little re-deposition.

Sediment deposition and smothering impacts on the eggs and early life stages of fish in the Pawgano and Maruba river mainstems will be countered by the preponderance of alternative spawning areas within side tributaries that will remain unaffected by project construction activities. It is more than likely that Pawgano and Maruba river mainstream fish species, such as the predominant river gobies, gudgeons and tandans, also breed and maintain self-sustaining populations in these tributaries, thus forming a recruitment source for mainstem riverine fish populations. Upstream migration from the Hegigio River mainstem will also serve to maintain fish populations in the Pawgano and Maruba rivers.

Increased Suspended Sediment Concentrations and Turbidity

Supporting Study 12 provides a review of the generalised effects of suspended sediment concentrations on freshwater fish fauna. In summary, the generalised effects of suspended solids on fish may be considered both directly and indirectly at both the species and population level. Lethal effects include mortality of fish and eggs and sub-lethal effects include suppression of growth and productivity and behavioural avoidance. Excessive concentrations of suspended sediments tend to be abrasive to fish body integuments, particularly the gills, causing tissue damage or the clogging of gill filaments and lamellae. Reduced survival of eggs, embryos, larvae, and juvenile stages in the life cycle of many fish species is a potential consequence of increased suspended sediment concentrations.

Numerous studies have documented the effects of total suspended sediments (TSS) and the deposition of the settleable solids component on fish populations (Berry et al., 2003; Caux et al., 1997; Waters, 1995; Newcombe & MacDonald, 1991; Ryan, 1991; Bruton, 1985; Alabaster & Lloyd, 1982; Peters, 1965). In general, the US EPA (2001) states that acute effects of TSS concentrations on fish are commonly observed at 80,000 mg/L with death occurring at 200,000 mg/L. Tolerance is more evident and recovery is more rapid at lower exposure levels (US EPA, 1977).

Table 13.8 presents a summary of laboratory experimental data on the effects of very high TSS concentrations on fish survival, mortality and tolerance. The data in Table 13.8 have been extracted from information provided in Supporting Study 12, which also provides the relevant references.

Table 13.8 Summary of the survival of selected freshwater fish species exposed to different concentrations of fine-grained sediments

Species	Life Stage	Medium	TSS (mg/L)	Duration (days)	Survival (%)
Rainbow trout	Adults	Mineral solids	5,000 to 300,000	>7	100
16 species	Adults	Montmorillonite clay	100,000	>7	100
Goldfish/carp	Adults	Montmorillonite clay	100,000	>7	100
Rainbowfish	Adults	Fine mine tailing	13,000	>7	100
Harlequin	Adults	Bentonite clay	6,000	>7	100
Zebrafish	Adults	Kaolin clay	2,000	>6	100
Redbreast tilapia	Juveniles	Silt	21,000 to 42,000	LC50*	50
Redbreast tilapia	Adults	Silt	42,000 to 48,000	LC50	50
Rainbow trout	Fingerlings	Gypsum clay	4,250	>17	50

Note: Data extracted from Supporting Study 12. * LC50 = lethal concentration at which half (50%) of a batch of laboratory fish died. The fish species listed (except for introduced carp) are not present in Papua New Guinea.

Most of the test fish species included in Table 13.8 have been demonstrated to survive or tolerate a range of very high concentrations of fine-grained TSS (range 4,250 to 300,000 mg/L) for about a week or more. Table 13.8 highlights the fact that both clear-water fish (e.g., rainbow trout) and turbid-water species (e.g., common carp) can tolerate short periods of turbid water with extremely high suspended sediment concentrations (range of 4,250 to 300,000 mg/L) for about a week or more – far greater than those concentrations predicted to occur in the mainstems of the Pawgano and Maruba rivers during the construction period (see below).

In Section 13.5.4, it was predicted that residual impacts on water quality (suspended sediments) of watercourses on flat karst terrain, steep karst terrain, swamplands and floodplains, in the Lake Kutubu catchment, and at the Kopi wharf and the Omati River landfall sites at the site scale or further afield would be negligible (not significant) in the short term or longer. Therefore, residual impacts of increased suspended sediment concentrations on fish at the site scale or further afield are predicted to be negligible (not significant). However, residual water quality impacts (suspended sediments) are predicted to be higher in steep terrain with readily erodible volcanic soils, such as the Pawgano to Maruba rivers section of the proposed Homa to Idauwi access way alignment. Suspended sediment residual impacts on fish in this steep terrain are discussed below.

Table 13.6 in Section 13.5.4 indicates that suspended sediment concentrations at high flows (represented by the 10% exceedence flow duration) in the lower Pawgano and Maruba river mainstems will increase during construction by 70 mg/L from an estimated background value of 80 mg/L to a total of 150 mg/L (about a 90% increase) and by 65 mg/L from an estimated background value of 80 mg/L to a total of 145 mg/L (about an 80% increase), respectively. Since high flows in the Pawgano and Maruba rivers are intermittent, occurring over 36.5 days per year for the 10% exceedence flow duration, the river mainstem fish populations will also be exposed intermittently to these elevated suspended sediment concentrations.

The effects of suspended sediments on freshwater fish are time-concentration dependent, and the suspended sediment concentrations occurring at median flows (represented by the 50% exceedence flow duration) are those to which fish would be exposed for the longest period of the time. Table 13.6 in Section 13.5.4 indicates that suspended sediment concentrations at median flows (represented by the 50% exceedence flow duration) in the lower Pawgano and Maruba river mainstems will increase during construction by 15 mg/L from an estimated background value of 40 mg/L to a total of 55 mg/L (about a 40% increase) and by 10 mg/L from an estimated background value of 40 mg/L to a total of 50 mg/L (25% increase), respectively. Since median flows in the Pawgano and Maruba rivers occur over a longer period (about 183 days per year) for the 50% exceedence flow duration, then fish would be exposed more frequently to these suspended sediment levels. Such small increments in suspended sediment concentrations at median flows attributable to project construction activities are expected to be readily tolerated by both clear-water and turbid-water fish species in the Pawgano and Maruba rivers.

Note that there are no predicted increases in suspended sediment concentrations at low flows (represented by the 90% exceedence flow duration), owing to the absence of significant overland flow and little or no fine sediment delivery from surface erosion of construction-related soils or sidecast spoil to the rivers. The small construction-related increases in suspended sediment concentrations at median flows and the absence of suspended sediment concentrations at low flows provide windows of opportunity for clear-water (sediment-intolerant) fish to enter or leave the mainstems of the Pawgano and Maruba rivers, as well as to undertake migrations or other longitudinal movements and to forage for food.

Overall, residual impacts on the fish fauna of the Pawgano and Maruba river mainstems at the site and local scales are predicted to be moderate and minor, respectively. Residual impacts at the regional scale (i.e., the receiving Hegigio River mainstem) are predicted to be negligible (not significant). The recovery potential of viable, self-sustaining fish populations in the Pawgano and Maruba river mainstems is expected to be high and to occur progressively as fish habitat quality improves through scouring and the clearing of bed sediments by flood flows, and as the increased suspended sediment concentrations diminish with time as construction-disturbed soil surfaces and sidecast spoil stabilise through natural and active revegetation. Stock recruitment and recolonisation will occur via upstream migration from the Hegigio River, by lateral migration from unaffected side tributaries (including the Kondari River) and by downstream displacement of fry and juveniles from the rivers' catchments upstream of the pipeline RoW/public road construction areas. The monitoring of fish in project-impacted watercourses will be included in the Environmental Management Plan (see Chapter 18).

Freshwater Turtles

Section 9.4.6 highlighted that six species of freshwater turtles inhabit the river systems of the project area. Most of the adults of these species tend to inhabit slow-moving river mainstems (both freshwater and estuarine reaches), grassy lagoons, swamps, lakes and water holes in the lower Kikori and Omati rivers and the Kikori-Omati delta.

In Sections 13.4.4 and 13.5.4, it was predicted that the residual impacts of bed sediment loading and increased suspended sediment concentrations at the site scale or further afield would be negligible (not significant) in the short term and longer for watercourses located on flat or low-lying karst terrain, in swamplands or floodplains and for watercourses receiving runoff from construction sites at the production facilities, laydown areas, quarries and borrow pits, the Kopi wharf development and Omati River landfall location. Therefore, residual impacts on freshwater turtles living in watercourses draining these terrain types and habitats at the site scale or further afield are predicted to be negligible (not significant). It is also unlikely that freshwater turtles are present in the steep-gradient, fast-flowing and turbid Pawgano and Maruba rivers, where aquatic habitat impacts are anticipated (see above).

In Section 13.5.4, it was predicted that no residual water quality impacts on Lake Kutubu would occur, owing to the implementation of appropriate site-specific mitigation and management measures to limit both coarse and fine sediment delivery to the lake's inflow streams. Therefore, no impacts on the turtle fauna of this lake are anticipated.

Crocodiles

Section 9.4.7 revealed that both the New Guinea freshwater crocodile and the saltwater crocodile are frequently found in turbid waters, mainly in the lower reaches of the Omati and Kikori rivers and their tributaries in Sections 13.4.4 and 13.5.4, it was predicted that residual impacts due to increased bed sediment loading and sedimentation and water quality at the site scale or further afield would be negligible (not significant) in the short term or longer. Therefore, residual impacts on crocodiles are predicted to be negligible (not significant). The absence of crocodiles in the Pawgano and Maruba rivers has not been confirmed, but their presence is unlikely given the high-flow regimes, and lack of floodplain swamp habitats and wetlands.

Amphibians

Section 13.7.4 assesses the impact of project construction activities on the amphibian fauna in the project area and employs spatial, temporal and severity impact assessment criteria (see Section 13.7.1) that are different from those used to assess residual impacts of the project on the aquatic environment. However, project construction-related changes on the aquatic environment are expected to impact those amphibians that live in watercourses or have an aquatic life stage (e.g., tadpoles) that depends on a specific type of habitat and water quality. Residual impacts are assessed below using the spatial and temporal classifications outlined in Section 13.1.1 and the level classification criteria outlined in Section 13.6.1 above.

The main impacts on amphibians will arise from the temporary sedimentation of their in-stream habitats and reproductive sites and the smothering of their food resources. In Sections 13.4.4 and 13.5.4, it was predicted that the residual impacts of bed sediment loading and increased suspended sediment concentrations at the site scale or further afield would be negligible (not significant) in the short term or longer for watercourses located on flat or low-lying karst terrain, in swamplands or floodplains, and for watercourses receiving runoff from construction sites at the production facilities, laydown areas, quarries and borrow pits, and the Kopi wharf development and Omati River landfall sites. Therefore, in the aforementioned watercourses, residual impacts of increased bed sediment loading and sedimentation on the aquatic life stages of amphibians at the site scale are predicted to be negligible (not significant) in the short term or longer. However, significant sedimentation and water quality impacts are expected in those rivers draining steep terrain with readily erodible volcanic soils, and these are discussed below.

In Sections 13.4.4 and 13.5.4, it was predicted that residual impacts from sedimentation and water quality changes (due to increased suspended sediment concentrations) in the middle Pawgano and Maruba river mainstems at the site scale would be moderate in the short term and negligible (not significant) in the medium to long term. At the local scale, residual bed sediment loading and sedimentation impacts in the lower Pawgano and Maruba river mainstems are predicted to be minor in the short term and negligible (not significant) in the medium to long term. Therefore, residual impacts due to increased bed and suspended sediment loading on the resident amphibian fauna (if present), their aquatic life stages and their habitats in these two rivers at the site and local scales are assessed in the short term to be moderate and minor, respectively. In the medium and longer term, residual impacts on amphibian fauna are predicted to be negligible (not significant) at the site and local scales in these two rivers.

The moderate and minor residual impacts discussed above at the site and local scales are expected to result in short-term reductions in the population densities of tadpoles brought about directly by mortality and downstream displacement and indirectly by a reduction in their food resources. However, potential impacts will be tempered by the presence of unaffected side tributaries, which are expected to harbour and maintain amphibian populations, including their aquatic life stages. In addition, the gills of tadpoles are simple and are not readily clogged by suspended sediments.

Recovery of amphibian habitat quality is expected to be rapid as project-related watercourse beds clear of settled sediments, as water quality improves, and as tadpole food resources, such as benthic algae, periphyton, diatoms and organic debris, rapidly recover.

Aquatic Mammals

Section 9.4.9 highlighted that three species of dolphins frequent the Omati-Kikori delta and occasionally enter the turbid freshwater reaches of the lower Omati and lower Kikori rivers. Potential impacts on those dolphin species during construction relate mainly to the generation of noise by localised construction works, as the very limited increased bed and suspended sediment loading at the Kopi wharf development and Omati River landfall at the site scale or further afield are predicted to be negligible (not significant) in the short term or longer and since these dolphin species frequent highly turbid waters, especially the Irrawaddy dolphin, which prefers turbid coastal waters and estuaries in southern Papua New Guinea and northern Australia.

Section 13.9 addresses aerial noise generated during construction. Underwater noise generation has not been evaluated for the lower Omati and Kikori rivers, owing to the general absence of sensitive aquatic mammalian species, such as baleen whales. However, the likely residual impacts of underwater noise on dolphins have been assessed qualitatively below.

No site-specific mitigation measures for dolphins are considered necessary given their high-frequency hearing thresholds, their high manoeuvrability and ability to readily avoid the sound field generated by localised construction activities, and their very occasional appearance in the lower Omati River and lower Kikori River.

Potential disturbance of dolphins by noise associated with the Kopi wharf development and construction of the Omati River landfall will only last as long as the construction activities themselves (i.e., a relatively short time period). It is anticipated that free-ranging dolphins will have the opportunity to avoid the sound field generated by the localised construction works at the Kopi wharf development and the Omati River landfall site by swimming away from these ensonified areas, should received sound levels be perceived as being threatening or become uncomfortable to their auditory systems. At the site scale or further afield, residual impacts of underwater noise on free-ranging dolphins entering and approaching the construction areas of the lower Omati and Kikori rivers are predicted to be negligible (not significant).

Aquatic Resource Use

The residual impacts of the project on aquatic resource use have been assessed in terms of impacts on village water supplies and other water uses, such as artisanal and subsistence fisheries.

Water Use

The water resources of the project area are relatively underdeveloped and under-utilised and, in general, several potable water sources are available to most villages. Most villagers abstract water for domestic uses (e.g., water for drinking, cooking and washing) from springs, groundwater and small clear-water streams. The mainstems of the larger rivers and tributaries of the project area are generally not used as a source of water supply, owing mainly to their turbidity.

In Section 13.5.4, it was predicted that the residual impacts of increased suspended sediment concentrations at the site scale or further afield would be negligible (not significant) in the short term or longer for watercourses located on flat or low-lying karst terrain, in swamplands or floodplains and for watercourses receiving runoff from construction areas, such as at the production facilities, laydown areas, quarries and borrow pits, and the Kopi wharf development and the Omati River landfall locations. The principal water quality impacts are associated with the watercourses that drain steep terrain with readily erodible soils, namely the Pawgano and Maruba rivers section of the proposed Homa to Idauwi pipeline RoW/public road alignment. However, there are no villages downslope or downstream of the proposed RoW/public road alignment within the Pawgano and Maruba rivers, and therefore there are no village water supplies that will be affected by project construction activities in this area.

Artisanal and Subsistence Fisheries

Residual impacts on fish are limited to the mainstems of the Pawgano and Maruba rivers downriver of the proposed pipeline RoW/public road alignment (see above). Since there are no villages in the middle and lower valleys of these two rivers, potential impacts on subsistence fisheries is negligible (not significant) at the site and local scales.

The key sites of artisanal or subsistence fishing in the project area are based on the fish resources of Lake Kutubu and the Omati-Kikori delta. In Section 13.5.4, it was predicted that there is unlikely to be any water quality impacts on Lake Kutubu, owing to the implementation of appropriate site-specific mitigation and management measures along the pipeline RoW/upgraded access way alignment within the inflow catchments of this lake. Therefore, no residual impacts on the artisanal and subsistence fisheries of Lake Kutubu are anticipated. Likewise, the absence of bed sediment loading and water quality residual impacts in the estuarine reaches of the lower Kikori and Omati rivers (see Sections 13.4.4 and 13.5.4) means that there will be no residual impacts on estuarine artisanal or subsistence fisheries.

13.6.4.2 Operations

In Section 13.5.4, it was predicted that there will be no residual water quality impacts from treated production facility site runoff or treated sewage effluents, since the discharges will be treated to comply with effluent quality standards included in the relevant waste discharge permits. Therefore, no residual impacts on aquatic ecology at the site scale or further afield are anticipated during operations.

The project's water quality and aquatic biological monitoring programs will be utilised to verify that residual impacts on aquatic ecology are as predicted (see Chapter 18). If unforeseen impacts occur, appropriate remedial mitigation and management measures will be implemented to reduce impacts.

13.6.5 Residual Impact Summary

13.6.5.1 Construction

Table 13.9 presents a summary of residual impacts on the aquatic habitats, aquatic flora and fauna, and water-associated fauna of project-area watercourses and water bodies during construction. The table highlights the fact that significant impacts on the aquatic habitats, flora and fauna of the project area are mainly limited to those watercourses (i.e., Pawgano and Maruba rivers) draining areas with steep terrain and readily erodible volcanic soils. Watercourses draining all other types of terrain and construction sites are predicted to have negligible (not significant) impacts in the short term or longer.

Table 13.9 Summary of residual impacts on the aquatic ecology of watercourses in the project area during construction

Spatial Scale	Site Scale (up to 2 km downstream)			Local Scale (between 2 km and 10 km downstream)			Regional Scale (greater than 10 km downstream)		
Temporal Scale	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**	**Short (<1 yr)**	**Medium (1 to 5 yrs)**	**Long (>5 yrs)**
Residual Impacts on aquatic habitats:									
Shallow-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient terrain with volcanic soils*	Moderate	N	N	Minor	N	N	N	N	N
Lake Kutubu catchment	N	N	N	N	N	N	N	N	N
Swamplands and wetlands	N	N	N	N	N	N	N	N	N
Kopi wharf development	N	N	N	N	N	N	N	N	N
Omati River landfall	N	N	N	N	N	N	N	N	N
Residual Impacts on aquatic flora and fauna:									
Shallow-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient terrain with volcanic soils*	Moderate	N	N	Minor	N	N	N	N	N
Lake Kutubu catchment	N	N	N	N	N	N	N	N	N
Swampland and wetlands	N	N	N	N	N	N	N	N	N
Kopi wharf development	N	N	N	N	N	N	N	N	N
Omati River landfall	N	N	N	N	N	N	N	N	N

Table 13.9 Summary of residual impacts on the aquatic ecology of watercourses in the project area during construction (cont'd)

Spatial Scale	Site Scale (up to 2 km downstream)			Local Scale (between 2 km and 10 km downstream)			Regional Scale (greater than 10 km downstream)		
Temporal Scale	Short (<1 yr)	Medium (1 to 5 yrs)	Long (>5 yrs)	Short (<1 yr)	Medium (1 to 5 yrs)	Long (>5 yrs)	Short (<1 yr)	Medium (1 to 5 yrs)	Long (>5 yrs)
Residual Impacts on water-associated fauna (frogs, freshwater turtles, crocodiles and dolphins):									
Shallow-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient karst	N	N	N	N	N	N	N	N	N
Steep-gradient terrain with volcanic soils*	N	N	N	N	N	N	N	N	N
Lake Kutubu catchment	N	N	N	N	N	N	N	N	N
Swampland and wetlands	N	N	N	N	N	N	N	N	N
Kopi wharf development	N	N	N	N	N	N	N	N	N
Omati River landfall	N	N	N	N	N	N	N	N	N

Note: N = Negligible (not significant). * Pawgano and Maruba rivers section of the proposed Homa to Idauwi pipeline RoW/public road alignment.

Figure 13.1 shows the aquatic biological impacts zones in the Pawgano and Maruba river mainstems affected by project construction in the short term (up to 1 year) and within the medium term (between 1 and 5 years).

In the short term (i.e., at the end of Year +1), the aquatic biological impact zones are classified as being major at the site scale, moderate to minor at the local scale, and negligible (not significant) at the regional scale of the receiving Hegigio River (see Figure 13.1 for impact criteria boxes). Within the medium term (i.e., at end of Year +2), the aquatic biological impact zones are classified as being minor at the site scale and negligible (not significant) at the local and regional scales. At the end of Year +3 (i.e., within the medium term and longer), the aquatic biological impact zones at the site, local and regional scales are classified as negligible (not significant). The sequence of aquatic biological impact zone maps shown in Figure 13.1 shows the relatively rapid recoveries of the mainstem aquatic ecosystems of the Pawgano and Maruba rivers.

The derivation of the aquatic biological impact zones in Figure 13.1 is based on integration of the residual impact assessments for aquatic habitats, fish and their food resources (i.e., aquatic flora and benthic macroinvertebrates) and professional knowledge and judgment. The aquatic biological zones represent a first approximation of project construction effects on the aquatic environment as a whole, which will be assessed by appropriate monitoring (see Chapter 18).

13.6.5.2 Operations

No significant residual impacts on the aquatic habitats, flora and fauna, and water-associated fauna of watercourses or water bodies in the project area are predicted during operations.

13.7 Biodiversity

The impact analysis presented in this section is based on the large volume of information and analysis contained in the specialist biodiversity studies (Supporting Studies 2 to 6). These studies identified a number of potential project-related impacts to be analysed and suggested several mitigation options that warranted further evaluation. The findings of these supporting studies were brought together in an overview (Supporting Study 1), which collated the suggested lines of impact analysis and potential mitigation options and expanded them into a detailed assessment of individual project components.

The assessment was further developed through a series of project team workshops involving design engineers, with particular attention being focussed on identifying appropriate mitigation options. Each potential mitigation option was individually evaluated based on its potential effectiveness, safety, practicality and cost, and based on this analysis, mitigation measures were either accepted, rejected or refined.

Supporting Study 1 presents detailed impact assessments in 12 tables, each of which addresses the nature of the impact, its likely level without mitigation, its potential duration, possible mitigation approaches and an assessment of the residual level of the impact after the application of appropriate mitigation measures. Table 13.10 presents the project focus of each of these detailed impact analysis tables.

Table 13.10 Focus of impact assessment tables in Supporting Study 1

Table	Impacts Assessed
21	Impacts applicable to the entire project for both construction and operations.
22	Impacts applicable to all segments of pipeline RoWs and access ways.
23	Hides Ridge area - development of Hides wellpads.
24	Hides Ridge area - drilling camp.
25	Hides Ridge area – segment 1 of proposed route - Hides gas gathering system and access way to Hides 4 well.
26	Hides Production Facility.
27	Kutubu Central Gas Conditioning Plant.
28	Gobe and Agogo Production Facilities modification.
29	Kopi modifications and new wharf.
30	Temporary construction camps.
31	Segments 2 to 14 of proposed sales gas pipeline route and associated access ways (includes the Gobe rich gas pipeline).
32	Kutubu to Hides glycol return line, Agogo rich gas pipeline, and associated access ways.

13.7.1 Residual Impact Assessment Criteria

The criteria for assessing the residual impacts associated with project-related activities that were used in Supporting Study 1 are followed in this section. Residual impacts were categorically classified according to potential level, area of influence and duration.

The classes of level of impacts are as follows:

- Very High (V) – Highly likely to have a very large impact on species' population, community or ecosystem survival or health, possibly even leading to extinction or system collapse.
- High (H) – Likely to have a significant negative impact on species' population, community or ecosystem survival or health.
- Moderate (M) – Detectable but not significant; species' populations or the areal extent of communities may be reduced but major changes to species' population, community or ecosystem survival or health are unlikely.
- Low (L) – Detectable but small and highly unlikely to have any significance.
- Negligible (I) – Unlikely to be detectable.

The extent of an impact is assessed as follows:

- Widespread (5) – In a large area of the Kikori Integrated Conservation and Development Program (KICDP) area (>approx 10%) up to the national scale.
- Regional (4) – In a large part (up to 10%) of the KICDP area region.
- Local (3) – Generally occurring within 10 km of a project-related impact site.
- Limited (2) – Immediate vicinity of a project-related impact site and extending for up to a 2 km radius.
- Very limited (1) – Immediate vicinity of a project-related impact site and extending for <200 m in radius.

This generates an impact evaluation matrix as follows:

Level	**Extent**				
	Very Limited (1)	**Limited (2)**	**Local (3)**	**Regional (4)**	**Widespread (5)**
Very high (V)	V1	V2	V3	V4	V5
High (H)	H1	H2	H3	H4	H5
Moderate (M)	M1	M2	M3	M4	M5
Low (L)	L1	L2	L3	L4	L5
Negligible (I)	I	I	I	I	I

The duration of an impact was assessed as follows:

- Short term (S) – lasting less than 7 years.
- Medium term (M) – lasting up to 25 years.
- Long term (L) – lasting more than 25 years.

The likely significance before the application of appropriate mitigation measures is based on estimates of impact level (negligible, low, moderate, high and very high) combined with the likely geographic extent of impact (scale of 1 very limited to 5 widespread).

13.7.2 Issues to be Addressed

For this section, the impacts in Supporting Study 1 have been grouped into thirteen and seven categories of direct and indirect impacts respectively. Table 13.11 relates these impacts to habitat and flora and fauna, and to the construction and operations phases of the project.

Table 13.11 Types of impacts on biodiversity during construction or operations activities of the PNG Gas Project

Impact Type	Construction		Operations	
	Habitat and Flora	Fauna	Habitat and Flora	Fauna
Direct Impacts				
Habitat loss	X	X		
Edge effects	X	X	A	A
Barrier effects	X	X	A	A
Fauna falling into the pipeline trench		X		
Hunting by project workers and contractors		X		X
Collection of flora by project workers and contractors	X		X	
Erosion, movement of spoil and changes to hydrology	X	X	A	A
Materials handling	X	X	C	C
Disposal of hydrotest water	X	X		
Dust	X	X	C	C
Loss of breeding and display grounds		X		A
Noise, lights and other sensory disturbances		X		A
Traffic		X		C
Indirect Impacts				
Fire	X	X	I	I
Dieback	X	X	I	I
Invasive species – weeds	X	X	I	I
Invasive species – exotic pest fauna	X	X	I	I
Collection of flora by non-project personnel	X		I	
Hunting by non-project personnel		X		I
Improved access			I	I

Note: X = impact mainly during this activity; A = impact ameliorating with time; C = impact continuing but at a low level; I = impact possibly increasing with time.

Direct impacts are those that are caused by project-related construction and operations activities and occur at the same time and place at which the activity in question occurs.

Indirect effects are not immediately related to the project but are induced as a result of the project's presence. Indirect effects may occur at or far away from the project area and may occur at the same time or later.

13.7.3 Mitigation and Management Measures

The proposed mitigation and management measures related to biodiversity are presented in Tables 13.12 and 13.13, cross-referenced by the issue(s) they address and the project component they are relevant to.

Table 13.12 Proposed mitigation and management measures in relation to biodiversity impacts

Proposed Mitigation or Management Measures	Biodiversity Element			Project Activity		Primary (1) or Secondary (2) Focus of Proposed Mitigation or Management Measure																				
						Direct Impacts														Indirect Impacts						
	Habitat	Flora	Fauna	Construction	Operations	Habitat Loss	Edge Effects	Barrier Effects	Physical Damage and Disturbance to Caves	Fauna Falling into the Pipeline Trench	Hunting by Project Workers and Contractors	Erosion, Movement of Spoil and Changes to Hydrology	Materials Handling	Disposal of Hydrotest Water	Dust	Loss of Breeding and Display Grounds	Noise, Lights and Other Sense Disturbance	Traffic and other Operation	Collection of flora by Project Workers and Contractors	Fire	Dieback	Invasive Species – Weeds	Invasive Species – Exotic Pest Fauna	Hunting by Non-Project Individuals	Collecting of Flora by Non-Project Individuals	Improved Access
Provide environmental sensitivity training to the project workforce that includes an overview of key flora and fauna issues, mitigation measures and policies/prohibitions related to wildlife disturbance/harassment, hunting and vegetation gathering.	X	X	X	X	X	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
The combined pipeline and access way RoW not to exceed the nominal design width with the exceptions of passing bays and pipe truck turning circles.	X	X	X	X		1	2	2				2														
Machinery will not leave pipeline or access way RoWs to unnecessarily clear forest.	X	X	X	X	X	1	1	1				2														
Limit the nominal width of the combined RoW and access way on Hides Ridge to 12 m for construction and revegetate the RoW and access way except for the 7-m-wide track required for maintenance access during operations and future drilling campaigns.	X	X	X	X		1	1	1				2														
If practicable, allow tree canopies to touch over the reclaimed access way in the narrower sections of the RoW or establish closed canopy 'bridges' periodically (e.g., 20-m-wide 'bridge' every 1 km).			X		X		1	1																		
If practicable and safe, retain trees over 1 m dbh.	X	X	X	X	X	1										1										

Table 13.12 Proposed mitigation and management measures in relation to biodiversity impacts (cont'd)

Proposed Mitigation or Management Measures	Biodiversity Element			Project Activity		Primary (1) or Secondary (2) Focus of Proposed Mitigation or Management Measure																				
						Direct Impacts														Indirect Impacts						
	Habitat	Flora	Fauna	Construction	Operations	Habitat Loss	Edge Effects	Barrier Effects	Physical Damage and Disturbance to Caves	Fauna Falling into the Pipeline Trench	Hunting by Project Workers and Contractors	Erosion, Movement of Spoil and Changes to Hydrology	Materials Handling	Disposal of Hydrotest Water	Dust	Loss of Breeding and Display Grounds	Noise, Lights and Other Sense Disturbance	Traffic and other Operation	Collection of flora by Project Workers and Contractors	Fire	Dieback	Invasive Species – Weeds	Invasive Species – Exotic Pest Fauna	Hunting by Non-Project Individuals	Collecting of Flora by Non-Project Individuals	Improved Access
Where practicable, utilise land clearing techniques that preserve the rootstock of removed vegetation in the ground.	X	X		X	X	X	X	X				X										X				
Fell trees either along the access of tracks/RoWs or so that they land in natural slots between standing trees to reduce damage to other trees.	X	X	X	X	X	2	1	1																		
Avoid the scraping of stems of standing trees on forest edge by machinery.	X	X	X	X	X	2	1	1																		
Assist revegetation in areas found to be slow to regenerate naturally.	X	X	X	X	X	1						1														
Where practicable, avoid routing access ways and pipelines: - Along side slopes, steep slopes, mid-slopes, and headwalls (at the source of tributary drainages). - Through swamps and wetlands. - In high erosion- and landslide-prone areas. - Through inner valley gorges. - On slopes where sidecast spoil material could directly enter streams or high-conservation value swamps at the base of some sinkholes.	X	X	X	X		1																				
The quarrying of rock on Hides Ridge will be avoided where practicable.	X	X	X	X		1																				

Table 13.12 Proposed mitigation and management measures in relation to biodiversity impacts (cont'd)

Proposed Mitigation or Management Measures	Biodiversity Element			Project Activity		Primary (1) or Secondary (2) Focus of Proposed Mitigation or Management Measure																				
						Direct Impacts														Indirect Impacts						
	Habitat	Flora	Fauna	Construction	Operations	Habitat Loss	Edge Effects	Barrier Effects	Physical Damage and Disturbance to Caves	Fauna Falling into the Pipeline Trench	Hunting by Project Workers and Contractors	Erosion, Movement of Spoil and Changes to Hydrology	Materials Handling	Disposal of Hydrotest Water	Dust	Loss of Breeding and Display Grounds	Noise, Lights and Other Sense Disturbance	Traffic and other Operation	Collection of flora by Project Workers and Contractors	Fire	Dieback	Invasive Species – Weeds	Invasive Species – Exotic Pest Fauna	Hunting by Non-Project Individuals	Collecting of Flora by Non-Project Individuals	Improved Access
Install appropriate erosion control measures to reduce sediment delivery to streams from quarries.	X	X	X		X	1																				
The number of special vehicle parks will be limited to the extent practicable.	X	X	X	X	X	1						2														
If practicable, establish only one Hides Ridge drilling camp at any one time.	X	X	X	X		1																				
Salvage timber felled during wellpad, pipeline, access way RoW, and facility site clearing for project uses to the extent practicable.	X	X	X	X		1																				
Direct lights to eliminate shine into the surrounding forest to the extent practicable.	X	X	X	X													1									
Implement speed limits along access way/pipeline RoWs.			X	X	X													1								
Herbicides will not be used unless for the eradication of a serious noxious weed.	X	X	X	X	X	1	1	1																		
Hydrotest water that may be discharged on Hides Ridge may be treated with a biocide to prevent cross-contamination with live aquatic organisms.	X	X	X	X										1									1			
The disposal of wastes from construction (not spoil) and operations activities into the forest or sinkholes will be avoided.	X	X	X	X									1													

Table 13.12 Proposed mitigation and management measures in relation to biodiversity impacts (cont'd)

Proposed Mitigation or Management Measures	Biodiversity Element			Project Activity		Primary (1) or Secondary (2) Focus of Proposed Mitigation or Management Measure																				
						Direct Impacts														Indirect Impacts						
	Habitat	Flora	Fauna	Construction	Operations	Habitat Loss	Edge Effects	Barrier Effects	Physical Damage and Disturbance to Caves	Fauna Falling into the Pipeline Trench	Hunting by Project Workers and Contractors	Erosion, Movement of Spoil and Changes to Hydrology	Materials Handling	Disposal of Hydrotest Water	Dust	Loss of Breeding and Display Grounds	Noise, Lights and Other Sense Disturbance	Traffic and other Operation	Collection of flora by Project Workers and Contractors	Fire	Dieback	Invasive Species – Weeds	Invasive Species – Exotic Pest Fauna	Hunting by Non-Project Individuals	Collecting of Flora by Non-Project Individuals	Improved Access
Procedures will be developed and implemented for the appropriate handling, transport, storage and disposal of materials including fuels, lubricating oils, drilling fluids, chemicals, and radionuclides, including: - Fuel, lubricating oils and chemicals will be stored in appropriately sized designated areas that have impervious liners and bunds. - Procedures for vehicle/equipment refuelling will be implemented to prevent spillages, and appropriate spill containment equipment will be available at refuelling sites. - Appropriate spill response equipment will be provided at construction sites, and at fuel storage and handling facilities.	X	X	X	X	X																					
The disposal of wastes from RoW/access way construction and drilling activities (not spoil) will not occur on Hides Ridge.	X	X	X	X									1													
Combustible non-dangerous wastes will be incinerated at project-specified sites.	X	X	X	X									1													

Table 13.12 Proposed mitigation and management measures in relation to biodiversity impacts (cont'd)

Proposed Mitigation or Management Measures	Biodiversity Element			Project Activity		Primary (1) or Secondary (2) Focus of Proposed Mitigation or Management Measure																				
						Direct Impacts														Indirect Impacts						
	Habitat	Flora	Fauna	Construction	Operations	Habitat Loss	Edge Effects	Barrier Effects	Physical Damage and Disturbance to Caves	Fauna Falling into the Pipeline Trench	Hunting by Project Workers and Contractors	Erosion, Movement of Spoil and Changes to Hydrology	Materials Handling	Disposal of Hydrotest Water	Dust	Loss of Breeding & Display Grounds	Noise, Lights and Other Sense Disturbance	Traffic and other Operation	Collection of flora by Project Workers and Contractors	Fire	Dieback	Invasive Species – Weeds	Invasive Species – Exotic Pest Fauna	Hunting by Non-Project Individuals	Collecting of Flora by Non-Project Individuals	Improved Access
Develop and implement appropriate bat protection measures, including: - Pre-construction surveys in areas likely to be inhabited by bats, especially in areas where blasting will occur. - Avoid blasting or use controlled blasting procedures, where practicable, within 100 m of known bat inhabited caves. - Survey potential quarry sites to ensure that they are not located on or near caves with bat colonies. - Avoid excavating or quarrying pinnacles with bat colonies. - Develop and implement appropriate measures if Bulmer's fruit bat is discovered.			X	X					1																	
Rescue and record fauna that fall into the open pipeline trench.			X	X						1																
Prohibition of the disturbance/harassment of wildlife, the hunting of fauna, or the gathering of plants or bush foods or the possession of wildlife products by project workers or contractors while working, travelling in project vehicles, and residing in project field accommodation.			X	X	X						1					1			1							

Table 13.12 Proposed mitigation and management measures in relation to biodiversity impacts (cont'd)

Proposed Mitigation or Management Measures	Biodiversity Element			Project Activity		Primary (1) or Secondary (2) Focus of Proposed Mitigation or Management Measure																				
						Direct Impacts														Indirect Impacts						
	Habitat	Flora	Fauna	Construction	Operations	Habitat Loss	Edge Effects	Barrier Effects	Physical Damage and Disturbance to Caves	Fauna Falling into the Pipeline Trench	Hunting by Project Workers and Contractors	Erosion, Movement of Spoil and Changes to Hydrology	Materials Handling	Disposal of Hydrotest Water	Dust	Loss of Breeding and Display Grounds	Noise, Lights and Other Sense Disturbance	Traffic and other Operation	Collection of flora by Project Workers and Contractors	Fire	Dieback	Invasive Species – Weeds	Invasive Species – Exotic Pest Fauna	Hunting by Non-Project Individuals	Collecting of Flora by Non-Project Individuals	Improved Access
Prohibition of the establishment of gardens and the introduction of exotic plants or live exotic animals by project workers and contractors.	X	X	X	X	X	1																1	1			
Establishment of a weeds and pathogen management plan to protect biodiversity of the Hides Ridge which will be detailed in the Environmental Management Plan (see Chapter 18).	X	X	X	X	X																1	1	1			
If a fire hazard exists at a location, allow removed/felled vegetation to rot at the forest edge rather than burning it.	X	X	X	X	X															1						
Develop and implement a fire management strategy for the project area.	X	X	X	X	X	1														1						
With the agreement of the impacted landowners, maintain the Hides Ridge access way as a private road for the life of the project and make the road impassable at the end of the project life (e.g., road will be ripped).	X	X	X	X	X																					1
Support WWF conservation activities in the project area during the construction phase.	X	X	X		X															1	1	1	1	1	1	1

Table 13.13 Relevance of proposed mitigation and management measures in relation to project sites

Proposed Mitigation or Management Measures	All Project Sites	Pipeline RoW/Access Way Segment														Noteworthy Areas				
		2 Hides 4 well to HPF	3 HPF to Maruba River	4 Maruba River to Kondari River	5 Upper Mubi River Segment	6 Kutubu Segment	7 Moro to Iwa Range	8 Ai'io River Segment	9 Ai'io River to Wassi Falls	10 Wassi Falls to Mubi Crossing	11 Mubi Crossing to Kikori Crossing	12 Kikori Crossing to Kopi	13 Kopi to Omati	14 Gobe Rich Gas Pipeline	Agogo Rich Gas Pipeline	Hides Ridge (Segment 2)	Sinkhole Swamps	Caves	Swamp Forest	Watercourse Crossings
Provide environmental sensitivity training to the project workforce that includes an overview of key flora and fauna issues, mitigation measures and policies/prohibitions related to wildlife disturbance/harassment, hunting and vegetation gathering.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
The combined pipeline and access way RoW not to exceed the nominal design width with the exceptions of passing bays and pipe truck turning circles.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Machinery will not leave pipeline or access way RoWs to unnecessarily clear forest.		X	X	X	X	X	X	X	X	X	X	X	X	X	X					X
Limit the nominal width of the combined RoW and access way on Hides Ridge to 12 m for construction and revegetate the RoW and access way except for the 7-m-wide track required for maintenance access during operations and future drilling campaigns.										X			X							
If practicable, allow tree canopies to touch over the reclaimed access way in the narrower sections of the RoW or establish closed canopy 'bridges' periodically (e.g., 20-m-wide 'bridge' every 1 km).																X			X	
If practicable and safe, retain trees over 1 m dbh.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X
Where practicable, utilise land clearing techniques that preserve the rootstock of removed vegetation in the ground.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Fell trees either along the access of tracks/RoWs or so that they land in natural slots between standing trees to reduce damage to other trees.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X

Table 13.13 Relevance of proposed mitigation and management measures in relation to project sites (cont'd)

Proposed Mitigation or Management Measures	All Project Sites	Pipeline RoW/Access Way Segment													Noteworthy Areas				
		2 Hides 4 well to HPF	3 HPF to Maruba River	4 Maruba River to Kondari River	5 Upper Mubi River Segment	6 Kutubu Segment	7 Moro to Iwa Range	8 Ai'io River Segment	9 Ai'io River to Wassi Falls	10 Wassi Falls to Mubi Crossing	11 Mubi Crossing to Kikori Crossing	12 Kikori Crossing to Kopi	13 Kopi to Omati	14 Gobe Rich Gas Pipeline	Agogo Rich Gas Pipeline	Hides Ridge (Segment 2)	Sinkhole Swamps	Caves	Swamp Forest	Watercourse Crossings
Avoid the scraping of stems of standing trees on forest edge by machinery.				X				X		X					X	X				
Assist revegetation in areas found to be slow to regenerate naturally.							X	X	X	X				X	X	X	X		X	X
Where practicable, avoid routing access ways and pipelines: - Along side slopes, steep slopes, mid-slopes, and headwalls (at the source of tributary drainages). - Through swamps and wetlands. - In high erosion- and landslide-prone areas. - Through inner valley gorges. - On slopes where sidecast spoil material could directly enter streams or high-conservation value swamps at the base of some sinkholes.																X	X	X	X	X
The quarrying of rock on Hides Ridge will be avoided where practicable.	X															X		X		
Install appropriate erosion control measures to reduce sediment delivery to streams from quarries.	X																	X		
The number of special vehicle parks will be limited to the extent practicable.																X	X	X		
If practicable, establish only one Hides Ridge drilling camp at any one time.																X				
Salvage timber felled during wellpad, pipeline, access way RoW, and facility site clearing for project uses to the extent practicable.																X				
Direct lights to eliminate shine into the surrounding forest to the extent practicable.	X																			
Implement speed limits along access way/pipeline RoWs.	X																			

Table 13.13 Relevance of proposed mitigation and management measures in relation to project sites (cont'd)

Proposed Mitigation or Management Measures	All Project Sites	Pipeline RoW/Access Way Segment														Noteworthy Areas				
		2 Hides 4 well to HPF	3 HPF to Maruba River	4 Maruba River to Kondari River	5 Upper Mubi River Segment	6 Kutubu Segment	7 Moro to Iwa Range	8 Ai'io River Segment	9 Ai'io River to Wassi Falls	10 Wassi Falls to Mubi Crossing	11 Mubi Crossing to Kikori Crossing	12 Kikori Crossing to Kopi	13 Kopi to Omati	14 Gobe Rich Gas Pipeline	Agogo Rich Gas Pipeline	Hides Ridge (Segment 2)	Sinkhole Swamps	Caves	Swamp Forest	Watercourse Crossings
Herbicides will not be used unless for the eradication of a serious noxious weed.	X															X	X		X	X
Hydrotest water that may be discharged on Hides Ridge may be treated with a biocide to prevent cross-contamination with live aquatic organisms.	X															X	X		X	
The disposal of wastes from construction (not spoil) and operations activities into the forest or sinkholes will be avoided.																X	X			
Procedures will be developed and implemented for the appropriate handling, transport, storage and disposal of materials including fuels, lubricating oils, drilling fluids, chemicals, and radionuclides, including: - Fuel, lubricating oils and chemicals will be stored in appropriately sized designated areas that have impervious liners and bunds. - Procedures for vehicle/equipment refuelling will be implemented to prevent spillages, and appropriate spill containment equipment will be available at refuelling sites. - Appropriate spill response equipment will be provided at construction sites, and at fuel storage and handling facilities.	X															X	X	X	X	X
The disposal of wastes from RoW/access way construction and drilling activities (not spoil) will not occur on Hides Ridge.	X															X	X			
Combustible non-dangerous wastes will be incinerated at project-specified sites.	X															X	X			

Table 13.13 Relevance of proposed mitigation and management measures in relation to project sites (cont'd)

Proposed Mitigation or Management Measures	All Project Sites	Pipeline RoW/Access Way Segment														Noteworthy Areas				
		2 Hides 4 well to HPF	3 HPF to Maruba River	4 Maruba River to Kondari River	5 Upper Mubi River Segment	6 Kutubu Segment	7 Moro to Iwa Range	8 Ai'io River Segment	9 Ai'io River to Wassi Falls	10 Wassi Falls to Mubi Crossing	11 Mubi Crossing to Kikori Crossing	12 Kikori Crossing to Kopi	13 Kopi to Omati	14 Gobe Rich Gas Pipeline	Agogo Rich Gas Pipeline	Hides Ridge (Segment 2)	Sinkhole Swamps	Caves	Swamp Forest	Watercourse Crossings
Develop and implement appropriate bat protection measures, including: - Pre-construction surveys in areas likely to be inhabited by bats, especially in areas where blasting will occur. - Avoid blasting or use controlled blasting procedures, where practicable, within 100 m of known bat inhabited caves. - Survey potential quarry sites to ensure that they are not located on or near caves with bat colonies. - Avoid excavating or quarrying pinnacles with bat colonies. - Develop and implement appropriate measures if Bulmer's fruit bat is discovered.							X	X	X	X		X	X	X	X			X		
Rescue and record fauna that fall into the open pipeline trench.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	
Prohibition of the disturbance/harassment of wildlife, the hunting of fauna, or the gathering of plants or bush foods or the possession of wildlife products by project workers or contractors while working, travelling in project vehicles, and residing in project field accommodation.	X															X	X		X	X
Prohibition of the establishment of gardens and the introduction of exotic plants or live exotic animals by project workers and contractors.	X															X	X		X	X
Establishment of a weed and pathogen management plan to protect biodiversity of the Hides Ridge which will be detailed in the Environmental Management Plan (see Chapter 18).	X															X	X		X	X
If a fire hazard exists at a location, allow removed/felled vegetation to rot at the forest edge rather than burning it.	X															X	X		X	

Table 13.13 Relevance of proposed mitigation and management measures in relation to project sites (cont'd)

Proposed Mitigation or Management Measures	All Project Sites	Pipeline RoW/Access Way Segment														Noteworthy Areas				
		2 Hides 4 well to HPF	3 HPF to Maruba River	4 Maruba River to Kondari River	5 Upper Mubi River Segment	6 Kutubu Segment	7 Moro to Iwa Range	8 Ai'io River Segment	9 Ai'io River to Wassi Falls	10 Wassi Falls to Mubi Crossing	11 Mubi Crossing to Kikori Crossing	12 Kikori Crossing to Kopi	13 Kopi to Omati	14 Gobe Rich Gas Pipeline	Agogo Rich Gas Pipeline	Hides Ridge (Segment 2)	Sinkhole Swamps	Caves	Swamp Forest	Watercourse Crossings
Develop and implement a fire management strategy for the project area.																X	X			
With the agreement of the impacted landowners, maintain the Hides Ridge access way as a private road for the life of the project and make the road impassable at the end of the project life (e.g., road will be ripped).																X	X			
Support WWF conservation activities in the project area during the construction phase.	X															X	X	X	X	X

13.7.4 Residual Impact Assessment

The discussion related to residual impacts associated with biodiversity is structured as follows:

Section 13.7.4.1 analyses direct residual impacts. Section 13.7.4.2 analyses indirect residual impacts. Section 13.7.4.3 analyses residual impacts on noteworthy areas. Section 13.7.4.4 analyses residual impacts on listed species or species new to science. Section 13.7.4.5 analyses residual impacts on migratory fauna. Section 13.7.4.6 presents an overall conclusion related to terrestrial biodiversity residual impacts.

13.7.4.1 Direct Residual Impacts

Habitat Loss

Habitat loss is the major project-related direct impact on flora and fauna. Most habitat loss due to the PNG Gas Project will be to various types of tropical forest; only limited amounts of secondary forests, scrublands and grasslands will be cleared.

The main direct residual impact on flora is related to vegetation clearing for the pipeline RoWs, access ways, temporary camps, wellpads, expansions to existing facilities, new facilities, laydown areas, quarries and wharves. Clearing of vegetation will vary across the project area, as follows:

- The new facilities at Hides, Kutubu, Gobe and Agogo are all within or adjacent to the footprint of the existing facilities, and additional clearing will therefore be negligible.
- Between Hides Ridge and Kutubu, temporary construction camps will be located to the extent practicable in settled areas of grassland, secondary growth, remnant forest, gardens and open areas, all of low conservation value.
- Between Kutubu and Kopi, the previous Kutubu and Gobe construction camps will be redeveloped on the same sites, with no loss of mature forest vegetation or any noteworthy habitats.
- The new and modified wharves at Kopi are the only facilities that will incur some habitat loss from the clearing of small areas of riparian forest and disturbed small crowned lowland forest.
- The primary loss of habitat associated with the PNG Gas Project will result from:
  - Clearing for ‘greenfield’ development of construction access ways, pipeline RoWs, quarries and lay down areas (anticipated to be limited in extent).
  - Limited widening of cleared areas within existing easements of roads and pipeline RoWs in the brownfield sections of the project.

Table 13.14 presents the estimated areas to be cleared for the project’s facilities, each segment of the sales gas pipeline RoW and its associated access ways. The figures for the new sections of RoW and access roads are based on a 21-m working width in most terrain and a nominal 12-m width in the steep terrain of the Hides ridge and between the Maruba and Kondari rivers. In areas where there are large cuts with associated sidecast spoil, the forest lost approximates to three times the nominal working width. This has been factored into the figures appearing in Table 13.14.

Table 13.14 Estimated areas (ha) of forest habitat that may be cleared during construction of wellpads, facilities, pipelines and access ways[1]

Broad Vegetation Group	Well-pads	Facility[2]							Pipeline RoW/Access Way Segment[3]														H[2]	A[2]	Totals (ha)
		HPF	CG	GE	KE	APF	Drilling camp	Other camps	1	2	3	4	5	6	7	8	9	10	11	12	13	14			
Lower montane very small crowned forest complexes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 32[4]	**0 – 32**
Lower montane very small crowned forest complexes with Nothofagus	6.4	0	0	0	0	0	0	0	90	0	0	0	0	0	8 – 24	0	0	0	0	0	0	0	0	0	**104.4 – 120.4**
Lower montane small crowned forest	0	0	0	0	0	0	0	0	0	0	63	64	30	0	0	0	0	0	0	0	0	0	0	0	**157**
Lower montane small crowned forest with Nothofagus	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	**8**
Medium crowned to small crowned forest complexes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 11	0 – 40	21 – 81	0 – 6	0	23	0	0	0	**44 – 161**
Medium crowned to small crowned forest complexes with Nothofagus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 35	0	0	0	0	0	0	0	0	0 – 18	**0 – 53**
Low altitude medium crowned forest on uplands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 34	0	0	0	0 – 1	0 – 25	**0 – 60**
Low altitude medium crowned forest on uplands with Nothofagus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 11	**0 – 11**
Low altitude medium to small crowned forest on uplands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 29	0	0	0	0	0	0	0	0	0	**0 – 29**
Small crowned lowland forest	0	7[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 2	0 – 40	0	17	0	0	0	**24 – 66**
Open lowland forest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 19	0	0	0 – 1	0	0	**0 – 20**
Swamp woodland and forest complexes	0	0	0	0	0	0	0	0	0	0	0	0	0	0 – 10	0	0 – 7	0	0	0	0	0	0	0	0	**0 – 17**
Swamp forest complexes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	0	**49**
Totals (ha)	6.4	7	0	0	0	0	0	0	**90**	**0**	**63**	**68**	**34**	**0 – 10**	**8 – 88**	**0 – 18**	**0 – 40**	**21 – 83**	**0 – 99**	**0**	**89**	**0 – 1**	**0 – 1**	**0 – 86**	**386.4 – 783.4**

1 All figures include an allowance for a trebling of forest loss at sites of steep cuttings.

2 HPF – Hides Production Facility, CG – Kutubu Central Gas Conditioning Plant, GE – Gobe production facility modifications, KE – Kopi Support Base modifications and new wharf, APF – Agogo Production Facility, H – Kutubu to Hides glycol return line, A – Agogo rich gas pipeline.

3 1 – Hides Ridge area, 2 – Hides 4 well to Hides Production Facility, 3 – Hides Production Facility to Maruba River, 4 – Maruba River to Kondari River, 5 – Upper Mubi River segment, 6 – Kutubu segment, 7 – Moro to Iwa Range, 8 – Ai'io River segment, 9 - Ai'io River to Wassi Falls, 10 - Wassi Falls to Mubi Crossing, 11 – Mubi Crossing to Kikori Crossing, 12 – Kikori Crossing to Kopi, 13 – Kopi to Omati, 14 – Gobe rich gas pipeline.

4 The pipeline will be laid along the existing road with virtually no vegetation clearance required, so the lower limit is most likely.

5 Mixture of riverine forest and secondary forest – most of the Hides site is cleared already.

Estimation of forest loss in 'brownfield' segments, i.e., the existing crude oil export pipeline RoW is difficult because there will only be additional clearing beyond the existing RoW if the working width is inadequate. At best no extra forest will be lost and at worst an extra 12 m will be cleared alongside the existing ROW. A range has therefore been estimated for forest loss on 'brownfield' RoW segments based on widening of between 0 and 12 m.

Most clearing of vegetation will occur in the areas of 'greenfield' development, particularly through steeper terrain. Table 13.15 presents predictions of the impacts before and after the implementation of appropriate mitigation measures in these segments.

The area of forest estimated to be impacted in the 'greenfield' segments is approximately 390 ha. Clearing in the 'brownfield' segments is estimated to be between 0 and 400 ha. In practice, the long sections of the existing crude oil export pipeline easement and road easements will probably incur little or no extra clearing, and so a range of between 400 and 600 ha probably defines the most likely lower and upper limits of total forest loss attributable to the project. (This equates approximately to the area of forest cleared in 1990 for the original Kutubu Petroleum Development Project.)

No open wetlands will be lost, although a limited area of closed canopy swamp woodland and forest complexes will be cleared in the Kopi to Omati segment of the sales gas pipeline RoW. The impacts on these wetland habitats before and after the application of appropriate mitigation measures are presented in Table 13.15.

Supporting Study 11 assesses the regeneration and rehabilitation of the civil works associated with the Kutubu Petroleum Development Project. The study shows that most of the area along the crude oil export pipeline easement (with the exception of the area kept clear over the pipeline proper) is naturally regenerating well. Soil-dominated surfaces (the dominant substrate through gentle terrain) and limestone cuttings have rehabilitated readily; limestone pavement, rubble and sidecast material, however, have not naturally regenerated very well to date. Mitigation measures have been proposed to assist regeneration in such areas associated with the PNG Gas Project.

Unlike the Kutubu and Gobe oil projects, the PNG Gas Project's sales gas pipeline RoW is required to be completed as a public road. Regeneration will therefore only be permitted over that part of the RoW bench not required for the road pavement or drainage. Exceptions to this are:

- The short climb up from the Mubi crossing to Kantobo, where the RoW and access road need to separate for grade reasons.
- Between Angore and Homa, where the pipeline is able to take shortcuts at gradients too steep for a public road.
- Between Kopi and Omati.

Table 13.15 Estimated impacts before and after the implementation of proposed mitigation measures in segments of the pipeline RoW/access way where construction habitat-loss, edge or barrier impacts are predicted to be high initially (see text for impact assessment criteria)

Pipeline RoW/Access Way Segment (from Table 13.13)	Potential Duration of Impact with Mitigation	Level and Extent of Impact								
		Before Mitigation			After Mitigation - All Areas Except Large Cuttings			After Mitigation – Large Cuttings		
		Habitat	Fauna	Flora	Habitat	Fauna	Flora	Habitat	Fauna	Flora
Habitat Loss										
Hides Ridge area (Segment 1; 90 ha)	L	H2	H2	M2	M2	M2	L1	H2	H2	L1
Maruba River to Kondari River (Segment 4; 60 ha)	L	H2	H2	L2	L1	L1	L1	M1	M1	L1
Wassi Falls to Mubi Crossing (Segment 10; 21 to 83 ha)	L	H2	H2	L2	L1	L1	L1	M1	M1	L1
Kopi to Omati (Segment 13; 0 to 1 ha)	M	H2	H2	L2	L1	L1	L1	–	–	–
Other segments	L	L1 – M2	L1 – M2	L1 – M2	L1	L1	L1	L1	L1	L1
Edge Effects*										
Hides Ridge area (Segment 1; 90 ha)	M	M1	M1	M1	I	I	I	I	I	I
Maruba River to Kondari River (Segment 4; 60 ha)	S	M1	M1	M1	I	I	I	I	I	I
Wassi Falls to Mubi Crossing (Segment 10; 21 to 83 ha)	S	M1	M1	M1	L1	L1	L1	L1	L1	L1
Kopi to Omati (Segment 13; 0 to 1 ha)	I	I	I	I	I	I	I	I	I	I
Other segments	S – M	I – M1	I – M1	I – M1	I	I	I	I	I	I
Barrier Effects*										
Hides Ridge area (Segment 1; 90 ha)	L	I	H2	I	I	L1	I	I	H2	I
Maruba River to Kondari River (Segment 4; 60 ha)	M	I	H2	I	I	L1	I	I	M2	I
Wassi Falls to Mubi Crossing (Segment 10; 21 to 83 ha)	S	I	I	I	I	I	I	I	I	I
Kopi to Omati (Segment 13; 0 to 1 ha)	S	I	I	I	I	I	I	I	I	I
Other Segments	S	I – L1	I – L1	I – L1	I	I	I	I – L1	I –L1	I – L1

*Estimated as a change to existing edge and barrier effects.

These sections excepted, the loss of forest will persist for as long as the public road remains in service.

The residual impact of clearing forest on fauna depends upon the degree of specialisation of the fauna. Table 13.16 summarises the range of responses of fauna to forest habitat loss. The response changes over time depending upon whether cleared areas are allowed to regenerate back to forest, only allowed to regenerate to low shrubs or kept clear. All fauna groups have species in all classes in column 1 of Table 13.16, although most microhylid frogs are Type 1 forest species.

Table 13.16 Impacts of forest habitat clearing on fauna

Species	Habitat Specialisation	Impact of Habitat Clearing
Type 1 forest species	Restricted to primary forest.	Population declines in the long term and little or no colonisation of regenerated areas for several decades.
Type 2 forest species	Will use both primary and secondary forests.	Population declines then slowly increases in areas that regenerate.
Type 3 forest species	Will use a range of forest, secondary growth, gardens and scrublands.	Population declines then rapidly increases in the early stages of regeneration, stabilising as the regeneration matures.
Grassland species	Use a range of grasslands, flooded grasslands and scrublands.	Rapid population increase in the early stages of regeneration. Permanent, sustainable, populations establish where grasslands and scrublands replace forest.
Wetland species	Use a range of open flooded grasslands, swamps and lakes.	Not impacted by forest clearing unless clearing impacts local hydrology. Hydrological changes determine trajectories of populations. Conversion of forest to open flooded habitats provides advantages to these species. Conversion of open swamps and flooded areas to wooded swamps disadvantages these species.
River species	Restricted to rivers.	No impacts expected on birds and amphibians that are river specialists. (Riverine mammals are covered in Section 13.6.)
Aerial species	Forage above the canopy.	No changes.

So long as clearing does not propagate from the edge of the RoW, the overall direct residual impact of the loss of habitat on flora and fauna is predicted to be low and restricted to the vicinity of construction sites (L1), because:

- Relatively small amounts of habitat will be lost due to clearing.
- Clearing for the pipeline RoW/access way RoW is in a thin line over a distance of approximately 300 km.
- This linear clearing is not predicted to eliminate whole territories of primary forest specialists.
- 30% to 50% of the anticipated clearing will entail patchy narrow clearing within existing easements (i.e., ‘brownfield’ areas).
- High biodiversity continues to persist in the existing oil project area after more than a decade of operations.
- All vegetation types in the Kikori River basin area are well represented.

Some regeneration will be allowed in the sales gas pipeline RoW (i.e., operations easement width will be less than construction easement width), and so forest recovery of between 20% and 40% of the cleared area will probably occur within the lifetime of the project. However, the balance of the forest loss, albeit it a small area, will persist in the long term, and recovery will not commence until project decommissioning.

Edge Effects

Edge effects occur at the boundary between unimpacted forest and a cleared area. In severe cases, edge effects can lead to a process of ongoing retreat of the forest edge. The causes of this phenomenon include:

- Exposure of the forest edge to sun and wind, which dries out the vegetation at the edge and makes the microclimate of the adjacent forest interior drier, hotter and lighter, to the disadvantage of the established shade-tolerant species. The dry ground cover becomes more susceptible to fire. A wide cleared area next to the forest or on steep batters exposed to the wind will exacerbate the edge effect.
- Greater wind exposure increases windthrow of trees close to the edge. This can be exacerbated by machinery damage to trees, trees felled during construction, and debris rolling down hills and striking or smothering otherwise live trees.
- The invasion of weeds and exotic species from the edge.

Fauna adapted to drier habitats and secondary forest will also opportunistically colonise the forest next to the edge.

Edge effects may extend several hundred metres into the forest and may be severe for the very sensitive ferns in the upland *Nothofagus* forests such as in the Hides Ridge area. Where roads and other linear clearings surround small blocks of forest (such as between hairpin bends), the edge effects can penetrate from all sides (Supporting Study 1).

Edge effects affect Type 1 forest fauna, such as microhylid frogs and interior bird species that are adapted to dark, humid, forest-interior microclimates (Supporting Study 1). Such species retreat from the forest edge as it dries out and becomes lighter. Type 3 forest fauna species and grassland fauna species adapted to drier, more open habitats can colonise the forest edge and compete with Type 1 forest fauna species. As the edge seals itself and microclimate conditions are restored, Type 1 forest fauna species are able to recolonise the area and the invading species can be expected to retreat.

The evidence from the existing oil and gas developments is that the forest edge rapidly seals over in all habitats at elevations below 1,800 m ASL (see Section 9.6). Fastest to recover will likely be the edges in volcanic areas (such as between the Maruba and Kondari rivers) and in alluvial areas (such as between Kopi and the Omati River).

Edge effects will likely be slowest to heal where vegetation growth rates are reduced by cold conditions at higher elevations and along long faces at the top of cleared areas exposed to prevailing winds.

Taking care to avoid unnecessary damage to trees along the edge will reduce or eliminate the potential for further erosion of the edge.

Edge effects after the implementation of appropriate mitigation measures are thus predicted to be negligible or low, very limited and short term in duration, even in areas where there will be large amounts of sidecast spoil.

Barrier Effects

Barrier effects occur where a strip of open habitat provides a barrier of unsuitable habitat that discourages or prevents certain fauna species, particularly Type 1 forest species, or the seeds or pollen of certain flora species, from moving across the gap, thus splitting or fragmenting species populations.

Quantitative studies of this barrier effect have been mostly performed in temperate habitats, and barrier effects have been demonstrated for a wide range of mammals from mice to caribou (e.g., Oxley et al., 1974; Swihart & Slade, 1984; Dyer et al., 2002). Quantitative information from the far more complex and speciose moist tropical rainforests is rare. Goosem (1997) reviews tropical studies that show that species most averse to crossing linear gaps in their habitat include some specialist terrestrial and arboreal marsupials, some Type 1 and Type 2 forest birds, and several reptiles and amphibians. Some species completely avoided crossing linear gaps, but there was no pattern to which particular species these were. Other species, such as rodents, would still cross gaps but at frequencies reduced by as much as 90% to 99% by roads between 12 m and 20 m wide.

Barrier effects on fauna become significant when they reduce an animal's ability to cross a gap so as to change the dynamics of their population and increase the risk that a given population will fall below a critical mass and not survive. This will only occur where a barrier is close to 100% effective, operates over the entire distribution of a population and the divided populations are too small to survive. Barrier effects through habitat with an extensive hinterland are less likely to have this effect than barriers through the habitat of restricted species or where the habitat is itself limited in area.

The combined nominal width of the RoW for the pipelines and access ways of the PNG Gas Project is designed to be either 12 m or 21 m. This narrow RoW is predicted to present no significant barrier to the movement of spores, pollen or seeds of flora.

As far as fauna is concerned, such widths are unlikely to create a complete barrier to any bird or bat species recorded in the Kikori River basin area. (The roads of the existing oil and gas facilities have been used for sampling birds, and all species have been recorded close to the edge.) Some species may be inhibited from crossing road gaps, but it is unlikely that this barrier effect will be total.

On the other hand, the arboreal mammals of the higher elevations, such as in the Hides Ridge area, rarely if ever come to the ground. Such species may well be reluctant to cross the RoW without a canopy connection across the gap.

At ubiquitously moist upper elevations, microhylid frogs may also have difficulty crossing dry roads. Some Type 1 terrestrial mammal species, such as the smaller rodents that are restricted to forest interiors, may also be inhibited from crossing the RoW.

In many places along the RoW, the canopy will touch across even a 21-m-wide gap and will therefore provide aerial pathways for arboreal species and a shaded area more conducive for Type 1 species to cross.

In very rugged areas, however, such as in the Hides Ridge area and between the Maruba and Kondari Rivers, high, wide cuts may treble the barrier of the access way or RoW bench alone to 50 m or more. While these cuts and associated clearances are unlikely to provide any barrier to the movement of seeds or pollen or to most fauna, the steep bare batters will be difficult for some fauna, particularly arboreal species, to negotiate (Plates 13.1, 13.7 and 13.9).

There is little that can be done to mitigate barrier effects in these sections of the RoW; and so locally, the residual impacts are predicted to be high. Even accounting for the beneficial effects associated with vegetation regrowth, barrier effects in such areas are predicted to remain high to moderate and long term in duration, albeit very limited in extent (see Table 13.15).

In the section of the sales gas pipeline between the Mubi River and Kantobo (KP 55), the associated public road will add a steep cutting to the existing regional barrier of the Mubi River gorge downstream of Wassi Falls.

In practice, the barrier effects in these rugged areas are unlikely to be total. There will always be places where the RoW will be narrow enough to allow floral and faunal movements across it. The types of areas where the RoW will be able to be kept narrow and where regeneration may allow trees to touch across the track are where the RoW passes through a saddle (Plate 13.10) and along ridges (Plate 13.11). For example, the Hides spine line traverses several ridges and crosses saddles in areas where only 12 m will need to be cleared. The LIDAR topographic imagery indicates up to 40 saddles or ridges where the RoW will be narrow enough to allow fauna movement once the forest edge regenerates – an average of one per 500 m.

Erosion, Movement of Sidecast Spoil, and Changes to Hydrology

Erosion and the sidecasting of spoil will impact on biodiversity through:

- Direct loss of habitat.
- Changes to the hydrology of wetlands and forests.
- Impacts to sinkhole swamps.

Sidecasting of spoil generated by the construction of road and RoW benches in steep areas may smother and fell trees downslope, increasing the effective width of clearing. Rapid regeneration on sidecast material will reverse these impacts; but slow or ineffective regeneration will facilitate ongoing erosion, which in turn could further impede regeneration.

The effects of erosion and the sidecasting of spoil on fauna arise from increased habitat loss and barrier effects. The latter can be the more significant in upland habitats where steep cuttings could present barriers to the movements of susceptible fauna, such as upland arboreal mammals and frogs. The regeneration of sidecast spoil materials will limit these effects to the short term.

In most areas, sidecast spoil will naturally regenerate and stabilise, and so the habitat loss and increased barrier effects produced by this phenomenon will ameliorate over the medium term.

On some sites, regeneration will be slow or will not occur or forest will be replaced by grasses and small shrubs. These are areas of potential instability where forest erosion through fire and landslides can occur. Such areas are predicted to produce only very small, localised sites of moderate to high impact; over the entire project area, this type of residual impact is predicted to be low. The main issue arising from these sites is not the clearing itself but its potential to produce widespread moderate to high impacts if fire is able to propagate in these areas in dry years. Promoting regeneration of these sites beyond fire-prone grasses can help to mitigate this risk. If this type of revegetation is achievable, it is predicted to reduce this type of impact to low or negligible.

The proposed mitigation measures aimed at promoting regeneration in difficult areas where regeneration may be slow are predicted to reduce the impacts on fauna to low, of very limited to limited extent and of short to medium term duration.

Overall, the residual impacts on habitat and flora after appropriate mitigation measures are implemented are predicted to be low to moderate, of very limited to limited extent and medium term in duration.

Changes in the hydrological regime – from wet to dry and vice versa – fundamentally alter the flora habitat and trigger a corresponding change in plant species. Forests adapted to dryland conditions die if they are flooded for even short periods. Mangroves will die if tidal effects are changed. Swamp forest, which is adapted to a regime of flooding and drying, may die if the natural cycle is altered.

Hydrological effects may be caused where bulk earthworks, such as the deposition of fill and the construction of causeways and drains in low-lying areas.

Hydrological changes can impact fauna directly through changes in seasonal and breeding cycles, but the major impacting mechanism is habitat loss. Species adapted to swamp woodland and forest complexes, such as the New Guinea flightless rail, are most at risk from this potential impact.

Construction is likely to only temporarily disturb the hydrology in the project area, and any changes are likely to occur in only very limited areas (see Section 13.4.4).

Materials Handling

Fuels and lubricating oils, chemicals, radionuclides, wastes and other potentially contaminating materials entering rivers, streams and sinkhole swamps during construction have the potential to impact biodiversity in or alongside these habitats.

Fauna can be directly impacted by ingesting or by coming into contact with spilled fuels, lubricating oils, chemicals, radionuclides, and solid and liquid wastes. They can also become trapped by wire and other abandoned hardware. If contaminants enter streams, they can impact frogs, turtles, crocodiles and fish.

During construction, there is the potential for contaminating materials to enter sinkhole swamps and impact the frogs and other fauna that inhabit them. Such effects, however, are highly unlikely to occur due to the materials handling safeguards to be implemented by the project.

Unless major spills occur, impacts from materials handling will be localised to construction and operations sites, be of negligible impact, and limited in extent and short term in duration.

Catastrophic spills from fuel tankers have the potential to have a moderate and short-term impact on biodiversity but would be limited in extent. The project would act immediately to limit any biodiversity impacts of such highly unlikely events.

Disposal of Hydrotest Water

Hydrotest water for onshore pipelines may be treated with very small quantities of a biocide and an oxygen scavenger (see Sections 13.5.4 and 13.6.4).

The disposal of hydrotest water presents two special issues: one related to the potential impacts of any added biocides and oxygen scavengers on fauna such as amphibians through residual toxicity at the point of discharge and the other to the translocation of organisms.

Hydrotest water not treated with a biocide could facilitate the transport of living organisms, including pathogens, between stream catchments (i.e., translocation). It is not only exotic species that are of concern; cross-contamination of stream catchments with native species also serves to break down natural biodiversity patterns in remote, relatively undisturbed places like the Kikori River basin area.

While there may potentially be losses of amphibians due to biocidal effects of discharged hydrotest water, these effects are predicted to be low, very limited to local in extent and short term in duration. Treatment of hydrotest water prior to discharge would reduce this risk.

The risk of an accidental release of hydrotest water containing small quantities of a biocide and an oxygen scavenger before treatment remains but does not outweigh the potential impact of allowing the transport of organisms and pathogens between stream catchments.

Dust

Dust may coat the leaves of plants along the forest edge of pipeline and access way RoWs and other construction sites, but frequent rain in the Kikori River basin area makes this impact very short term in nature (a few weeks at most). It is possible that the input of dust to the edge habitat would increase its nutrient status and speed up sealing of the forest edge.

It is unlikely that the dust will impact any fauna unless an El Niño year produces particularly dry conditions for several months.

It is predicted that project-related dust will have negligible residual impacts on biodiversity.

Fauna Falling into the Open Pipeline Trench

Small animals – mostly reptiles, frogs, small mammals and flightless birds – may fall into the open pipeline trench, be unable to escape and perish. Deaths of a few individual animals will be very unlikely to have effects upon entire populations unless they are from a small population of a very rare species (see Section 13.7.5).

The mitigation measure (i.e., positioning wildlife escape ramps periodically along the length of the open trench) aimed at rescuing fauna from the trench is predicted to reduce residual impacts on all species to a negligible level.

Hunting by Project Workers and Contractors

Many birds and the larger mammals and turtles of Papua New Guinea suffer greatly from hunting by local inhabitants, in particular those species that are specifically targeted for food or decorative plumage. Hunting can drive some species to local extinction. Most of the listed species in the Kikori River basin area are threatened by hunting (Supporting Study 1).

The experience of the petroleum industry has been that species that are heavily hunted and are consequently now difficult to find elsewhere in Papua New Guinea remain relatively abundant near the oil production facilities at Kutubu. For example, Pesquet's parrots and birds-of-paradise are still common right alongside the facilities at Kutubu, and southern cassowaries are numerous between the Kaiam and Mubi river crossings, particularly in the untrafficable section of the crude oil export pipeline RoW between the Gobe airstrip and the Mubi River.

Hunting bans and bans on the possession of hunting equipment and wildlife products by project workers and contractors while working, while residing in project camps, and while in project vehicles and logistical facilities will prevent workforce-related impacts on wildlife. Where contractors or workers are also project-area landowners, they will retain the right to hunt on their own land during non-working hours and while residing in their own domiciles. Enforcement of the project's hunting-related prohibitions will act to ensure that present-day hunting pressures are not increased by the project.

Collection of Flora by Project Workers and Contractors

The collection of specific valued plants (e.g., orchids, medicinal herbs) in small areas such as around camps could potentially lead to local extinctions of some species thereby degrading the local habitat.

Impacts will be avoided by the project's policy of prohibiting the gathering of vegetation (e.g., orchids, medicinal herbs) by project workers and contractors while working and while residing in project camps, and prohibiting the use of project vehicles and equipment for gathering or transporting flora.

Loss of Breeding and Display Grounds

Some birds-of-paradise display trees and sites will inevitably be lost due to the construction works, but areas of potential trees for display sites are large and they are not individually a critical resource.

Since identified display trees may be able to be avoided if practicable, it is predicted that the residual impact will be negligible.

Noise, Lights and other Sensory Disturbances

Direct disturbance by humans does have an impact on fauna, and a lack of such disturbance is a major factor in maintaining the high biodiversity values that occur in the Kikori River basin area alongside the existing oil and gas facilities.

Fauna adapt readily to noise, but lights can affect the behaviour of nocturnal birds.

Human disturbance issues are very local in nature, and experience with the existing oil and gas facilities shows that noise and lights have not noticeably impacted the resident local fauna. Any disturbance to fauna causing them to retreat from construction sites will be temporary, and the fauna will return to the site if the indirect impacts are controlled appropriately.

Overall residual impacts are predicted to be low, very limited in extent and short term in duration; the implementation of appropriate mitigation measures is predicted to reduce these impacts to a negligible level.

Traffic

Standard traffic control and speed limits will limit the loss of fauna from accidents involving project vehicles and equipment. Accordingly, overall residual impacts of project-related traffic on fauna are predicted to be negligible.

13.7.4.2 Indirect Impacts

Fire

Moist tropical forests can burn in dry periods, and fire can permanently eliminate forest over large areas. Broad-scale fires are not uncommon in Papua New Guinea, occurring mostly in El Niño years, and can be catastrophic events with long-term effects.

Fire in forests on karst pavements and in swamp woodland and forest complexes could burn away the organic soil layer and root mat, leaving bare rock or subsoil upon which regeneration of the original vegetation would be very slow. It is not known how the upland *Nothofagus* forests in the Hides Ridge area would respond to fire.

Fires with widespread impacts can occur when small fires burn out of control. A fire management strategy that will be developed and implemented during the construction and operations phases of the PNG Gas Project is predicted to reduce the likelihood of such fires to a very low level.

Dieback

A variety of species of root-rotting fungi cause vegetation dieback, involving an assortment of plants. Dieback has been found in parts of the Kikori River basin area and in the lowlands, possibly as a consequence of natural occurrence and/or changes to drainage brought about by previous roadworks.

Supporting Studies 8 and 9 review dieback in *Nothofagus* forests. This phenomenon may be actually related to drought. Dieback does not inevitably prevent successful regeneration of *Nothofagus*.

Dieback is usually localised, but major changes to hydrology and multiple points of infection may increase the significance of this indirect impact.

The implementation of appropriate quarantine procedures for equipment and vehicles during construction and operations are will reduce the likelihood of the spread of dieback to a very low level.

Invasive Species - Weeds

Exotic and native noxious weeds can penetrate habitats, change their ecology and reduce biodiversity. Intact tropical forests tend to be resistant to weed invasion. Weed invasion usually occurs when roads open up the forest to edge effects and human activities (e.g., settlement, gardening and vehicle movement) that promote noxious weed invasion.

The absence of problematic weeds in the Hides Ridge area is thought to be a major contributor to its conservation value. Hence, the project will install a washdown point at the Hides Facility to clean vehicles and equipment prior to their entry onto the Ridge.

The implementation of appropriate quarantine procedures for equipment and vehicles, and controls on the importation of plants by project workers and contractors into the project area in the construction and operations phases is predicted to reduce the likelihood of the introduction of a new exotic weed species or the spread of existing weeds in the Kikori River basin area by the PNG Gas Project to low levels.

Invasive Species – Exotic Pest Fauna

Like noxious weeds, exotic animals, such as the crazy ant (*Anoplolepis gracilipes*) and the crab-eating macaque (*Macaca fascicularis*), can have extensive and severe impacts on a region's indigenous fauna. Introductions can take place by accident (typically with inbound freight), ignorance or by design (e.g., by attempting to control a pest species by introducing another, or by bringing in 'pets').

The implementation of appropriate quarantine procedures in the construction and operations phases is predicted to reduce the likelihood of the introduction of an exotic pest fauna species by the PNG Gas Project to low levels.

Hunting by Non-Project Individuals

Hunting is an important cultural and subsistence activity amongst local people (more so at higher elevations), and household surveys undertaken by the project (see Supporting Study 10) indicate that birds-of-paradise and possums have declined in some areas due to hunting pressure. A major factor that promotes and extends the scope of hunting is road access, which to date has been localised and incomplete across the project area. Hunting impacts have therefore been correspondingly localised.

The PNG Gas Project has no ability to control the behaviour of local people not working directly for the project, and the impact of hunting by non-project individuals will depend upon the extent to which access in the project area is improved by the system of public roads that the project is required to construct or upgrade. This situation is analysed further in Chapter 16.

Collecting of Flora by Non-Project Individuals

Collecting flora (timber, medicinal plants, firewood etc.) is a fundamental and vital local activity but can result in local declines in abundance of some species around villages.

The PNG Gas Project has no ability to control the behaviour of local people not working directly for the project, and the impact of collecting of flora by non-project individuals will depend upon the extent to which access in the project area is improved by the system of public roads that the project is required to construct or upgrade.

Improved Access

Improved access facilitates biodiversity losses in an area by:

- Encroachment and clearing along roads.
- Facilitation of illegal logging.
- Facilitation of legal logging by making unprofitable areas profitable by reducing or eliminating costs associated with building access roads.
- Over-hunting.
- Increased probability of the accidental or deliberate introductions of weeds, pests and pathogens.
- Increased probability of fire.
- Facilitation of the creation of broad-scale agricultural schemes, such as oil palm plantations and fish farms, resulting in broad-acre habitat loss.

The only place where impacts due to improved access can be effectively controlled by the PNG Gas Project is in the Hides Ridge area. Here, the PNG Gas Project will control the access way, and mitigation measures aimed at preventing unauthorised access will be implemented to reduce potential indirect impacts from improved access in this area to low levels.

Mitigation of the potential impacts elsewhere in the project area that are the result of government infrastructure construction requirements will ultimately require government oversight to manage whatever benefits will be brought by the roads while controlling potentially undesirable impacts due to in-migration, hunting, timber harvesting, plantation agriculture, squatting and land clearing. This is analysed further in Chapter 16.

However, the existing oil and gas projects in the project area bring considerable experience regarding this situation. The original impetus for WWF's work in the KICDP area was to reduce indirect impacts associated with petroleum development (Leary et al., 1996; McCall and Flemming, 2002). In particular, it was thought that new, improved road access created by the Kutubu Petroleum Development Project's infrastructure would enable large-scale and unsustainable logging in the region that would lead to extensive impacts on the environment and on subsistence communities. To address this situation, the Kikori Integrated Conservation and Development Project, a collaboration between Chevron Niugini (the former operator of the Kutubu Joint Venture) and WWF was established. Its goal was to work with local communities to foster local-scale, revenue-generating development of a type and at a scale that would maintain the biodiversity of localities and the region (McCall and Flemming, 2002).

The new public roads mandated by the government of Papua New Guinea to be built or upgraded by the PNG Gas Project raise similar issues of in-migration and improved access for logging (see Chapter 16). Moreover, the initial KICDP initiative had a number of beneficial consequences in its own right, notably: a major upgrade in biodiversity knowledge for the Papuan Fold Belt in particular and Papua New Guinea in general; and raising the conservation profile of the KICDP area. These benefits will provide a foundation for future conservation initiatives at national and regional scale.

The PNG Gas Project's continuing association with and/or support for conservation initiatives via a revived KICDP has the potential to reduce residual project-related indirect impacts related to improved public road access to a low, limited and local in extent, albeit probably persisting over the long term.

13.7.4.3 Impacts in Noteworthy Areas

Hides Ridge Area

Construction activities on Hides Ridge have the potential to produce a high impact in this sensitive area, and a range of mitigation measures is therefore proposed to appropriately address project-related impacts. Table 13.15 presents predicted potential project-related impacts due to habitat loss, edge effects and barrier effects for this area. Mitigation measures are focused on reducing construction footprints, reducing damage to the forest edge, undertaking prudent procedures for materials handling and disposal, strictly controlling the workforce, quarantine for equipment and vehicles and actively re-establishing vegetation where warranted. These measures, particularly those related to quarantine and revegetation, are predicted to result in an overall direct residual impact of construction in this area as follows: low to moderate, of limited or very limited extent, but lasting for the medium to long term.

Indirect impacts are the most significant issue in this area. Invasion by weeds or exotic pest fauna, the spread of dieback, over-hunting by non-project individuals and facilitating the spread of logging and deforestation could result in high impacts, regional in extent and long-lived. Mitigation measures to manage access to this area, as well as the implementation of quarantine procedures during the life of the project are predicted to reduce the residual impacts of these pressures to low levels.

Sinkhole Swamps

Potential construction-related impacts on swamps in sinkholes are predicted to be highest in the Hides Ridge area. These impacts will be very difficult to mitigate, with the shallow sinkholes (less than 50 m deep) being the most susceptible to infilling.

An estimate was made of the total number of sinkholes and dolines in a 50-km^2 area, approximately 5 km wide and centred on the Hides spine line above 1,800 m ASL. Dolines and sinkholes were counted in five 1-km^2 quadrats randomly placed on the LIDAR topographic maps of the area. The mean number of dolines and sinkholes per quadrat was 11.6 with a 95% confidence interval of 3.355. This gives an estimate of the number of dolines and sinkholes on Hides Ridge of between 8.25 and 15 per hectare. The 46 sinkholes or dolines estimated to be impacted by construction of the RoW represent between 3 and 5.6 hectares of the total Hides Ridge sinkhole habitat, which extends for an area of approximately 133 hectares.

Swamps in sinkholes form when eroded sediment or organic matter impedes drainage through the base of a sinkhole. In some instances, this process may be mimicked by sidecast spoil washing down to the bottoms of dolines and sinkholes, impeding drainage and allowing new swamp habitat to develop.

Project-related earthworks will not fill in all the potentially affected sinkholes, and the area of Hides Ridge sinkhole habitat that will remain unaffected will continue to be large. There is additional and extensive sinkhole terrain and habitat at similar elevations on the Karius Range to the southwest and in the ranges to the northwest. Overall, the project's impact on sinkhole swamps is predicted to be low to moderate, limited in extent and of medium- to long-term duration.

Caves

The Kikori River basin area is rich in bat species, many of which inhabit caves. Cave bats are very sensitive to disturbance, and blasting within 100 m of a cave can impact a colony (Supporting Study 4). Of particular importance is the possibility of the existence of as-yet unknown caves inhabited by the critically endangered Bulmer's fruit bat (*Aproteles bulmerae*) in the higher altitudes of the basin, particularly in the Hides Ridge area.

Next to physical destruction of a cave, human visitation and hunting are the most important impacts on cave bats. Colonies can easily be eliminated by human disturbance. It is desirable, for engineering reasons alone, to avoid passing through and impacting caves. Disturbances to bat colonies in caves near construction sites could range from negligible to very high depending upon the species.

Mitigation measures have been proposed to identify whether significant bat-supporting caves occur near proposed construction works areas and then to implement appropriate measures according to the proximity of the caves and their susceptibility to disturbance of its resident bat species. Three levels of clearance survey are proposed (see Supporting Study 1), the most intensive being in the Hides Ridge area. In addition mitigation measures will be implemented to prohibit workers and contractors from disturbing caves, to control blasting near caves and to avoid locating quarries near caves.

These proposed mitigation measures are predicted to reduce potential residual impacts on cave-dwelling bats to negligible or low levels. Any residual direct disturbance impacts are predicted to be very limited in extent and short term in duration.

Swamp Forest

Limited amounts of swamp woodland and forest complexes will be cleared in the Kopi to Omati segment of the sales gas pipeline RoW, and the direct impact of this clearing is predicted to be initially high, limited in extent and of moderate duration. It is predicted that rapid growth rates of this type of vegetation and the implementation of appropriate mitigation measures (see Table 13.12) will reduce residual impacts in swamp forests to low levels and will be very limited in extent.

Residual impacts on hydrology in swamp forests after the implementation of appropriate mitigation measures are predicted to be low, and so no change to the overall occurrence of swamp forest is predicted.

Watercourse Crossings

None of the specialist reports (see Supporting Studies 2 to 6) has suggested a need for the implementation of non-standard mitigation measures at watercourse crossing locations in the project area. The lowland rivers carry heavy silt loads, and the upland torrents carry large boulders and trees during rainstorms. In these situations, trenching for pipeline construction will have little impact on riverine fauna such as torrent frogs, which are adapted to a shifting substrate.

Loss of riparian vegetation will occur at each watercourse crossing point. Riparian vegetation and riverbanks can be a specialised habitat for hydromyine rodents, and while some upland birds are stream specialists, there does not appear to be a bird community restricted to riparian vegetation. The absolute amount of riparian vegetation loss associated with project-related construction works will be very small.

There will be a permanent access way or public road along all of the pipeline RoWs, and so all rivers will need to be bridged or forded. This will result in the same small loss of riparian vegetation at the site whether the river is trenched or horizontally directionally drilled.

The major potential residual impact of project-related construction works on watercourses will not be at the major crossings (where the rivers are swift and turbid) but instead will be in the small creeks higher up the catchment (where suspended and bed sediment loads can be low and where there are holes and riffles vulnerable to sedimentation from erosion at construction work areas). The most susceptible fauna in these creeks are frogs, but the length of small streams affected in this way will be small.

The implementation of appropriate mitigation measures at watercourse crossings (see Section 13.4) is predicted to reduce residual impacts to insignificant or low levels, and they will be of limited extent and of a short duration.

13.7.4.4 Impacts on Listed Species or Species New to Science

Supporting Study 1 presents individual impact analyses for all listed species.

The only situation where a listed species of plant would be impacted by project-related construction works would be if the species existed as one tiny population that was restricted to a hectare or less and could be eliminated or severely reduced by clearing, erosion or collecting.

Supporting Studies 1 and 2 indicate that no listed or new plant species have such a small distribution and that project construction activities are likely to have negligible impacts on listed plant species or plant species new to science.

The listed fauna species are either widespread in the Kikori River basin or in New Guinea or have not yet been recorded along the proposed route. The major threat to the majority of the fauna species in the project area is hunting. Accordingly, the project will prohibit hunting and the possession of hunting equipment and wildlife products by project workers and contractors while working, while in project camps, and while in project vehicles.

Few fauna species are predicted to be impacted by the project's construction works. Habitat loss is predicted to be low, and consequently it is expected that there will be negligible impact on listed or new fauna or flora species. Some bat species could be impacted by cave disturbance, which will be mitigated as indicated above, and birds will be impacted mostly by the limited loss of breeding sites (see above).

Barrier effects could impact arboreal species, but such effects will be local in extent and will not impact any species as a whole.

Listed species that could be impacted by falling into the open pipeline trench include the large leptomys (*Leptomys elegans*), Fly River leptomys (*L. signatus*), large pogonomelomys (*Pogonomelomys bruijni*), one-toothed shrew mouse (*Mayeremys ellermani*), greater small-toothed rat (*Macruromys major*), giant naked-tailed rat (*Uromys anak*), rock-dwelling giant rat (*Xenuromys barbatus*), long-beaked echidna (*Zaglossus bartoni*), short-beaked echidna (*Tachyglossus aculeatus*), long-nosed murexia (*Phascomurexia naso*), ground cuscus (*Phalanger gymnotis*), and New Guinea flightless rail (*Megacrex inepta*). Residual impacts on these species may range from insignificant to high but will be of limited extent and medium term in duration. The major issue associated with this particular impact would be if there were a small population of a critically endangered species along the RoW that would be particularly susceptible to being trapped in the open trench. Of these, the three critically endangered rodents (the large leptomys, Fly River leptomys and large pogonomelomys) are of most concern. Rescuing fauna from the open pipeline trench is predicted to reduce this impact to a negligible levels.

The only listed fauna species of concern in relation to direct project-related impacts is the possible occurrence of an unknown colony of Bulmer's fruit bat in the Hides Ridge area. If such a cave exists and is accidentally destroyed, the impact would be very severe. The implementation of mitigation measures aimed at surveying for caves of this species and establishing an appropriate course of action should it occur, is predicted to reduce potential impacts of this type to a low level. Since such a cave would be only the second known colony in existence, the impact would be widespread, i.e., occurring through most of the species' range, and would be long term in duration.

In view of the mitigation measures the project intends to implement, the residual impacts on listed or new species are predicted to be insignificant or low, of very limited or limited extent and short term in duration.

13.7.4.5 Impacts on Migratory Fauna

No significant habitats of migratory species will be impacted in any part of the project area, and therefore residual impacts on these species are predicted to be negligible.

13.7.4.6 Conclusions

In terms of construction, the PNG Gas Project is in large part an extension of existing oil and gas developments, and therefore experience with the latter gives a high level of confidence regarding predictions of the impacts of the former with regard to flora and fauna. The PNG Gas Project will be largely a 'brownfield' development within the footprint of existing oil and gas infrastructure, but has spatial extensions into 'greenfield' sites and an extended project life. The essential infrastructure to produce, process and export the gas is not overly different from what is already in place and will therefore have generally similar impacts, albeit over a wider area and for a longer time, to the existing petroleum operations.

The main direct impact issues related to floral and faunal impacts associated with the PNG Gas Project revolve around the spatial and time extensions and the fact that:

- The ‘greenfield’ sections of the project will involve high-altitude environments with high biodiversity values that have been little disturbed.
- Regeneration of the RoW will be limited to allow for the existence of a permanent public road.

Some restricted areas of moderate to high impact in ‘greenfield’ upland sites will recover slowly. In general, however, the post-mitigation construction residual impacts of the PNG Gas Project on terrestrial biodiversity are predicted to be mostly negligible to low and limited to very limited in extent, although some will persist in the long term.

No further large-scale vegetation clearing will occur during operations, and the only potential operations phase biodiversity impacts that have the potential to be moderate to high in level would be major spills of fuels, chemicals and lubricating oils, an explosion of gas facilities, and widespread intense hunting or collecting of plants by project workers and/or contractors, which could produce local extinctions over the long term. The implementation of appropriate mitigation measures during operations is intended to prevent such impacts or reduce them to a negligible level.

Over the operational life of the project, only indirect impacts are predicted to have the potential to produce long-term and widespread biodiversity impacts of a high to very high level.

For the most part, these indirect impact mechanisms have existed for the life of the existing oil and gas developments. However, isolation and the difficulty of access have been critical factors in reducing these indirect impacts and maintaining the habitat integrity and biodiversity of the Kikori River basin. Now, the requirement of the PNG Gas Project to complete construction access ways as public roads presents a new impact mechanism to the area. The low biodiversity impact of the existing oil and gas developments cannot be taken as a directly applicable analogue for this new source of impact.

The PNG Gas Project will have no ability to control the activities of people using these new or upgraded public roads; accordingly, the improved road system may result in the possible spread of settlement, gardens, fire, noxious weeds, exotic fauna, dieback, over-hunting and over-harvesting of flora.

There is little previous experience with increased access related to the existing oil and gas projects in Papua New Guinea and impact predictions for the PNG Gas Project are consequently imprecise. The global experience with roads in tropical forests indicates that long-term uncontrolled access can result in loss of fauna and often deforestation leading to landscape fragmentation.

On the other hand, the Kikori River basin area has considerable natural protection due to its poor and inhospitable karst terrain. Widespread deforestation is therefore highly unlikely. Even so, improved access is very likely to lead to local extinctions or population declines of some fauna. With facilitated vehicle access, it will be relatively easy for outsiders to hunt/poach fauna in previously inaccessible lowland areas. The healthy populations of the southern cassowary in the Mubi River area are likely to be targeted, and their decline to low levels may occur.

The extent to which these potential indirect impacts will be borne out depends on the settlement, land use and movement patterns that develop over the life of the PNG Gas Project and the measures, if any, implemented by the Papua New Guinea government to manage or control the indirect impacts. This issue—the biodiversity impact implications of government infrastructure policy—is explored more fully in Chapter 16.

13.8 Air Quality and Greenhouse Gas Emissions

This section presents impact assessment criteria (Section 13.8.1) and addresses the principal issues (Section 13.8.2), proposed mitigation measures (Section 13.8.3) and residual environmental impacts of project construction and operations activities (Section 13.8.4) related to air quality in the project area. Estimated greenhouse gas emissions are also discussed. This section summarises Supporting Study 14, which presents an analysis of the project-derived air quality impacts and greenhouse gas emissions.

13.8.1 Air Quality Impact Assessment Criteria

Due to a lack of relevant PNG air quality guidelines, project air quality targets follow the World Bank recommendation that, where possible, the World Health Organisation (WHO) Air Quality Guidelines for Europe (WHO, 1987; WHO, 2000) be used to assess air quality.

While the WHO guidelines prescribe a risk-based approach to assessing the BTEX (i.e., benzene, toluene, ethylbenzene and xylene) group of volatile organic compounds (VOCs), it is also relevant to assign project targets for each of these compounds. Therefore, in the absence of any specific WHO air quality targets, effective screening levels used by the Texas Natural Resources Conservation Commission (TNRCC, 2003) have been adopted by the PNG Gas Project.

Table 13.17 summarises the project's air quality targets.

Table 13.17 Project air quality targets

Substance	Assessment Criteria	Project Target ($\mu g/m^3$)	Source
Sulfur dioxide (SO_2)	1-hour	350	WHO (2000)
	24-hour	100-150	WHO (2000)
	1-year	40-60	WHO (2000)
Carbon monoxide (CO)	15-minute	100,000	WHO (1987)
	30-minute	60,000	WHO (1987)
	1-hour average	30,000	WHO (1987)
	8-hour average	10,000	WHO (1987)
Nitrogen dioxide (NO_2)	1-hour	400	WHO (1987)
	24-hour	150	WHO (1987)

Table 13.17 Project air quality targets (cont'd)

Substance	Assessment Criteria	Project Target (µg/m^3)	Source
Hydrogen sulfide (H_2S)	1-year	<5,000 at boundary†	World Bank (1998)
Benzene	1-hour	74	TNRCC (2003)
	24-hour	12	TNRCC (2003)
	1-year	3	TNRCC (2003)
Toluene	1-hour	1,880	TNRCC (2003)
	1-year	188	TNRCC (2003)
Ethylbenzene	1-hour	2,000	TNRCC (2003)
	1-year	200	TNRCC (2003)
Xylene	1-hour	3,700	TNRCC (2003)
	1-year	370	TNRCC (2003)
p-Xylene	1-hour	2,079	TNRCC (2003)
	1-year	208	TNRCC (2003)
PM_{10}*	24-hour	125	WHO (1987)
	1-year	50	WHO (1987)
Total suspended particulates (TSP)	24-hour	150-230	WHO (1987)
	1-year	60-90	WHO (1987)

*Health indicator for respirable dust capable of being inhaled into the lungs.
†Corresponds to no offensive odour at plant/facility boundary.

13.8.2 Issues to be Addressed

13.8.2.1 Construction

Construction activities associated with the onshore portion of the PNG Gas Project are described in detail in Chapter 6.

Emissions to the atmosphere during the construction period will consist of dust generated during earthworks (i.e., vegetation and soil removal and wind erosion of exposed surfaces, soil stockpiles and sidecast spoil), together with exhaust emissions from construction vehicles and equipment; these sources may temporarily increase the amount of airborne particulate matter and certain gaseous compounds in the project area atmosphere, including nitrogen oxides (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), VOCs and welding fumes.

Certain forms of particulate matter in dust can, if the concentrations are sufficient, affect human health and aesthetics. Health issues involve respirable dust as PM_{10}[1]. Aesthetic issues include total suspended particulates (TSP) and dust deposition.

13.8.2.2 Operations

No air quality-associated issues are expected to occur during operations of the project's pipelines and access ways.

[1] Health indicator for respirable dust capable of being inhaled into the lungs.

The following pieces of equipment at the Hides Production Facility will produce air emissions, sometimes 24 hours a day:

- Stage 1 Operations:
  - One high-pressure flare.
  - One low-pressure flare.
  - Two Centaur 40 gas-fired turbine power plants.
  - One Essential diesel generator.
- Stage 2 Operations:
  - One additional Centaur 40 gas-fired turbine power plant.
  - Three Titan 130 gas-fired turbine compressors.

The following pieces of equipment at the Kutubu Central Gas Conditioning Plant (incremental to the existing Central Production Facility equipment) will produce air emissions, sometimes 24 hours a day:

- One Centaur 50 gas-fired turbine power plant.
- Four Titan 130 gas-fired turbine compressors.
- One elevated flare.
- Oil heaters.

Air emissions will be in the form of NO_x (as NO_2), CO, SO_2 and PM_{10}.

13.8.2.3 Greenhouse Gas Emissions

Papua New Guinea is a signatory to the Kyoto Protocol United Nations Framework Convention on Climate Change (Kyoto Protocol), which has as its objective the reduction of negative changes to the earth's climate, with a particular focus on greenhouse gases (GHGs).

Project construction and operations activities will generate GHG emissions from a number of sources, including:

- Combustion of diesel fuel by equipment and vehicles.
- To a lesser extent combustion of petrol by light vehicles and passenger transport vehicles.
- Combustion of natural gas to power turbine compressors, generators and incinerators.
- Flaring of natural gas (mainly from existing operations, but also during facility commissioning/start-up and process upset and emergency situations).

13.8.3 Mitigation and Management Measures

13.8.3.1 Construction

Construction phase atmospheric emissions will be predominately dust generated by earthworks and exhaust emissions from vehicles and equipment. Proposed mitigation measures can be summarised as follows:

- Dust mitigation measures will be detailed in the construction EMP (see Chapter 18) for the project. Such mitigation measures are anticipated to include the following:
  - Vehicle speeds will be restricted on unsealed roads and pipeline RoWs to reduce dust emissions.
  - The extent of clearing and earthworks will be limited and the time period that surfaces are exposed prior to rehabilitation will be reduced to the extent practicable.
  - Water carts will be used to suppress dust when and where required. Note that the climate of the project area (i.e., abundant rainfall) will help to naturally reduce project-related dust emissions.
- Exhaust emissions from construction vehicles will include particulate matter, NO_2, VOCs, CO, CO_2 and SO_2. Construction equipment and vehicles will be maintained to limit such emissions.
- Diesel fuel quality standards relating to sulfur content will comply with local regulations.
- The siting of ‘fixed’ pieces of equipment, such as generators required for welding, lighting, etc., will, wherever practicable, be in locations removed from settlements. Additionally, appropriately sized exhausts will be fitted so that emissions are adequately dispersed.

13.8.3.2 Operations

Modelling of emissions produced by the project during operations (see Section 13.8.4 below) indicate that the project’s air quality targets will be met; therefore no special management and mitigation measures related to air emissions are warranted.

13.8.4 Residual Impact Assessment

Due to the limited quantities of gaseous emissions that will be generated during the construction period and the fact that a large percentage of these emissions will occur transiently over a several hundred kilometre-long work area, particulate matter (i.e., dust) is the emission of most relevance during construction.

Emissions of particulate matter and CO and SO_2 emissions associated with the burning of natural gas will be very low during operations. Therefore NO_x (as NO_2) is the only air emissions species of relevance during this phase of the project.

13.8.4.1 Construction

Adoption of appropriate dust control techniques (where or when required) during construction activities will reduce human health and aesthetic impacts due to airborne particles to low, transient levels.

The majority of construction work will take place in areas of low population. Sensitive human receptors that exist along the pipeline and access way and around the Hides and Kutubu facilities are not expected to be significantly impacted by project-generated dust due to the implementation of appropriate mitigation measures, such as those described in Section 13.8.3.

Any problematic increase in airborne dust generation and deposition resulting from construction activities will be very limited in nature due to the limited extent and duration of the work in any one area. Further, the humid climate of the project area will contribute to the natural suppression of dust levels from the construction works. Dust emissions may be aggravated if construction activities coincide with drier El Niño years, but implementation of appropriate dust control measures where and when required will ensure that such emissions are maintained at acceptable levels at the nearest sensitive receptor.

Modelling of PM_{10} concentrations during construction was undertaken using representative construction scenarios (as described in Supporting Study 14), incorporating appropriate mitigation techniques to determine residual impacts. Modelling results indicate that:

- During pipeline and access way/RoW construction, PM_{10} concentrations will be well below the project's 24-hour average PM_{10} target of 125 $\mu g/m^3$ as shown in Figure 13.2. As pipeline and RoW construction will not occur in any one area for extended periods of time, the project's annual PM_{10} target is not particularly relevant. However, modelling predicts that the project's annual PM_{10} target of 50 $\mu g/m^3$ will be met within a kilometre of construction works. It should be noted that the effects of terrain will influence the area of dust-related impacts, but not by a significant amount; i.e., modelling results are relevant for the whole of the pipeline and RoW construction path.
- Construction activities at the Hides and Kutubu facilities will result in the generation of airborne particulate matter. However, concentrations will be below the project's PM_{10} targets as shown in Figures 13.3 and 13.4 respectively. The project's 24-hour and annual PM_{10} concentration targets are predicted to be met approximately 500 and 400 m from the Hides and Kutubu facilities' construction sites respectively. All settlements in the vicinity of these facility sites lie outside these potential impact zones.

13.8.4.2 Operations

No air emissions will be associated with the normal operation of the gas pipelines, and therefore no air quality impacts associated with the pipelines will occur. The only air quality impacts associated with the access ways during operations will be very limited dust and gaseous emissions generation due to occasional vehicle use.

Emissions of particulate matter (as PM_{10}), oxides of sulfur and unburnt hydrocarbons will occur from the project's facilities during operations, but are expected to be in negligible quantities; and are not expected to have adverse impacts on the surrounding air quality[1].

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[1] Note that the natural gas from the project-associated gas fields is sweet.

13.8.4.3 NO_x Dispersion Modelling

The atmospheric dispersion of certain project-related NO_x (as NO_2) emissions has been assessed using the CALPUFF computer model.

Modelling of both the existing Hides Gas Plant and the proposed Hides Production Facility predicts that the project's NO_2 targets will be met at the nearest sensitive receptors at Hides (Figure 13.5), which is predicted to experience a 1-hour average NO_2 concentration of 200 $\mu g/m^3$ and an annual average concentration of 30 $\mu g/m^3$ during periods of highest emissions.

Likewise, modelling of emissions from both the existing Kutubu Central Production Facility and the proposed Kutubu Central Gas Conditioning Plant predicts that the project's NO_2 targets will be met at the nearest sensitive receptor (Figure 13.6), where the 1-hour average and annual average NO_2 concentrations are predicted to be 50 and 0.2 $\mu g/m^3$ respectively during periods of highest emissions.

Therefore, based on the project's air quality targets, no adverse air quality impacts related to the Hides or Kutubu facilities are expected to occur at the nearest residential receptors during operations.

13.8.4.4 Emissions of Greenhouse Gases

Emissions of greenhouse gases (GHGs) associated with the PNG Gas Project have been estimated and are summarised year by year in Table 13.18.

Table 13.18 Predicted emissions of greenhouse gases (CO_2-equivalent) (kt/yr)

Year	Total CO_2-equivalent
2005	0
2006	19
2007	79
2008	92
2009	25
2010	261
2011	261
2012	261
2013*	489

*Emissions from 2013 onwards are predicted to remain constant at the 2013 level through 2029.

Peak annual construction phase GHG emissions will occur in 2008 (92 kt [CO_2-equivalent]). Peak annual operations phase GHG emissions of 489 kt (CO_2-equivalent) will begin in 2013 and will remain at this level through 2029.

13.9 Noise

This section presents impact assessment criteria (Section 13.9.1) and addresses the principal issues (Section 13.9.2), proposed mitigation and management measures (Section 13.9.3) and residual environmental impacts (Section 13.9.4) of the project related to construction and operations phase noise impacts. This section summarises Supporting Study 15, which presents a detailed analysis of the project's noise impacts.

13.9.1 Impact Assessment Criteria

The most effective method for assessing the project's noise impacts is to establish project noise targets and determine whether these targets are met at sensitive human receptors (i.e., nearby settlements). Due to a lack of relevant PNG noise guidelines, project noise targets have been established based on the following standards:

- Australian New South Wales (NSW) Environment Protection Agency (EPA) Industrial Noise Policy (NSW EPA, 2000).
- World Bank Pollution Prevention and Abatement Handbook (World Bank, 1998).
- Australian State Pollution Control Commission (SPCC) of NSW (now Department of Environment and Conservation [DEC]) Environmental Noise Control Manual (SPCC, 1987).

The guidelines for noise control contained in these international standards are designed to protect humans against the adverse effects of noise.

13.9.1.1 Background Noise

In general terms, it is the increment above background (existing) noise levels that determines whether a problematic noise situation exists. Therefore, the first step in establishing project noise targets is to establish background noise levels in areas where the project could potentially have a noise impact.

The residential area closest to the proposed Hides Production Facility (Figure 13.7) was selected as the most appropriate receiver-monitoring location in the Hides area as this location will be most affected by any project-related long-term noise impacts during operations. The background noise level (L_{A90}, the noise level statistically exceeded 90% of the time) at this location was measured by an unattended monitor over a 24-hour period from 31 May to 1 June 2005. The monitor was programmed to continuously sample noise levels and store data at 15-minute intervals. Results from this study are provided in Table 13.19.

Table 13.19 Unattended ambient noise environment, 31 May to 1 June 2005

Average Background (L_{A90}) Noise Level (dB(A))		
Day*	**Evening***	**Night***
39.5	43.5	42.5

*Day = 0700 to 1800, Evening = 1800 to 2200, Night = 2200 to 0700.

The quietest period during the monitoring period occurred during the day. This is unusual but occasionally occurs when distant noise sources are more prominent during the evening and night time when noise propagation is improved due to the presence of more stable atmospheric conditions.

Based on established background noise levels, project targets selected for each stage and component of the project are detailed below and are summarised in Table 13.20.

Table 13.20 Project noise targets, dB(A)

Project Activity	Criteria	Day (0700 – 1800)	Evening (1800 – 2200)	Night (2200 – 0700)
Construction	Sensitive human receptor exposure for less than 4 weeks (L_{A10})	60	48	47
	Sensitive human receptor exposure for 4 to 26 weeks (L_{A10})	50	48	47
Operations	Intrusiveness (L_{A90}, measured over a 15-minute period)	44	48	47
	Amenity (L_{Aeq}, measured over the entire period)	55	50	45

13.9.1.2 Project Noise Targets During Construction

Project noise targets adopted for the pipeline RoW, access way, Hides and Kutubu facilities, Kopi wharf modifications and associated work during construction activities are based on criteria set out in the Australian NSW DEC Environmental Noise Control Manual[1] where:

- Sensitive human receptors subject to construction-related noise of less than four weeks duration should not be exposed to L_{A10} (the noise level statistically exceeded 10% of the time) noise greater than 20 dB(A) above background levels when measured over a 15-minute interval.
- Sensitive human receptors exposed to construction-related noise between four and 26 weeks duration should not be exposed to noise greater than 10 dB(A) above background levels when measured over a 15 minute interval.

When blasting activities occur in proximity to residences, instantaneous blast charges will be limited so that:

- Ground vibration will not exceed 5 mm/s.
- Blast overpressure will not exceed 115 dB_{Linear}.

13.9.1.3 Project Noise Targets During Operations

The two noise target criteria described in the NSW EPA Industrial Noise Policy that are relevant for the project's operations are the need to:

- Control intrusive noise impacts in the short-term for sensitive human receptors.
- Maintain noise level amenity over the long-term for sensitive human receptors.

[1] The World Bank Pollution Prevention and Abatement Handbook (World Bank, 1998) does not provide maximum allowable construction noise limits.

Intrusiveness

Based on existing background noise levels (see Table 13.19), application of the NSW EPA Industrial Noise Policy criteria result in the following intrusiveness project noise targets at all sensitive human receptors during operations:

- 44 dB(A) during daytime periods (L_{A90}, measured over a 15-minute period).
- 48 dB(A) during evening periods (L_{A90}, measured over a 15-minute period).
- 47 dB(A) during night periods (L_{A90}, measured over a 15-minute period).

Amenity

Application of the NSW EPA Industrial Noise Policy criteria result in the following amenity project noise targets at all sensitive human receptors during operations:

- 55 dB(A) during daytime periods (L_{Aeq}, or the steady-state sound level that has the same acoustic energy as that of the time-varying sound averaged over the specified time interval measured over the entire period).
- 50 dB(A) during evening periods (L_{Aeq}, measured over the entire period).
- 45 dB(A) during night periods (L_{Aeq}, measured over the entire period).

The World Bank (1998) stipulates daytime and night allowable 1-hour average L_{Aeq} noise limits of 55 dB(A) and 45 dB(A) respectively, which are equivalent to the NSW EPA Industrial Noise Policy amenity criteria.

13.9.2 Issues to be Addressed

13.9.2.1 Construction

Construction activities related to the PNG Gas Project are described in detail in Chapter 6.

Pipeline and Access Way Construction Noise Emissions

Construction of the access ways and pipelines will involve the following steps, each of which would be expected to result in noise emissions, primarily from diesel-powered, earthmoving and electricity generation equipment:

- Vegetation and soil removal.
- Major earthworks.
- Blasting.
- Rock hammering.
- Pile driving (during construction of larger bridges).
- Transportation and handling of pipe strings.
- Trench excavation.
- Pipe welding and lowering-in.
- Backfilling and compaction of pipe trench.
- Pipe hydrotesting and dewatering.
- Rehabilitation.
- Electricity generation.

Hides and Kutubu Facilities Construction Noise Emissions

Construction of the Hides and Kutubu facilities will require the use of machinery and equipment that has the potential to generate noise from the following activities:

- Site preparation.
- Excavation, rock breaking and blasting.
- Preparation and pouring of concrete foundations.
- Delivery of components to site.
- Installation of structural, mechanical and electrical components.
- Construction of ancillary buildings and facilities.
- Commissioning.

Well Drilling

Well drilling equipment and methods are described in Section 6.3. Drilling activities will generate noise; and as a result, a number of settlements in the vicinity of the Hides 4 well may be temporarily impacted.

13.9.2.2 Operations

Pipeline and Access Way Operational Noise Emissions

There will be no noise associated with the normal operation of the pipelines, except for periodic inspections involving vehicles and helicopters and infrequent repair activities, which may require digging up the pipe and reinstatement; such repair activities would normally take place over a period of one to two weeks.

Access ways will be subject to operational traffic, which will include light and heavy vehicles.

Hides and Kutubu Facilities Operations Noise Emissions

Operation of the Hides Production Facility will involve running a number of noise-generating units and pieces of equipment, nominally 24 hours a day, including:

- Initial Operations:
  - Two Centaur 40 power plants.
  - One essential-services diesel generator.
  - Two elevated low pressure flares.

- Later Operations:
  - One additional Centaur 40 power plant.
  - Three additional Titan 130 compressors.

Similarly, operation of the Kutubu Central Gas Conditioning Plant will involve running the following noise-generating units and pieces of equipment, nominally 24 hours a day:

- One Centaur 50 power plant.
- Four Titan 130 compressors.
- One elevated flare.

13.9.3 Mitigation and Management Measures

13.9.3.1 Construction

To reduce noise generated during construction of the project's pipelines, access ways, and the Hides and Kutubu facilities, the following acoustic treatments will be implemented during this period:

- Construction activities will incorporate appropriate techniques for the control of noise to limit impacts on sensitive human receptors in the vicinity of the noise source as follows:
  - Pneumatic tools operated near settlements will be fitted with an effective air exhaust port silencer.
  - Noise labels will be affixed to all mobile air compressors. The unit with the lowest noise rating that meets the requirements of the job will be used where work is conducted in a noise-sensitive location.
  - Noise suppression devices on construction vehicles and equipment will be maintained.
  - Where noise from construction activities may impact a sensitive human receptor, the affected party will be notified of the intended work and its duration. Compensation related to demonstrable project-associated damages is described in Section 15.7.2.
  - Where required (locations in close proximity to sensitive human receptors), maximum instantaneous blast charges will be limited by controlling the magnitude and sequence of blasting so that ground vibration will not exceed 5 mm/s and blast overpressure will not exceed 115 dB_{Linear}. Locations where blasting controls will be required will be determined during construction.

13.9.3.2 Operations

Acoustic treatments will be implemented at the Hides and Kutubu facilities as needed, including housing the turbines in manufacturer’s enclosure kits.

13.9.4 Residual Impact Assessment

13.9.4.1 Construction

Pipelines and Access Ways

Appropriate techniques will be adopted during access way and pipeline construction activities to limit noise-related impacts to sensitive human receptors. Pipeline and access way construction work is expected to progress along the RoW at a rate that would limit activities in any one area to a maximum of approximately 12 weeks.

Noise modelling of a generic pipeline and access way construction scenario (as described in Supporting Study 15), incorporating appropriate mitigation techniques, such as those proposed above, was undertaken to determine residual noise impacts attributable to the project.

Modelling results are shown in Figure 13.7 and indicate that the project’s noise targets will be met at varying distances from construction works. A number of settlements will be unavoidably impacted as shown in Table 13.21 and Figures 13.8 and 13.9.

Table 13.21 Pipelines and access ways construction-related noise impacts

Criteria	Time of Day	Project Noise Target (dB(A))	Distance from RoW Noise Target is Achieved (m)	Estimated Number of Affected Settlements
Sensitive human receptor exposure for less than 4 weeks (L_{A10})	Day (0700 – 1800)	60	500	31
	Evening (1800 – 2200)	48	1,300	43
	Night (2200 – 0700)	47	1,600	50
Sensitive human receptor exposure for 4 to 26 weeks (L_{A10})	Day (0700 – 1800)	50	1,100	41
	Evening (1800 – 2200)	48	1,300	43
	Night (2200 – 0700)	47	1,600	50

The maximum period of time that any one settlement is expected to experience pipeline and access way construction-related noise impacts is anticipated to be 12 weeks.

It should be noted that the 44 dB(A) operational project (amenity) noise goal will be met 2,000 m from the construction RoW. Therefore, any sensitive human receptors located further than this distance from the RoW will not be adversely impacted by pipeline and road construction noise, no matter how long construction occurs at any one location.

Hides and Kutubu Facilities

The noisiest construction period (i.e., earthworks) associated with facilities construction will occur over a period of four weeks at Hides and six weeks at Kutubu. Modelling undertaken for these periods at the Hides and Kutubu facilities predicts that:

- The closest sensitive human receptor in the vicinity of the proposed Hides Production Facility will experience a 1-hour L_{Aeq} noise level of 53 dB(A), which is below the project's 4-week construction day time noise target of 60 dB(A). It is above the evening and night noise targets of 48 db(A) and 47 dB(A) respectively. Therefore, construction activities will unavoidably impact on the closest sensitive human receptor during the evening and night. To limit the noise impacts, consideration of scheduling construction activities so that noisiest activities occur during the day and not during the evening or night is warranted.

- The closest sensitive human receptor in the vicinity of the proposed plant at Kutubu will experience a 1-hour L_{Aeq} noise level of 40 dB(A), which is below the project's 4- to 26-week day (50 dB(A)), evening (48 dB(A)), and night (47 dB(A)) noise targets. Therefore, based on expected periods of earthwork activities, no adverse construction-related noise impacts on sensitive human receptors are expected to occur.

Well Drilling

Well drilling activities may occur for up to six weeks at the Hides 4 well. Based on the equipment and methods required for the drilling of wells, modelling predicts that the project's noise target of 50 dB(A) will be met approximately 250 m from drilling activities.

The closest residence to the Hides 4 well is approximately 470 m from the site of proposed drilling activities. Therefore, no adverse impacts are predicted to occur during the project's well drilling program in this location.

13.9.4.2 Operations

Pipelines and Road

The project's pipelines will not normally produce any noticeable noise during operations and will therefore not have a noise-related impact on sensitive human receptors.

Periodic pipeline inspections will occur. The vehicles and helicopters used for these inspections will cause limited localised and non-problematic noise impacts.

Any pipeline repair activities will be infrequent and may involve digging up the pipe and reinstatement over a period of one to two weeks. Noise impacts during such repairs will be limited, localised and non-problematic in most instances.

Hides and Kutubu Facilities

Modelling of the operation of the Hides Production Facility predicts that the project's noise targets will be met at the nearest sensitive human receptor (Figure 13.10) (i.e., a 1-hour L_{Aeq} noise level of 41 dB(A)).

Likewise, modelling of the existing operation and proposed plant at Kutubu predicts that the project's noise targets will be met at the nearest sensitive human receptor (see Figure 13.10) (i.e., a 1-hour L_{Aeq} noise level of 38 dB(A)).

Therefore, after adopting suitable acoustic treatments, no adverse noise impacts related to the operation of the Hides or Kutubu facilities are expected to occur at the nearest sensitive human receptor locations.

14. Environmental Impacts and Mitigation Measures – Offshore

This chapter discusses the impact assessment related to the installation of the offshore sales gas pipeline. Impact assessment criteria are described (Section 14.1), followed by a presentation of the environmental issues, proposed mitigation measures, and residual impacts after the mitigation measures have been applied with regard to the following topics:

- Seabed habitats (Section 14.2).
- Water quality (Section 14.3).
- Resource use (Section 14.4).
- Air quality, light and underwater noise (Section 14.5).
- Injuries to marine mammals and other fauna (Section 14.6).
- Maritime safety (Section 14.7).
- Quarantine (Section 14.8).
- Waste management and emergency response (Section 14.9).
- Impacts during operations (Section 14.10).

Note that all but the last topic are associated with the installation of the offshore pipeline.

Methods for mitigating potential impacts to the marine environment can be either active, where specific actions and procedures are implemented, or passive, where the natural variation in ambient conditions will mask any localised or short-duration impacts caused by pipeline installation activities.

14.1 Impact Assessment Criteria

Impact assessment is predicated on the successful implementation of appropriate mitigation measures and is therefore an evaluation of residual impacts. Criteria for assessing residual impacts in the marine environment are based on duration and extent as follows:

- **Prolonged** – impacts expected to last beyond one year from the completion of pipeline installation.

- **Short Duration** – impacts not lasting beyond one year from completion of pipeline installation and are generally restricted in duration to the time of installation itself.

- **Extensive** – impacts affecting an area more than three times the direct physical area of disturbance.

- **Localised** – impacts restricted to within three times the direct physical area of disturbance and, for the most part, are restricted to the physical impact area itself.

14.2 Seabed Habitats

14.2.1 Issues

During the installation of the offshore pipeline, localised impacts will occur to those areas of the seabed physically covered by the pipeline. Slightly greater disturbance will occur to those areas affected by activities such as presweeping, trenching to bury the pipeline and the placement of laybarge anchors. These activities are fundamental to offshore pipeline installation and the assurance of long-term pipeline integrity.

14.2.2 Mitigation Measures

The seabed habitats of the Gulf of Papua and Torres Strait must be crossed by the offshore sales gas pipeline and the vessels involved in its installation. The key proposed mitigation measures aimed at limiting impacts to seabed habitats are as follows:

- Alignment of the pipeline route to avoid coral reefs and to limit the extent of seagrass beds traversed.
- Limiting the use of the activities that cause the most disturbance to the seabed, particularly presweeping, trenching and anchor deployment, to the extent practicable. Note that trenching should only be required in shipping channels, in the Omati River section and at shore approaches.

14.2.3 Residual Impact Assessment

Disturbance to the seabed will be limited since the majority of the pipeline will be laid directly on the seabed, with its own weight providing necessary stability. Active burial is proposed only in the Omati River sections (see Section 7.3.5), in nearshore waters to the 6-m depth contour and in defined shipping channels. In the main, residual impacts to seabed habitats can be expected to be of short duration and highly localised.

Table 14.1 summarises the areas of seabed disturbed by the proposed pipeline trench excavation and anchor abrasion in the Gulf of Papua and Torres Strait.

14.2.3.1 Soft Seabed Habitats

Table 14.1 shows that, in the Gulf of Papua, the total area disturbed by trenching and anchor abrasion is only 10.2 km^2 out of a total area of 36,000 km^2, which represents a disturbance of 0.028% of that seabed habitat type. In the unconsolidated sediments found along much of the proposed pipeline route across the Gulf of Papua, residual impacts to seabed habitats will be of short duration and spatially localised since:

- The disturbance involves a single pass at any one location.
- The coastal waters of the Gulf of Papua are naturally too turbid for the development of seagrass or algal beds.

Table 14.1 Areas of seabed habitat disturbed

Seabed Habitat Type	Distance Crossed by Pipeline (km)	Total Area of Feature (km^2)	Seabed Anchor Scarring and Anchor Chain Abrasion†		Seabed Trench Excavation††		Total Area Disturbed (rounded)	
			km^2	%	km^2	%	km^2	%
Gulf of Papua sediments**	170	36,000	1.70	0.005	8.50	0.024	10.20	0.028
Torres Strait epibenthos*								
Dense	0	3,700	0	0	0	0	0	0
Sparse	20	4,040	0.20	0.005	1.00	0.025	1.20	0.030
Very sparse	65	7,200	0.65	0.009	3.25	0.045	3.90	0.054
Absent	119	4,450	1.19	0.027	5.95	0.134	7.14	0.160
Torres Strait seagrass	76	8,710*	0.76	0.009	3.80	0.044	4.56	0.052

* The area of Torres Strait for which mapped information exists (Long et al., 1997).
** Gulf of Papua to 60 m depth.
† At 1 ha/km.
†† At 5 ha/km.

- The unconsolidated, terrigenous prodelta muds are not extensively colonised by benthic fauna.
- Remobilised fine sediments are not likely to settle in areas where they do not naturally occur, as they will be moved by the same currents that move the existing suspended sediments.

The installed pipeline will protrude above the soft sediments and may accelerate local current flows and erosion. This process will tend to cause the pipeline to self-bury. Provided sediments are deep enough, this will occur until local equilibrium is reached. The environmental implications of gradual burial of the pipeline are not significant, unless the erosion causes spanning above underlying harder areas, in which case remedial protective measures, such as the installation of grout bag support or rock dumping, may be required to ensure the pipeline's integrity.

14.2.3.2 Hard Seabed Habitats

In areas of harder substrate where the pipeline will be laid directly on the seabed (i.e., any hard seabed habitat not in a defined shipping channel), the sedimentation and turbidity effects associated with its installation will be small, localised and of short duration. Strong currents also characterise such areas, and any material mobilised into the water column will be expected to be swept away to join the natural sediment regime and will settle out in existing sedimentary environments where the currents are weaker.

The disturbance in question will not change the most important characteristic of this type of seabed, namely its hardness. The physical surface will remain available for recolonisation, as will the hard substrate offered by the pipeline itself and any displaced seabed material. Having grown there once, epibenthos is expected to regrow in such locations in a short period of time.

14.2.3.3 Mobile Bedform Habitats

After presweeping, mobile bedform features, such as sand waves, are expected to reform around the laid pipe in a relatively short period of time, with no lasting or residual environmental effects. The sand waves that are typical of parts of the pipeline route in the western Gulf of Papua and Torres Strait arise from bed sediment mobilisation by tidal currents and, occasionally, by cyclones. Consequently, mobile seabed habitats would not appear to be particularly sensitive to localised, temporary, pipeline construction-induced disturbances.

14.2.3.4 Seagrass Beds

Once west of the influence of the turbidity of the Fly River, the proposed pipeline route passes through flat seabed areas and passages between reefs where seagrass beds occur. In the Torres Strait Protection Zone, the total area of seagrass disturbed is predicted to be very small; about 0.052% of the mapped area of seagrasses (see Table 14.1).

The installation of the pipeline on the seabed will progress at a rate of 2 to 4 km/day, limiting the effects of bed sediment resuspension and deposition on seagrass to short-duration, small magnitude, localised events.

The seagrass communities affected by anchor chain abrasion (see Table 14.1) or anchor scarring will recover over time at a rate that depends on the extent and depth of the disturbance. The area abraded by anchor chains will be more extensive than that scarred by the anchors but will be disturbed to a lesser depth. The anchor chains may damage seagrass leaves and shoots but will have less impact on the root systems.

Regrowth in areas affected by scarring from the anchors and abrasion from the anchor chains may be prolonged (i.e., take more than one year to fully regrow). However, the project's impacts will be localised, and only a very small area (4.56 km^2, or 0.052%) of the seagrass cover in Torres Strait is expected to be impacted.

14.2.3.5 Coral Reefs

The route through the western Gulf of Papua and the Torres Strait Protection Zone has been chosen along inter-reef passages in order to avoid any impacts to coral reefs.

14.2.3.6 Epibenthos

The epibenthic communities inhabiting the seabed directly beneath the pipeline will be initially smothered and then replaced either by different communities colonising the exposed surface of the pipeline or, if the pipeline becomes buried over time, by the original communities gradually re-establishing themselves in the overlying sediments. Either way, the benthic communities will tend to resemble those of the adjacent areas. The prodelta muds of the Gulf of Papua do not have high densities of epibenthos (Chapter 10), because of their dynamic nature. In the Torres Strait Protection Zone, only 0.01% and 0.05% of the mapped area of epibenthos will be affected by anchor abrasion and trenching, respectively (see Table 14.1).

In the limited areas where spoil will be sidecast as a result of trenching, the spoil material will be similar to that of the adjacent area. Consequently, the benthic communities will rapidly recolonise the settled, sidecast material from within or from adjacent, undisturbed areas. Residual effects to epibenthic communities due to the installation of the pipeline are therefore expected to be of short duration and highly localised.

14.3 Impacts to Water Quality

14.3.1 Issues

The activities associated with offshore pipeline installation (pipelaying, presweeping, pipeline burial, and the placement and retrieval of anchors) will affect water quality by resuspending bottom sediments and increasing turbidity downcurrent of the areas of disturbance. Increased suspended sediments could, in turn, affect seagrass beds and coral reefs, which generally grow in areas of relatively clear water with sufficient light penetration. Consequently, seagrass beds and coral reefs may be susceptible if suspended sediments caused by pipeline installation activities persist at concentrations significantly above typical background levels to which they are naturally tolerant.

Local water quality will also be minimally affected by discharges of other domestic wastes and deck wash from the pipeline installation vessels.

Water quality may also be affected by the discharge of the water used to hydrotest the offshore pipeline. As discussed in Chapter 7, this water will be treated with small concentrations of a biocide and an oxygen scavenger.

14.3.2 Mitigation Measures

Mitigation of suspended sediment and turbidity impacts associated with the installation of the offshore sales gas pipeline is proposed to be achieved by:

- Limiting to the extent practicable the use of those activities that cause the greatest increases in turbidity, namely presweeping, trenching and the setting and retrieval of anchors.
- Domestic wastes will be treated by disinfection of grey water and maceration of solid food waste before discharge, in accordance with the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978) requirements.
- Deck water potentially in contact with oily surfaces will be passed through oil/water separators before discharge overboard.

Application will be made to the Independent State of Papua New Guinea to discharge the hydrotest water under a waste discharge permit, and all conditions of the permit addressing water quality issues are to met.

14.3.3 Residual Impact Assessment

The residual impacts to water quality from the installation of the pipeline will be of short duration and spatially localised because:

- The disturbance involves a single pass at any one location.
- The water is naturally turbid for much of the pipeline route through the Gulf of Papua, largely masking any effects related to pipelaying activities.
- Remobilised fine sediments are not likely to settle in areas where they do not naturally occur, as they will be moved by the same currents that move existing suspended sediments.
- Discharges of treated domestic wastes and water from oil/water separators will be in compliance with MARPOL requirements and will be rapidly diluted.
- The naturally high suspended sediments in the areas where resuspension of sediment is likely to be highest, namely, the buried section of the pipeline from the Omati River to the 6 m depth contour in the Gulf of Papua.

No residual impacts to water quality from the discharge of hydrotest water are expected due to the effects of dilution (see the detailed explanation of these dilution effects in Section 14.8.3).

14.4 Resource Use

14.4.1 Issues

The proposed offshore sales gas pipeline route crosses or is in the vicinity of commercial and subsistence fisheries in the Gulf of Papua and Torres Strait. The presence of the pipelaying vessels may pose a short-duration inconvenience to fishing and other vessels in the immediate area of pipelaying activity.

14.4.2 Mitigation Measures

The proposed route of the offshore sales gas pipeline avoids areas that are most intensively fished by the trawlers of the Gulf of Papua prawn fishery and also passes to the north and west of the main trawling grounds in Torres Strait and is too far offshore to affect village-based subsistence fisheries.

Timing the installation of the offshore sales gas pipeline during the months of December to March to coincide with the closed season for the Gulf of Papua prawn trawl fishery was considered. This measure was found to not necessarily possess any advantage, as the closure period applies east of longitude 144º28'00"E (to protect juvenile recruitment areas), which is east of the proposed pipeline route as shown in Figure 10.14 in Chapter 10. The outcome of implementing such a measure is, in fact, likely to be negative, since it is possible that more trawlers would be fishing in the area of the pipeline route at that time.

The following additional mitigation measures are proposed to be implemented to manage possible interactions between fishing and other vessels and the vessels involved in pipeline installation:

- Fishing and other vessels will be requested to remain outside a safe buffer zone around the pipeline installation vessels and the anchor cables (if used).
- Regular radio communication procedures will be established to provide fishing and other vessels operating nearby with information on day-to-day activities so that they can observe the safe buffer zone.
- The survey vessel (see Section 7.3.4) will also act as a scout vessel to warn fishing and other vessels of the need to maintain a safe distance.

14.4.3 Residual Impact Assessment

The main residual impact faced by fishing boat operators in the Gulf of Papua and Torres Strait is the temporary inconvenience of having to keep clear of vessels involved in the installation of the pipeline. Fishing boat skippers will need to select alternative locations to obtain their catches if, at any time, the pipeline construction activities pass through their preferred fishing grounds. The fishery grounds in question are extensive in relation to the small, temporary and moving safe buffer zone area, and so any inconvenience will be highly localised and of very short duration.

Observance of safe buffer zones around the pipeline installation vessels will also be requested by fishers and hunters in Torres Strait, but the inconvenience should be highly localised and of very short duration as alternative fishing areas are available.

There will be no exclusion zone around the offshore sales gas pipeline once it is installed.

The installation of the offshore pipeline is anticipated to have no direct (and therefore no residual) impact on the various small-scale coastal fisheries in the Gulf of Papua and to the west of Daru, since this work will occur well offshore.

As described in Sections 14.2 and 14.3, impacts to the seabed are also predicted to be very small, highly localised and of very short duration and will have no adverse ecological effect on fish resources.

14.5 Air Quality, Light and Underwater Noise

14.5.1 Issues

The pipelaying and supporting vessels will operate 24 hours per day using deck lights and will emit exhaust emissions to the air. The pipelaying vessels will also emit underwater noise that will be characteristic of the source (engine size, thrusters etc.), and the sound will have the potential to interfere with nearby marine mammals that communicate using sound.

14.5.2 Mitigation Measures

Since air emissions will be restricted to the exhausts from the normal operations of the pipelaying vessels, no particular mitigation measures are practical or necessary. The emissions will be limited in quantity, highly localised and of very short duration in any one location.

In recognition of the fact that the underwater sound associated with the offshore pipelaying activities is anticipated to be highly localised and of very short duration in any due location, no sound mitigation measures are practical or necessary.

Deck lighting on construction vessels will be kept to the lowest levels needed to maintain safe working conditions. In principle, this will not be materially different from the lighting associated with other vessels traversing the area and no adverse impacts to flora and fauna are therefore predicted.

14.5.3 Residual Impact Assessment

Owing to their limited quantity, short duration and spatially limited nature, no residual impacts are anticipated from air emissions or deck lighting from the vessels involved in the installation of the offshore sales gas pipeline.

Marine mammals (and other fauna such as turtles) will be able to detect the sound produced by the pipelaying vessels and avoid them. For example, whales typically keep a standoff distance extending to a few kilometres from vessels with loud sound signals (APPEA, 2005). Therefore, no residual impacts related to underwater noise are expected.

14.6 Injuries to Marine Mammals and Other Fauna

14.6.1 Issues

There are a number of protected and endangered species inhabiting the waters of the western Gulf of Papua and Torres Strait, such as dugongs and some species of whales, that could be injured by collisions with the vessels involved in laying the offshore sales gas pipeline.

14.6.2 Mitigation Measures

The vessels associated with the installation of the offshore pipeline will move at very slow speeds and will operate with equipment (e.g., anchors and the pipeline itself) on the seabed; consequently their ability to take avoiding action is extremely limited. However, the risk of injury to marine mammals will be mitigated by the slow vessel speeds and by the implementation of a Marine Mammal Observation Procedure. This procedure, which will require all observations and encounters with marine mammals to be documented in a Marine Mammal Observation Log, will also be used to warn the vessel crew of any whale or dugong activity within close proximity (e.g., 500 m) of the pipelaying vessels. The procedure will require pipelaying activities to be slowed to the extent practical until the animals have moved further away.

The sounds associated with the pipeline installation activities should deter marine mammals temporarily from the immediate areas of activity, further lessening the likelihood of collision.

14.6.3 Residual Impact Assessment

No residual impacts are expected with regard to collisions between pipelaying vessels and marine mammals owing to the unlikelihood of collisions occurring.

Furthermore, although endangered species of whales have been observed in the Gulf and Strait, there are no areas of recognised aggregation, breeding or resting activity for any endangered species of whales in the region traversed by the offshore sales gas pipeline (DEH, 2005).

14.7 Maritime Safety

14.7.1 Issues

The construction and operation of the offshore sales gas pipeline must meet company, national and international standards of safety as described in Section 2.5. Safety during construction will be strictly observed by the offshore construction spread.

Weather and sea conditions present safety issues for the vessels engaged in construction of the pipeline. Strong winds and strong currents will periodically generate difficult sea states, especially during the southeast trade wind season, and in the event of cyclones.

The installation of the offshore pipeline raises the following shipping and navigation issues:

- Construction vessels will add to offshore traffic, creating a short-term obstacle for other vessels and vice versa.
- The pipelaying and support vessels will pose a hazard to small boats and sea-going canoes if the latter approach too closely.
- The pipeline route through Torres Strait will cross defined shipping channels.
- If a section of the pipeline becomes unsupported during operations due to scouring of the underlying sediments, there is a risk of spanning in areas where ships anchor or where trawling occurs.

14.7.2 Mitigation Measures

14.7.2.1 Project Safety

Offshore pipelaying operations and other associated construction activities will be carried out to comply with:

- Safety, health, and environment plans for all offshore construction activities and operations to be developed by the Operator and its contractors.
- Applicable PNG occupational health and safety legislation and the Operator's safety policies.

- The DNV OS-F101 International Offshore Construction Standard and AS 2885.
- A post-pipelaying survey to detect scour areas.

Similar safety performance expectations will be established between the contractor and its subcontractors, and these will be documented in the EMP (as described in Chapter 18).

The pipelaying vessel will also be evaluated and inspected to its ability to work safely and maintain its position in the sea states likely to be encountered.

14.7.2.2 Interaction with Other Vessels during Construction

Normal maritime communication systems and procedures are to be followed by the offshore pipeline installation vessels to ensure safety at sea.

A hazard may apply to villagers, if out of curiosity, their boats or canoes approach too close to the pipeline installation vessels. Such encounters are most likely to take place close to shore near the Omati River, and therefore will only occur for the short period when the vessels are within access of the small boats. Villagers will be informed about the hazards of pipelaying vessels. The survey vessel associated with the laybarge will also patrol a safe buffer zone around the pipelaying activities and warn small boats of potential dangers.

Where the offshore sales gas pipeline route crosses designated shipping channels (mostly in Torres Strait), the crossing distance will be reduced to a practical minimum (e.g., the pipe will be aligned perpendicular to the channel). The pipeline will either be laid on the seabed in areas where there is adequate water depth or will be buried to maintain minimum (charted) drafts. Navigation charts will be updated to show the as-laid position and to designate this area as a no-anchor zone.

Vessels involved with the offshore sales gas pipeline installation are to be in communication with the Australian Maritime Safety Authority at all times. All ships over 50 m entering Torres Strait are required to report their position regularly whilst in Torres Strait to the Reef Vessel Traffic System in Mackay, Queensland.

There is mandatory pilotage for large vessels in the Torres Strait, and these pilots should be aware of ongoing construction activities.

14.7.3 Residual Impact Assessment

The implementation of the mitigation measures described above will ensure that the risk of safety hazards from installation activities will be very short duration and highly localised in nature.

14.8 Quarantine

14.8.1 Issues

Installation of the pipeline involves two potential pathways for the introduction of non-native marine flora and fauna into PNG waters:

- Presence in the ballast water of cargo vessels or on the hulls of the vessels associated with the installation of the offshore sales gas pipeline.
- Presence in hydrotest water. During commissioning, the entire subsea section of the pipeline will be filled with hydrotest water. After testing, the hydrotest water will be discharged to the environment. The impacts on water quality have been discussed in Section 14.3, but here this matter is presented as a potential quarantine issue, since water that potentially will be sourced near Cape York in Australia (as described in Section 7.4) will be discharged into the Omati River in Papua New Guinea.

14.8.2 Mitigation Measures

Vessels entering the Gulf of Papua for project purposes are expected to arrive fully loaded, rather than empty and ballasted, and so there will be limited need to discharge ballast sourced from overseas ports. This significantly reduces the risks of introducing non-native marine species. In the event that discharge of ballast water is required, vessels will adhere to MARPOL requirements (MARPOL 1973/1978) and industry best practice (e.g., AQIS, 2005). Hull anti-fouling records of vessels entering PNG waters can be inspected by State authorities.

The risks of introducing non-native marine species (bacteria and larger organisms) and contaminants into the marine environment via the discharge of hydrotest water is to be limited by the application of the proposed mitigation measures presented below:

- The hydrotest water will be tested for suspended sediment content and, if necessary, filtered before filling the pipeline and again before discharge to remove most solid contaminants.
- The dosage of biocidal and oxygen-removing treatment chemicals, together with the high pressure within the pipeline will create a hostile environment for organisms.
- The combination of the natural degradation of the treatment chemicals in the hydrotest water and dilution at the discharge site (in the Omati River near the PNG landfall location) will rapidly reduce concentrations of the chemicals to inactive levels.
- The habitats at the proposed source and discharge locations are dissimilar, and so the successful colonisation of species from open, clear saline waters in the vicinity of the discharge location is unlikely.
- Application will be made to the Independent State of Papua New Guinea to discharge the hydrotest water under a waste discharge permit and the conditions applicable to quarantine issues.

14.8.3 Residual Impact Assessment

No residual impacts are predicted in relation to the introduction of non-native marine species from the discharge of ballast water or on the hulls of vessels involved in the installation of the offshore sales gas pipeline.

The maximum total volume of hydrotest water inside the entire length of the offshore sales gas pipeline to be discharged at any one time is approximately 160,000 m^3. It is proposed that this hydrotest water be discharged to the Omati River over a period of 7 to 10 days, corresponding to a discharge rate ranging from 11 m^3 to 16 m^3 per minute (Section 7.4.2). The hydrotest water is to contain small quantities of an oxygen scavenger (e.g., Champion OS-2), originally dosed at 100 mg/L (16 m^3 total volume) and a biocide (e.g., Bactron B1150), originally dosed at 200 mg/L (32 m^3 total volume).

These chemicals and the conditions within the pipeline are to prevent the introduction of potentially harmful species into Papua New Guinea. In addition, the dissimilarity between the aquatic environments at the hydrotest water sourcing and discharging points are unfavourable to the survival of non-native species.

On disposal, organisms in the receiving water may be exposed to these chemicals. Chemical Data Safety Sheet information states that Champion OS2 is a reducing agent, biodegradable and slightly toxic to aquatic fauna. Bactron B1150 has a degradation rate of 64% in 28 days under aerobic conditions. Table 14.2 gives the aquatic toxicity data (effect of concentration to 50% of test organisms after a particular time) for Bactron B1150.

Table 14.2 Aquatic toxicity data for Bactron B1150

Test	Organism	Test Type	Result
Algae	Skeletonema costatum	EC50 72 hr	1.2 mg/L
Crustacean	Acartia tonsa	EC50 48 hr	0.21 mg/L
Fish	Sheepshead minnow	EC50 90 hr	64 mg/L

Tidal conditions in the Omati River are estimated to flush approximately 93 million m^3 of water past the point of discharge over each six hour tidal cycle. Therefore, hydrotest water is estimated to be diluted with Omati River water to 0.006% of the total water volume at the discharge point within six hours of discharge.

Concentrations of Champion OS2 and Bactron B1150 in receiving waters six hours after discharge to the Omati River at Kopi are estimated to be 0.011 and 0.022 mg/L respectively, indicating that concentrations will be well below levels harmful to aquatic organisms.

Thus, no residual impacts related to the discharge of hydrotest water are expected.

14.9 Waste Management and Emergency Response

14.9.1 Issues

Activities on the pipeline construction vessels include the handling and storage of wastes, including domestic wastes and small quantities of wastes with hazardous properties that could impact the marine environment.

14.9.2 Mitigation Measures

14.9.2.1 Waste Management

A waste management procedure will be developed to ensure that all hazardous and dangerous goods that will be used on the pipelaying vessels, including diesel fuel, oxy-acetylene gas (for welding), solvents (for repair of corrosion coating), oxygen-reducing agents and corrosion inhibitors (additives to hydrotesting water) and X-ray sources (for radiography of pipeline welds) are transported to shore and disposed of in accordance with international standards (MARPOL 1973/1978) governing the transport, handling and disposal of hazardous and dangerous goods.

Domestic wastes (i.e., kitchen scraps) are to treated by maceration before discharge (into international waters). Sewage and grey water are to treated in accordance with MARPOL requirements prior to being discharged.

The vessels employed in the installation of the offshore pipeline are to store, use and handle all hazardous chemicals and materials in accordance with MARPOL (1973/1978) requirements. This will include:

- The development of a hazardous materials register.
- Separate storage of paints and other flammable materials.
- Wastes produced by vessels involved in the installation of the offshore pipeline will be stored on board and then transferred to approved onshore facilities for treatment, reuse, recycling or disposal.
- Storage of radioactive materials used for weld inspection in suitable, adequately marked, purpose-built containers, to be handled by qualified personnel only.

14.9.2.2 Emergency Response Spill Contingency Planning

Personnel on the offshore pipelaying vessels are to inducted into the relevant contractor's environment, health and safety policies, and emergency response procedures pertaining to the offshore pipelaying activities will be outlined.

Spill response procedures will be developed and implemented in the event of a spill; these will include:

- Spill prevention measures for the most likely situations (refuelling, routine operations).

- Inductions (for all on-board personnel) regarding responsibilities and lines of communication related to spill response.
- A listing of containment and clean-up equipment to prevent and respond to spills.
- Training for those workers responsible for implementing emergency procedures.

Details related to emergency response and spill contingency planning and capabilities will be provided in the offshore construction Environmental Management Plan (see Chapter 18).

14.9.3 Residual Impact Assessment

Residual impacts after the project's defined procedures are applied to wastes generated during offshore pipelaying activities will be limited to the discharge of treated grey and black water and macerated kitchen wastes into offshore waters. This will be a once-off discharge in any particular location, and the subsequent rapid dilution will result in only extremely localised and very short-duration impacts to water quality.

14.10 Impacts During Operations

14.10.1 Issues

Once laid and commissioned, the offshore sales gas pipeline will become a passive feature of the seabed, and impacts during operations are therefore predicted to be very limited. Boat traffic associated with the operations phase will be negligible, typically restricted to a post-construction, as-built survey and then inspections approximately every 5 years. This section therefore describes:

- Interaction with fishing (Section 14.10.2).
- Interference with rock lobster migration (Section 14.10.3).
- Emergency situations (Section 14.10.4).

14.10.2 Interaction with Fishing

There will be no exclusion zone established for fishing vessels over the pipeline during operations. The pipeline will be concrete-coated and is therefore not susceptible to damage from conventional fishing gear. The pipeline is expected to self-bury for most of its length in the soft sediments of the Gulf of Papua based on a pipeline inspection and maintenance program (PIMP) survey undertaken in 2002 of the existing Oil Search – operated crude oil export pipeline, which has self-buried for approximately half its length.

Analysis has shown that spans occurring due to scouring are self-limiting i.e., before critical span length is reached, the span will touch down in the middle, thereby reducing span length (Forbes, pers. com., 2005) and the likelihood that snagging by fishing gear used by prawn trawlers will occur. The effect of scouring over time will have the effect of burying the pipeline. Skippers of prawn trawlers will nevertheless need to apply due diligence when trawling in the vicinity of the pipeline in order to avoid potential risks to the safety of their vessels. As-laid information on the pipeline location will be passed on to the PNG hydrographers office by the project for incorporation into navigation charts.

If trawl gear is lost or damaged by an undersea pipeline, the principle of compensation has been established by international agreement. Article 29 of the 1958 Convention on the High Seas extends Article VII of the Submarine Telegraphs Convention of 1884 to include undersea pipelines. Under this regulation:

- Shipowners who can prove that they have sacrificed gear fastened on an undersea pipeline will be compensated.
- Evidence will need to be prepared and the incident reported within 24 hours of the affected vessel returning to port.
- Port authorities are to communicate the incident report to the consular officials of the country to which the company responsible for the pipeline belongs.

A process for the evaluation and payment of compensation for any loss of fishing gear will be developed by the project and documented in the Operations Environmental Management Plan (see Chapter 18).

14.10.3 Interference with the Rock Lobster Migration

Adult tropical rock lobsters undertake annual migrations from the reefs of the Torres Strait and the northern Great Barrier Reef across the Gulf of Papua to the reefs off Yule Island and further to the east. This takes place from August to December each year. The offshore sales gas pipeline presents a potential obstacle to this migration. However, the ability of tropical rock lobsters to crawl over a pipeline has been demonstrated (NSR, 1998b), and therefore the presence and operation of the pipeline presents no obstacle to the annual rock lobster migration. No special mitigation measures are required to be implemented in relation to this issue.

14.10.4 Emergency Situations

Catastrophic failure of the offshore sales gas pipeline, once operational, is an extremely remote prospect. The most conceivable scenario would be a large ship with engine failure deploying its anchor over the pipeline, either inside or having drifted outside the shipping channel. Even so, the large diameter of the pipeline, its burial and charted location within the two shipping channels, make such an event extremely unlikely.

Failure of the pipeline, for any reason, would be immediately detected at the Kutubu control room and the gas flow would be immediately stopped in order to limit the duration of any risks to safety. Any lost gas would rapidly disperse to the atmosphere with limited effects on the marine environment.

15. Sociocultural Impacts and Mitigation Measures

This chapter provides a summary of the sociocultural impacts of the PNG Gas Project. It is based on the information contained in Supporting Study 10. Mitigation measures proposed to by the PNG Gas Project are also described.

15.1 Economic Impact

The net economic benefits associated with the PNG Gas Project are potentially very significant for Papua New Guinea. Based on indicative economics, the impact on the national income is projected to be approximately US$3.2 billion in net present value[1] over the anticipated life of the project. These benefits are not so much an increase over existing oil revenues as an extension – by several decades – of the oil and gas industry's current contribution to the national wealth.

The predicted net direct cash flow to the State and project area landowners associated with the PNG Gas Project is shown in Figure 15.1 After debt repayment, the combined direct government plus landowner annual income rises to a maximum of about US$190 million (2005 US$). (This is a subset of the total direct income realised from the project.)

15.1.1 Value of Output

The project will provide a significant boost to PNG's energy exports, which otherwise will fall from current levels of US$485 million per year to zero as oil production declines over the period to 2025.

As shown in Figure 15.2, the total value of output from the PNG Gas Project during operations will peak at around US$700 million per year between 2014 and 2021, Thereafter, it will decline progressively to approximately US$400 million per year by 2038.

The total value of outputs from the PNG Gas Project is estimated to be US$18.8 billion (undiscounted US dollars of 2005).

This large inflow of revenue due to increased exports has the potential to cause an appreciation in the real exchange rate of the local currency (the kina), thus reducing the international competitiveness of the country's non-resource export- and import-

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[1] The figures presented are based on a study performed by ACIL Tasman (2005). This study is included as a supporting document to Supporting Study 10. The ACIL Tasman (2005) study was prepared for the PNG Gas Project, but the estimate of benefits is indicative only. It does not necessarily reflect changes that may have occurred since the study's preparation or analyses that may have been undertaken separately by project stakeholders.

competing activities. This impact can be ameliorated by the State by the prudent management of foreign exchange earnings.

15.1.2 Income Generated by the Project

The income that will be generated by the project during operations has direct and indirect components.

The direct income will consist of economic flows to those supplying the resource or land required for the project, investors, and people working for the project.

The State will capture a share of profit and labour income via company and personal income taxes. An additional share of profits will be captured via dividends associated with the State's equity participation in the project. In addition, local and provincial governments and landowners will receive royalty income, a development levy and a share of profits via equity dividends. (See Section 15.1.3 below for details.)

Labour income will be earned by national and expatriate workers.

The project will also have indirect impacts on the national economy due to so-called 'spin-off' effects. These will arise as the income generated by the project is spent and 'ripples' through the economy.

Figure 15.3 shows the estimated direct and indirect income due to the project. The annual impact on the PNG economy will be significant, peaking at approximately US$600 million per year (2005 US$), or 9% of the forecast gross domestic product.

The total incremental impact of the project is estimated to be almost US$3.5 billion in net present value terms[2]. After taking into account the flow of some of this income to foreign investors and labour, as well as the potential displacement of economic activity elsewhere in the economy, the net benefit of the project to Papua New Guinea is estimated to be approximately US$3 billion in net present value terms over the anticipated life of the project.

15.1.3 The State and Landowner Direct Income

The economic impact of the direct income described in this section has the potential to significantly enhance the quality of life of the people in the project impact area[3] and the general populace of Papua New Guinea.

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[2] ACIL Tasman (2005) used a 10% discount rate on estimated constant dollar (2005 US$) cash flows to calculate net present values.

[3] 'Project impact area' is defined in Section 11.3.

15.1.3.1 Composition of Government and Landowner Direct Income

The major components of government and landowner direct income are described below.

Tax

This is a combination of income tax paid by the participating companies on profits, income tax on contractor work performed during construction and operations, and salary tax levied on the wages paid to workers during construction and operations.

Upstream Equity

These are dividends that flow from shareholding in various upstream entities related to the project resource. Currently, the landowner trustee companies listed below and managed by Mineral Resources Development Corporation Limited hold a total of approximately 3% equity in the PNG Gas Project by virtue of their respective licence interests:

- PDL-2: Petroleum Resources Kutubu Limited (6.75%).
- PDL-4: Petroleum Resources Gobe Limited (2.0%).

With the expected participation of PDL-5 landowner interests represented by Petroleum Resources Moran Limited and Eda Oil Limited and additional participation rights of the State under the Gas Agreement, these local PNG interests would have an increased project equity stake of about 14.3%.

Infrastructure Equity

The entities associated with landowners and the State (referred to above) are expected to have at least the same percentage stake in the infrastructure component (i.e., the sales gas pipeline within Papua New Guinea) of the PNG Gas Project.[4]

It is estimated that the various local PNG interests associated with upstream and infrastructure equity participation in the project will not realise dividends from gas operations until 2016/17 when financing obligations have been repaid. Some of the equity dividends are expected to flow to landowners and local-level governments. Allocation of these dividends among these parties will be decided through the GPCSA negotiation process (see Section 11.13.6 for a description of this process).

Oil Search Equity

The Independent Public Business Corporation (IPBC), as trustee of the General Business Trust of Papua New Guinea, is a shareholder in Oil Search Limited (OSL), which in turn holds a significant share in the project.

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[4]The upstream and infrastructure components associated with the PNG Gas Project will be held by two separate unincorporated joint ventures.

Royalty

Royalty is calculated at 2% of wellhead value, derived by adjusting total revenue at point of sale less transport and processing tariffs and direct operating costs.[5]

Development Levy

The development levy is calculated at 2% of wellhead value as in the case of royalty. It is proposed to use development levies to fund road upgrading and construction contemplated in the Gas Agreement and other infrastructure investments by the provincial and local-level governments.

Landowner-Company Dividends

Landowner-company dividends are paid to landowner-company shareholders from the net profits from landowner-company business activities. Although this is a direct benefit to landowners, its distribution is a private matter for each landowner company to manage.

Land Use

This is direct compensation paid to landowners for the use of land by the project.

15.1.3.2 Gas Project Co-operation and Sharing Agreement

As described in Chapter 11, the Gas Project Co-operation and Sharing Agreement (GPCSA) will provide for the allocation among eligible landowners and local-level and provincial governments of a share of the State's equity and royalty entitlements in the PNG Gas Project.

It is premature to estimate the overall value of the direct benefits that will be distributed within the scope of the GPCSA.

15.1.4 Capital Investment and Operating Expenditure

The project is expected to deliver capital investments of approximately US$2.5 billion over an anticipated 30-year life.

Recurrent operating expenditures are expected to be in the order of US$110 million per year by 2010. Approximately 25% of these expenditures is expected to be spent in Papua New Guinea kina, with the balance being spent in various foreign currencies. Over the life of the project, operational expenditures are expected to be some US$2.9 billion (2005 US$).

[5] In the past, part of the royalty allocated to landowners was paid in cash and part was paid into two trust funds: the Future Generation Trust and the Community Infrastructure Trust. This approach is expected to continue and may be applied similarly to equity dividends.

15.1.5 Employment

The PNG Gas Project will provide an estimated 2,500 jobs during the construction phase, and to the maximum extent practicable and all things being equal, hiring preference will be given to appropriately skilled individuals from communities in the project area. Once the PNG Gas Project moves into its operational phase, approximately 400 full-time equivalent positions would be maintained directly by the oil and gas production operations (ACIL Tasman, 2005)[6]. These operations positions will also be filled for the most part by local workers. Without the PNG Gas Project, employment in the project impact area would decline as oil production decreases.

Recurrent services and occasional civil construction work will be contracted with local businesses (NECL and/or landowner companies) to the maximum extent practical, thus providing additional (direct) employment to local workers.

15.1.6 Discretionary Spending

Discretionary spending represents expenditures by the PNG Gas Project related to community outreach programs or to direct contributions to community initiatives. Such spending may be made directly or through agents (e.g., NGOs, grassroots organisations, missions or local faith-based organisations). Although discretionary spending does not represent direct cash flow to the government or to project impact area landowners, it provides relevant benefits in the areas of health, education, agricultural extension and capacity building.

15.2 Infrastructure Impact

A portion of the State's PNG Gas Project-generated revenue is expected to be used to fund the construction of public roads and other infrastructure investments in the project impact area.

The Gas Agreement has provision for public road construction, which could be funded from development levies, general tax revenues, or tax credits granted to the participants.

Provincial and local-area infrastructure projects will be financed with funds from the development levy as noted previously.

It is also possible that other community infrastructure investments could be financed and built using the Infrastructure Tax Credit Scheme.

[6] This employment figure excludes contract service providers (see Chapter 8).

15.3 Transportation Impacts

Development of transportation ranks as the second most frequently cited issue (behind education) among surveyed residents in the project impact area.

The project entails the construction of public roads and road improvements in the project impact area as depicted in Figure 11.6 in Chapter 11. It is proposed that over 95 km of new public roads will be built, and almost 230 km of existing roads will be improved. Several hundred culverts will be installed to improve drainage, several new bridges will be built, and some existing bridges will be upgraded. (See also Table 2.5 in Chapter 2.)

A number of potentially positive business opportunities and spin-offs will emerge when the road network from Tari to Kikori is completed. These include small trade stores, passenger or freight transportation, petrol stations, vehicle repair facilities, small-scale cash cropping, and the growing of coffee and other agricultural products. The existence of improved public roads will improve access to health care and education services.

There are, however, potential negative impacts related to the improved road system in the project impact area: an increase in social tensions between local residents and outsiders, an influx of squatters and criminals, an increase in prostitution and sexually transmitted diseases, increased pollution and environmental degradation, and disruptions due to road closures during periods of conflict.

Support for the Tari to Kikori public road is relatively low among Gulf Province people, who are concerned about law and order issues, the possibility that 'highlanders' will marry their women and become landowners, and the eventual disappearance of their culture.

15.4 Social Sector Impacts

15.4.1 Health

The public road extension, larger towns and greater disposable wealth could pose risks of an increased number of cases of sexually transmitted diseases and associated health problems in residents of the project impact area.

A favourable impact of the PNG Gas Project on the health sector will be that government and landowner revenue entitlements can provide resources to improve public health services delivery.

Separately, the PNG Gas Project may assist local health initiatives by fostering new community health outreach programs and through direct contributions to community health programs via the discretionary spending program.

15.4.2 Education

As noted above for the health sector, government and landowner project-related revenue entitlements can provide resources to improve the ability of the public sector to build, improve and sustainably staff schools.

The PNG Gas Project may participate in education initiatives in ways similar to those mentioned above for the health sector. In addition, there will be Operator interest in supporting community and vocational-education programs that may have as their objectives engaging and preventing school dropouts, providing for general welfare, targetting women and girls, and improving the availability of a better-trained local workforce.

15.4.3 Agriculture

There may be paradoxical, inverse relationship between an increase in cash income associated with project benefit streams and a decrease in cash-crop farming. This raises the issue of the long-term sustainability of agricultural activity in the project impact area.

In the short and medium terms, the PNG Gas Project will provide opportunities to increase food in the project impact area by stimulating local demand and improving market access along new and improved roads.

The Operator may also support efforts to promote local sustainable agricultural ventures via its discretionary spending program.

15.4.4 Representative Community Organisations

The PNG Gas Project is likely to have continuing effects on representative community organisations.

15.4.4.1 Incorporated Land Groups

In view of the proliferation of incorporated land group registrations related to current oil projects, the PNG Gas Project has the potential to further stimulate incorporated land group registrations, which, in turn, could further complicate the distribution of benefits. At present, women are known to be disadvantaged in the benefits distribution process due to the nature of incorporated land groups.

15.4.4.2 Landowner Companies

The Operator has provided support to the formation of National Energy Company Limited (NECL), which is intended to be an umbrella landowner company with shareholders who are landowners in the project impact area. The objective for this single purpose landowner company is to achieve a transparent and sustainable business venture which can facilitate business and employment opportunities.

Communities view their current landowner companies as symbols of success, identity and independence, and therefore some residents or communities in the project impact area may oppose the NECL initiative. The existence of NECL could also increase inter-landowner-company rivalry, based on traditional clan-based politics.

A strategy is being developed that will differentiate boundaries and operations undertaken by existing landowner companies from new areas and operations associated with NECL. This is designed to mitigate some of the aforementioned issues.

15.4.4.3 Landowner Associations

Landowner associations have no formal status in the PNG petroleum regulatory regime. However, they have lobbied for, and gained access to trust monies and seed grants. In the past, landowner associations have bridged political factions to facilitate the installation of infrastructure, but there is uncertainty about the legitimacy of the landowner associations' constituency and their perceived lack of transparency. A State-defined policy and protocol related to landowner associations are needed to establish a frame of reference to guide future interactions.

15.5 Land Use and Damages

The new Hides Production Facility will occupy about 5 ha of undeveloped land. The Kutubu Central Gas Conditioning Plant will be built on an existing developed site.

Additional land rights (purchased or leased) will need to be secured for 95 km of new construction access ways (incremental to 229 km of existing roads or access ways) and 53 km of pipeline RoW (incremental to 299 km of RoW in new or existing roads). The pipeline RoW will have widths that vary between 12 and 22 m, depending on topographical constraints.

A portion of the land planned for the new Hides Production Facility is currently under agricultural use, and there are isolated cases along the proposed new pipeline RoWs/access way alignments that will impact small-scale, primarily subsistence-type agricultural activities.

The project intends to exercise care to avoid collateral damage to areas outside of the facilities sites and the pipeline RoW perimeters during construction.

15.6 Archaeology and Cultural Heritage

A series of archaeology and cultural heritage surveys was completed to identify significant cultural heritage sites and materials along the proposed RoW/access way alignments and to assist the design engineers to site facilities and align pipeline routes so as to avoid or limit impacts to these resources to the maximum extent practicable.

A significant number of archaeological and cultural sites were identified in the project impact area, and these have been listed in the National Site Register. The significance of each site was estimated, and further work is under way to expand understanding of the sites.

15.7 Mitigation Measures (Operator)

The following measures are proposed by the Operator to mitigate specific sociocultural impacts related to the project.

15.7.1 Landowner Companies

- National Energy Company Limited (NECL): The Operator will seek to contract labour for construction and services with or through NECL and in conjunction with existing project impact area landowner companies. This will be done to fulfil the objectives and obligations under the Gas Agreement and the Oil and Gas Act to maximise the use of local labour and materials and to stimulate the creation of sustainable local business ventures. The Operator will also provide assistance to NECL by meeting the costs of business advisers to assist the NECL directors in the organisation and planning for sustainable operation.

15.7.2 Land Use

The Oil and Gas Act provides that compensation is payable to landowners and land occupiers for:

- The deprivation of the use and enjoyment of the surface of the land.
- Damage to the surface of the land or to trees, fish or animals.
- Rights-of-way over the land.
- Any other damages that are a consequence of the use of land under a licence.

Compensation agreements with landowners and occupiers must be in writing and, where applicable, amounts of compensation are to be determined by reference to the values published by the Valuer-General. If a project and a landowner or land occupier cannot agree as to the amount of compensation, then the Chief Warden or Warden can be asked to determine the amount of compensation payable.

- Compensation: A policy that is consistent with applicable legislative requirements (see above) will be developed to provide fair and transparent compensation for:
  - Land use changes necessitated by the establishment, construction, or operation of project facilities.
  - Demonstrable project-associated damages to agricultural crops and landowner/land occupier property during construction and operations.

15.7.3 Road Security

- Operator Education and Security: Training will be provided to project and contractor personnel about how to manage heightened security and health risks associated with the extended public road system. Project security personnel will work cooperatively with area police officials.

15.7.4 Cultural Heritage

(Note: The details and precise location of the identified cultural heritage sites are not being made available to the public out of respect for landowners who provided information in confidence and to protect this cultural patrimony.)

- Project Planning: Recommendations have been made regarding the mitigation of project-related impacts on known cultural and archaeological sites. These recommendations are being analysed by the project design and construction planning staff in consultation with landowners and other stakeholders. Following this analysis, an appropriate suite of mitigation measures will be adopted.

- Monitoring During Construction: Fieldwork is under way to follow up the archaeological surveys that were associated with the EIS in order to more tightly define archaeological priority zones. The results of this work will enable protocols to be established in consultation with the National Museum of PNG. The protocols will cover monitoring during construction and will include procedures to deal with archaeological material exposed by land clearing and subsurface trenching works (for example, notification, expert assessment and knowledge/artefact salvage).
- Cultural Heritage Management: The Operator will provide partial funding or in-kind support through a Community Area Planning or Contributions Program to any formal initiative undertaken by the National Museum to develop a Cultural Heritage Management Plan, Cultural Foundation, or cultural centres in the project impact area.

15.7.5 Other

Listed below are Operator initiatives proposed to address specific high-priority social issues in the project impact area, even though these issues are not necessarily a direct consequence of the PNG Gas Project.

15.7.5.1 Health

- Health Outreach Program: The project will support programs and initiatives in the project impact area during the project construction period to address priority health issues (e.g., malaria, HIV/AIDS, and medical or paramedical training) with a view towards enhancing and sustaining existing health delivery services by public agencies in the long term.

15.7.5.2 Education

- Education Outreach Program: The project will support programs and initiatives in the project impact area during the project construction period to address vocational and community-skills educational needs (e.g., waste management, fostering a consumer goods maintenance culture, a maintenance culture, and conflict resolution), improved access to the College of Distance Education (CODE), additional scholarship programs, and educational issues (e.g., enrolment, teacher training, field support and gender equity) with a view towards enhancing and sustaining existing educational services and needed vocational education training by public agencies in the long term.

15.7.5.3 Agriculture

- Agricultural Outreach Program: The project will support programs and initiatives in conjunction with appropriate public development and agricultural agencies during the project construction period to engage target project impact area populations in workshops aimed at improving agricultural techniques (extension activities) and in planning for sustainable agricultural development.

15.7.5.4 Gender Issues

- Women and Girls Initiative: The project will support programs and initiatives that provide educational and training opportunities for women, including health and vocational education targeted toward women, scholarships for local female managers of community organisations, and support for women's projects in the project impact area.

15.7.5.5 Public Engagement

- Public Access to the EIS: The EIS and its supporting documents will be made available to the public in the project impact area and in Papua New Guinea as a whole[7].

15.7.5.6 Cultural Miscommunication

- Cultural Sensitivity Training: Workshops will be held with Operator and contractor workers (including landowner companies' personnel) to explain cultural sensitivities and issues in the project impact area and vulnerabilities for cultural miscommunication, as well as to communicate strategies to assimilate and adapt to the local population in ways that can facilitate understanding.

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[7] Hard copies of the EIS and its supporting studies can be obtained on request from Esso (see Chapter 1).

16. Cumulative and Associated Impacts

16.1 Definitions and Objective

This chapter places the PNG Gas Project into the broader context of its relationships to the activities of other parties. It does not, however, constitute a regional planning study. By its very nature, most of this discussion is speculative, and therefore the situations and developments presented herein cannot, in most instances, be viewed as an accurate prediction or depiction of situations, developments or events that might actually occur.

For the purposes of this discussion, cumulative impacts are defined as those that might arise at particular places in the project area as a result of the activities or initiatives of other parties, but which are or may be in some way related to the PNG Gas Project (for example, the completion of construction access ways as public roads). These impacts are discussed individually in Sections 16.2 and Sections 16.3.1 to 16.3.6. Their combined impacts are reviewed in Section 16.3.7.

Associated impacts have been defined as those impacts arising outside the project area as a result of the activities or initiatives of other parties that are dependent on the PNG Gas Project, for example, gas consumption in Australia. These impacts are discussed in Section 16.4.

16.2 Cumulative Impacts—Oil and Gas

16.2.1 Existing Developments

Existing oil and gas fields, facilities and infrastructure developments in the project area include:

- Hides, Kutubu, Gobe and Moran fields.
- Kutubu Central, Gobe and Agogo production facilities.
- Hides Gas Plant.
- Moro Airfield and camp, other camps at Nogoli, Kopi, Agogo, Gobe and the Ridge and field camps.
- Kutubu crude oil export pipeline.
- 273 exploration, production and water and gas reinjection wells (130 within the Kikori River basin).
- In-field flowlines, pipelines and access ways (Gobe, Kutubu, Agogo, Moran and SE Mananda [under construction]).

Cumulative impacts of the PNG Gas Project with those of existing oil and gas facilities include air emissions, treated wastewater and other discharges, waste treatment and disposal, land use, and noise. Project-related impacts regarding these topics have been assessed in Chapter 13.

Based on the fact that the PNG Gas Project is for the most part a ‘brownfield’ project, cumulative impacts associated with land use are predicted to be very limited. With regard to treated wastewater and other discharges, cumulative impacts are anticipated to be negligible since all such discharges will conform with the requirements of waste discharge permits.

Modelling of the air and noise emissions associated with the PNG Gas Project indicates that cumulative air emissions impacts with the existing oil and gas operations will be negligible.

Finally, regarding waste treatment and disposal, as is mentioned in Chapter 17, the project will develop and implement prudent waste management strategies and processes that are aimed at waste minimisation. In addition, proven gas conditioning technologies will be used by the project, and these will give rise to reduced quantities of waste. Taken together, these considerations reveal that the incremental quantities of operations wastes produced by the PNG Gas Project requiring disposal will be limited, and therefore cumulative impacts related to waste management with the existing crude oil and gas operations are anticipated to be minor.

16.2.2 Future Developments

16.2.2.1 Onshore

There are potential hydrocarbon resources near, and to the northwest of, Hides, and new discoveries may be made in the future. Those discoveries that give rise to commercially viable developments could potentially result in cumulative impacts with the PNG Gas Project if the new developments are in the immediate vicinity of facilities associated with the PNG Gas Project. The nature of such impacts would be expected to be similar to those associated with the cumulative impacts involving the PNG Gas Project and the existing oil and gas operations (i.e., minor to negligible).

16.2.2.2 Offshore

There are oil and gas resources and discovery prospects in the Gulf of Papua and the northern Coral Sea, including the Pasca gas field and the Pandora gas field. The Pandora field is a sizeable resource, but the gas has a high hydrogen sulfide content (sour gas) and has yet to be developed.

16.3 Cumulative Impacts—Upgraded Public Road System

Existing public roads within the project area include the following:

- Moro to Poroma Road (Kutubu access road).
- Highlands Highway connecting Tari to Mendi and Mt Hagen to Lae.
- Local roads connecting Tari to Nogoli and Komo.
- The road from Moro to Homa village.

The PNG Gas Project is required to complete some sections of pipeline construction access ways or RoWs and build new sections of dedicated road as appropriate, in order to create the western of two new public road links between the Highlands and the Gulf coast at Kikori. These links are (see Section 3.8):

- The western link from Tari via Idauwi, Homa, Moro, Kutubu, Kaiam and Kopi to Kikori. Parts of this road are currently under construction.
- The eastern link from Mendi and Mt Hagen via Kisenapoi, Erave, Kagua and Samberigi to join the western link at the Samberigi (Gobe airstrip) turnoff. This road is currently under construction.

These links fulfil the longstanding infrastructure policies of successive national and provincial governments and, some people of Gulf Province excepted, the expressed wishes of project area landowners.

The upgraded road system will have an effect on different sectors of the economy and on patterns of movement and settlement within the project area and between the project area and elsewhere. These effects are discussed in Sections 16.3.1 to 16.3.6 below.

The PNG Gas Project is not in a position to be able to prevent or mitigate any of the potential cumulative impacts discussed in Sections 16.3.1 to 16.3.6.

16.3.1 Forestry

Supporting Study 16 outlines the forest industry in the project area, and this information has been summarised in Section 9.6.

There are extensive declared forest management areas (FMA) in both Gulf and Southern Highlands provinces and eight existing or proposed future forest management areas are generally within or overlap the project area (Figure 16.1).

One small FMA has been mapped on the road between Agogo and Moran, but it has no name and no information is available about the timber resource in this area. Accordingly, its commercial viability is not able to be assessed at this time and therefore this potential timber harvesting area is not discussed further.

Large-scale timber harvesting requires road networks to access coupes and transport logs for export. Consequently, the improved access via the improved public road system associated with the project could, in principle, facilitate logging in some areas that may not otherwise have been feasible. The likelihood and extent of this occurring can only be speculatively inferred, in part because data on the timber quality in the FMAs in question are not available, in part because landowners may not agree to logging in these areas and in part because the plans of forestry companies are confidential.

With these caveats in place, the effects that the improved public road system associated with the PNG Gas Project could potentially have on timber harvesting in the project area are discussed below.

16.3.1.1 Turama Block 1

This FMA has been logged since 1996 (Plate 16.1a and b). The proposed sales gas pipeline construction access way south of Kopi will not be completed as a road, while the rest of this FMA already overlaps the existing road from Kopi to Gobe. Logs from this block are exported by barge down the Omati River (Plate 16.1c), and there appears to be no reason why the operators of the concession would change from their present-day approach in favour of exporting logs by road to, for example, Kopi (which is inaccessible to log export vessels). Accordingly, the improved public road system associated with the project will not lead to expanded or accelerated timber harvesting in this FMA.

16.3.1.2 Kikori Block 2

This FMA has overlapped the existing road between Kopi and Gobe since large-scale logging began in the Lower Kikori region in 1996. With an effective log exporting system based on river transport (Plate 16.1d) already in place, there is no reason why the operators of this concession would incur the cost of the large bridge required to connect its operations to the improved public road system. Accordingly, the improved public road system associated with the project will not lead to expanded or accelerated timber harvesting in this FMA.

16.3.1.3 East Kikori

Logs from this concession are moved along the existing road network within the Kikori Block 2 concession via a barge terminal on the Sirebi River (Plates 16.1e and f). Accordingly, the improved public road system associated with the project will not lead to expanded or accelerated timber harvesting in this FMA.

16.3.1.4 Hekiko

The PNG Forest Authority will offer the Hekiko concession for competitive tender if sufficient landholders resolve a clan dispute and sign the FMA. This will probably be forthcoming at some stage, and so the Hekiko FMA will be probably be logged in due course.

Like most FMAs, much of the gross area of the Hekiko block (some 430,000 ha) seems unlikely to be commercially viable. An examination of PNGRIS data on the terrain and soils in this concession suggests that between a quarter and a third of the area of this FMA might support accessible timber of adequate quality. [1]

The future operators of this concession would probably follow existing log export practice and construct a road to a point on the western bank of the Hegigio River, from which barges would travel downriver to ships moored off the Kikori delta. If the river were too shallow, a second possibility would be to move logs across the river to the eastern bank for trucking to a barging point.

Figure 16.1 shows the relationship of various roads to this FMA:

- The existing road from Kopi to Gobe runs through the southeastern portion of the block for 30 km.

[1] The footnote to Table T114 in Section 16.3.7 labelled *** explains the basis for this estimate.

- The new public road beyond the Gobe turnoff to the Mubi River bridge will run through a further 18 km of this FMA before climbing away from the Kikori River to rejoin the pipeline RoW at KP55 near Kantobo. This section of the new public road is separated from the FMA by steep grades, swamps and polygonal karst.
- The project-upgraded public road is on the opposite bank of the Kikori/Hegigio River from most of the southwestern portion of this FMA.

In other words, the section of road that might facilitate the trucking of logs on the eastern side of the river already exists and is accessible to light vehicles up to the Gobe turnoff, beyond which point it is closed. It is possible that the improved public road system associated with the project could potentially lead to expanded or accelerated timber harvesting in this FMA.

16.3.1.5 Nogoli (Proposed)

This proposed FMA is probably too far inland to supply export markets in the foreseeable future but could possibly support small-scale operations to supply domestic markets in the Tari region and the rest of Southern Highlands. Roads already exist from Nogoli to these markets and traverse the southern part of the proposed block.

As far as the new public roads that will be constructed/upgraded by the project are concerned:

- The upgraded public road will run some 8 km along the northern edge of the southern part of the concession. This may enable logs from the southern part of the block to be carried to Nogoli.
- About one-fifth of the FMA covers the northeastern face of Hides Ridge, where the project's spine line access way will be gated and will therefore be inaccessible to logging trucks.
- Much of the Nogoli block does not meet the terrain and karst environmental protection criteria of the Logging Code of Practice (PNG, 1996), although numerous exceptions can be seen in the FMAs around Kikori.

A minor upgrade of the existing road system in the Nogoli area would allow logs from the proposed Nogoli FMA to be transported by road to a mill at Tari. However, accessing the timber of the Hides ridge area would probably be uneconomic since a road would have to be built separate from the PNG Gas Project's access road; this would be a difficult and expensive undertaking in this very rugged terrain. Therefore, while the improved public road system associated with the project could in principle lead to expanded or accelerated timber harvesting in the southern section of this FMA, this seems unlikely for the foreseeable future. This area (Hides) has been mooted as a Wildlife Management Area, which, if so declared, would bring all activities under a single set of objectives. Such an arrangement would require the agreement of the impacted landowners, and its effectiveness would require their ongoing involvement in the management of the area, particularly in relation to access to the Hides area.

16.3.1.6 Kutubu-Poroma (Proposed)

This proposed FMA is likely to be too far inland to supply export markets in the near future but may be able to support small-scale local operations. Much of the block is in steep karst terrain, where logging is precluded for environmental protection reasons (Plate 16.1g).

The block overlaps the road from Moro to Poroma, which was built in the early 1990s as a condition of approval of, and subsequent to, the Kutubu Petroleum Development Project. This road has not been maintained and is currently untrafficable. The new section of public road from Idauwi to Homa (under construction) will open alternative access to domestic markets for timber. Therefore, while the improved public road system associated with the project could in principle lead to expanded or accelerated timber harvesting in this FMA, this seems unlikely for the foreseeable future.

16.3.1.7 Bosavi

The western flanks of Mt Bosavi lie within this FMA. The forest on the gentle footslopes of this volcano is likely to be productive. It could be logged by extending roads from the Hekiko FMA. Attempts have been made in the past by forestry interests to get landowners in the area to agree to timber harvesting on their land (Crome, pers. comm., 1997). Haulage distances would be long for exporting logs, and the block is separated from the upgraded public road system by a considerable distance of difficult terrain. Accordingly, it seems highly unlikely that the improved public road system associated with the project could lead to expanded or accelerated timber harvesting in this FMA.

16.3.1.8 Pi Tukere

This small FMA lies north of Tari in the far northeast of the Kikori River basin. It is constrained by slopes and terrain and is therefore unlikely to support a major commercial timber operation. If this concession were to be developed, it would be more likely to be on the basis of markets in Tari being accessed by existing roads. Therefore, the improved public road system associated with the project will not lead to expanded or accelerated timber harvesting in this FMA.

16.3.1.9 Concluding Remarks

Roads are expensive to construct and maintain in PNG and so a good-quality public road would, in principle, assist any enterprise that might otherwise need to build its own road(s) into its place(s) of business. However, an economically feasible large-scale forestry development involves a complex equation with many variables. A ‘no-cost’ section of new public road would be only one element in the context of the potentially several hundreds of kilometres of logging roads that a large operation might need.

One existing and two potential FMAs have been identified that could potentially benefit from the improved public road system associated with the project. One (Hekiko) seems to have a strong prospect of being developed in its own right, with or without the improved public road. In any event, the road section that might lower the cost of developing the Hekiko FMA has already been built. The other two concessions (Nogoli and Kutubu-Poroma) still remain to be gazetted as FMAs. There is at present no inventory data or other assessment information available for these concessions. In all three cases, terrain and access constrain a large proportion of the blocks.

This analysis suggests that only timber harvesting in the Hekiko FMA has the potential to be expedited or accelerated as a result of the improved public road system associated with the project.

16.3.2 Agriculture

Agricultural potential in the project area is very limited (Bleeker, 1975). Agricultural pursuits in most of the area are severely constrained by poor soils, flooding and steep terrain. Existing small-scale gardens and settlements are located in the better-quality soils on gentler terrain, mainly to the northeast and east of Hides, and on the more gentle volcanic terrain around Komo.

Agriculture contributes less to subsistence production than does sago cultivation, fishing, hunting and gathering. Various attempts to commercialise agriculture on a large-scale basis in the project area have proved to be unsustainable, and smallholders[2] have generally focused their agricultural efforts on subsistence production.

The household survey conducted by the PNG Gas Project in the defined project impact area (see Supporting Study 10) reported a large percentage of respondents as receiving income from cash crops, including coffee (35%), sago (39%), garden food crops (64%), vanilla (15%) and other crops (e.g., chilli, rice, mandarins, silkworms). However, cash cropping is at a small scale, and smallholders remain focused on subsistence production. Commercialisation of agriculture on a large scale has been promoted for the last 100 years and a range of cash enterprises have been trialled, including copra, cocoa, rubber, rice, crocodiles, and butterflies, but with variable and few sustained results. These efforts have generally failed because of poor planning, transport and logistical problems, profits not being reinvested into the business, and apathy when quick returns are not forthcoming.

However, there are active programs in the project area aimed at broadening and diversifying the product base of subsistence farming; and a range of new crops and livestock have been introduced, including African yams, Chinese cabbage, nutmeg, wongbok, salabeer, capsicum, pak choi, new varieties of taro and muscovy ducks distributed from the Moro Agriculture Resource Centre. Crocodile skins have been successfully exported, and there is strong local interest in vanilla, with small plots being established around Gobe, Kikori and Kutubu (see Supporting Study 10).

The main driver for the development of agriculture in the project area is a public road linking Kikori to Southern Highlands and possibly a new separate link to Port Moresby at some future time. This road has the potential to open up new markets and increase the demand for agricultural and livestock products and fish. Flows of agricultural produce

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[2] The terms ‘smallholder’ and ‘smallholdings’ refer to agricultural developments that produce high-value crops, such as chillies or vanilla beans, on small plots of land.

from the Highlands southwards and of coconuts, bananas, betel nut, fish and lowland *pit pit* northwards would be facilitated by such a road. With continued agricultural extension programs and a diversifying crop base, there is likely to be a continuing increase in cash crop production and export in the project area.

However, the crops with the greatest potential for major expansion and export potential are sago based around Kikori, vanilla at Samberigi, Kutubu, Moran, Pimaga and surrounds, and coffee at Hides, Kutubu, Samberigi and surrounds. Supporting Study 10 notes that:

> [t]he general consensus among those who know the areas well is that sago and coffee are the only crops likely to offer a commercially viable basis for sustained agricultural business in the [project impact area].

A feasibility study has already been conducted on a Kikori-based sago operation and the landowner companies Kikori Oil Investments Limited and Gobe Field Engineering have expressed interest in a sago growing and milling project at Kutubu (see Supporting Study 10).

Two other crops have some potential to develop into broad-scale industries in the lowlands: rice in some alluvial areas and oil palm in logged-over lowland forest. There does not seem to have been any assessment of the long-term potential or viability of such crops in the Kikori lowlands.

In conclusion, while the agricultural potential of the project area is generally very low, there is the potential for the increased cultivation of cash crops in particular areas. New and expanded markets should increase the potential for this to occur in the decades ahead. The improved public road system associated with the project would potentially facilitate the creation of commercial agricultural ventures. Such ventures are likely to vary in size and scale; but in general, the environmental impacts associated with undertakings of this type – in terms of forest converted to agriculture by individual smallholdings – is likely to be small and limited in spatial distribution.

16.3.3 Fisheries

Up to 70 tons of fish are taken from Lake Kutubu annually with an estimated value of K400,000. It is reported that the fish catch is in decline and the recent discovery of European carp may cause further declines. The saline and brackish swamps in the Kikori delta are among the largest in the South Pacific, and fish, crabs and shell-fish have traditionally been an important source of food for the inhabitants of the area. In addition, more than 60% of the households surveyed in the Kikori area reported cash income from fish during the past year. There was a small local export fishery in Kikori, where frozen fillets were sold to domestic markets (see Supporting Study 10), but there are at present no commercial nearshore fisheries or fish farms in Gulf Province.

A number of deltas of southeast Asia have been converted into prawn or other fish farms, but no such projects have been proposed to date for the Kikori-Turama delta complex. Such ventures would probably require export markets to be viable, but the roads to the Highlands would also provide some limited domestic sales opportunities.

The improved public road system associated with the project is not anticipated to give rise to increased commercial fishing in the project area.

16.3.4 Tourism

Eco-tourism potential in the Kikori River basin is very high, and WWF and others have promoted small-scale schemes, such as guiding and lodges. The main hindrances to tourism development in the area are inadequate access and law and order challenges. Improved access by the public roads upgraded and constructed by the PNG Gas Project and the level of personal security and law and order that the project requires could provide a boost to what is perhaps the industry with the greatest potential for expansion in the project area. It is possible to envisage within the next decade direct international flights to Kopi or Tari and a government-built road system connecting lodges catering to cultural and nature tourism, fishing and sustainable hunting.

16.3.5 Mining

There are no mines in the project area. The Porgera mine, for which electricity is generated at Hides, is approximately 76 km from the Hides facility.

PNG is highly but not uniformly prospective for gold and base metals, and historically productive areas are under active exploration at present. However, the Kikori River basin is relatively less prospective, and there are currently no mineral exploration licences in the region. Exploration, let alone a new mine, seems unlikely in the foreseeable future with or without the presence of the improved public road system associated with the project.

16.3.6 Enhanced Population Mobility

The roads that will be built or upgraded by the PNG Gas Project will enable people to travel between previously disconnected parts of the project area and to and from adjacent areas. This discussion explores the settlement and other activities that the upgraded road system might facilitate, and forms a basis from which to assess cumulative biodiversity impacts.

Supporting Study 10 (Table 2.5) records a population growth in the defined project impact area from 11,200 (rounded) to 24,000 between 1990 and 2000 as follows:

- ‘Highlands’:
  - A near doubling of the population around Gobe, Kutubu and to a lesser extent Moran (to 10,900) in response to crude oil developments.
  - A two-and-a-half fold growth at Hides (to 9,800), due in part to the natural gas developments in the area but due mainly to malaria control programs in the Tagari valley implemented by the petroleum development operator.

  These two factors will not continue to be as significant a driver of population growth in the future as they have been – from a low base – in the past.

- ‘Lowlands’: A much lower growth rate in the Gulf Province lowlands (‘lowlands’) of 25% (to 3,300).

Supporting Study 10 also sets out the land-use and cultural characteristics of the population of the defined project impact area, from which inferences can be drawn about the future movements and activities of people.

16.3.6.1 Future Population Movement, Settlement and Activities

The scenario for future population movement, settlement and activities in the project impact area is based on the following:

- Enhanced business opportunities will arise from the new/upgraded public road system associated with the project, such as:
  - Small trade store businesses along the route.
  - Opportunities to sell fish, agricultural products, and timber and to service vehicles.
  - Public motor vehicle (PMV) freight and passenger operations.
  - Banking services.
  - Reactivation of cash cropping, such as coffee or vegetables, for export via Kikori (a much shorter [less than 300 km] and less risky route to port than the Highlands Highway to Lae – more than 600 km from Tari).
- The ability to settle, establish subsistence gardens and conduct business with travellers will be constrained by:
  - Inhospitable and unproductive terrain and soils.
  - Malaria.
  - No legitimate claim to land and the resistance of current landowners to squatting.
- Permanent settlement will most likely centre on Moro, Kopi and Kikori and, if the eastern road link were ever completed, at its junction with the western link at the Samberigi turnoff. Some newcomers may marry into the area, rent land for a period or seek work from the very small number of local employers (most of whom will probably give employment preference to local people).
- The prospects of settlement will become more attractive as time passes, as the three existing centres grow and as the number of wantoks (relatives) rises. However, these are secondary encouragements. The primary drivers – the prospect of acquiring money – will remain a constraint: first, because there will be little employment available; and second, because the quantum of money flowing to project area landowners, although a material sum, has not been in the past – and should likewise not be in the future – sufficient to support an ever-growing population.
- Most travellers on the new/upgraded roads will be motivated by curiosity or by an alternative to flying to Port Moresby.
- Travellers are predicted to be almost entirely Highlanders visiting Gulf Province. Travel in the other direction will be discouraged by an inhospitable reception from the local clans.

These factors suggest a potential population movement scenario as follows:

- There will not be a tide of migration from the Highlands to Gulf Province.
- The high historic population growth rates between 1990 and 2000 in the 'highlands' parts of the project area are probably a consequence of one-off factors, such as malaria control in the Tagari River valley and the arrival of the oil and gas industry at Hides and Kutubu. This growth rate is unlikely to be sustained. Equally, however, there is no basis for predicting future growth, and this has not been attempted. What can be concluded, though, is that the pattern of future growth will probably concentrate on existing towns, as was the situation between 1990 and 2000 at Moro. Only sporadic settlement along the improved public road system associated with the project is expected.
- The population growth in the 'lowlands' between 1990 and 2000 was much less, despite the arrival of the crude oil export pipeline. As for the 'highlands' section, the environment outside the towns remains inhospitable, and so only sporadic settlement along the improved public road system associated with the project is expected.

16.3.6.2 Refugee Movements or Migrations

Catastrophic social and environmental pressures, such as a major drought in the PNG Highlands, could force refugees to seek food, safety, shelter and better conditions elsewhere. Such large refugee movements are likely to overwhelm traditional systems of defending land. In addition, desperate people could be forced to establish gardens in areas where terrain and poor soil would normally inhibit such activities. While unsustainable in even the medium term, gardens in marginal areas would be sufficient to provide some sustenance in the short term (2 to 3 years). The improved public road system associated with the project would likely facilitate refugee movements or migrations.

16.3.6.3 Hunting of Fauna and Collection of Flora

There are no quantitative estimates of the total hunting or poaching impact on the fauna within the project impact area and levels of hunting or the consumption of wildlife products in the logging concessions are unknown.

The improved public road system associated with the project will enable hunters to use vehicles to travel further afield to poach wildlife from the property of other landowners and to transport their prey home or to markets. Concentrations of valuable species, such as the southern cassowary in the Mubi River valley, will be able to be more easily accessed and exploited. If the public road system were to be connected to the complexes of roads associated with logging operations, then the areas over which vehicles could transport hunters and their prey would be further increased. This would lead to local declines and possible local extinctions of some species.

Table 16.1 sets out the factors that might encourage or constrain hunting and poaching in the project area and indicates that the main potential lies between the Hides Production Facility and Moro and between Moro and Kopi. An assumption that a corridor 5 km wide on either side of a public road would be available to an easy day's return walk would lead to a zone of hunting pressure of around 260,000 ha, or 12% of the Kikori

River basin. To this could be added perhaps a similar area again if existing and new forestry roads were to become available to public access.

Table 16.1 Potential hunting pressure in the project area

Locality Length of Road	Constraints	Drivers	Impact Causes
Hides Ridge (19 km)	No public access	Rich with hunting target fauna	No access change from the present
Hides 4–HPF (7 km)	Already fully occupied, aggressively defended	Rich soil, gentle terrain; project benefits	No access change from the present - largely cleared
HPF–Moro (96 km)	Difficult terrain; malaria	Sparsely settled Benaria River to Homa – valuable fauna	Already hunted in parts; occasional businesses, settlements, gardens along the road
Moro–Kopi (163 km)	Difficult and flood-prone terrain; poor soils; malaria	Large, abundant high-value fauna close to road	Little hunting now; poaching by visitors; occasional businesses, settlements, gardens along the road
Kopi–Omati landfall (34 km)	Karst, swamp; off the though road; minor high-value fauna; malaria	Low attraction, limited settlement, mostly inaccessible except by boat (swamp section)	Little change from present

Crocodile skins have already been exported from the Kikori River basin, and this industry has the potential to expand. More widespread harvesting of crocodiles (i.e., at the unsustainable commercial scale) could result in the extinction of crocodile populations in some areas. The improved public road system associated with the project would enable boats to be transported to points near or at the Kikori River up to the Mubi confluence. The road will not improve access to either river beyond this point.

16.3.7 Cumulative Impacts Summary

The key potential cumulative impacts associated with the PNG Gas Project will be related to the improved public road system and, in particular, the extent to which it facilitates future logging and wildlife hunting/poaching. These impacts, however, need to be placed in the context of logging that would occur regardless of the existence of the improved public road system.

Table 16.2 presents estimates of existing and future forest clearing from all sources within the Kikori River basin. Clearing for agriculture has historically been the biggest source of forest habitat loss (96.7% of the area that has been cleared to date). Estimates of forest habitat loss from timber harvesting activities are based on the loss attributable to the building of access roads (see Figure 16.1). The estimates exclude small snig tracks and the degradation of forest habitat by selective logging. The Hekiko FMA might involve clearing for roads of the order of 2,000 ha to support timber extraction over perhaps 115,000 ha, in which the removal of the larger trees will create irregular gaps in the forest canopy. In any given area, these gaps might range from between 20% to 80% of the extent of an area, depending on the spacing of the merchantable trees[3].

As far as population movement is concerned, population growth is unlikely to occur uniformly over the project impact area:

- In the 'highlands', growth will focus on the existing oil town of Moro and possibly Nogoli. Here, gas royalty wealth will be the main driver.
- In the 'lowlands', growth will focus on Kopi/Kikori. Here, the existence of the upgraded public road associated with the project will be the main driver.

Settlement along the upgraded public road associated with the project will be sporadic, and there will be some localised impacts on the forest due to the establishment of new gardens and burning to clear vegetation (Plates 16.2 and 16.3). The zone of this impact might extend for a few kilometres on either side of the settlements along the road. Numbers of settlers and associated impact areas are difficult to estimate, but might involve on the order of one to two thousand people along the approximately 260 km of road between the Hides Production Facility and Kopi and the clearing of perhaps a thousand hectares of forest.

The existence of the upgraded public road associated with the project is unlikely to give rise to large-scale developments in agriculture, mining and fisheries.

[3] Selective logging is not the same as clearfelling, and there is no basis from which to derive values for Table T114 from the clearing effect of the variable and unpredictable spacing characteristic of selective logging.

Table 16.2 Existing and predicted forest clearance in the Kikori River basin

Source of Forest Clearing	Data Source or Basis of Calculation	Approx. Forest Loss (ha)	
		Existing	Predicted Additions
Agriculture and settlements	FIM mapping (veg type ='O')[a]	127,900[b]	7,750[C]
Existing oil and gas project facilities[d]	Digitised satellite imagery[e]	466	0
Existing oil and gas wells [d]	130 wells @ 1 ha /well	130	0
Existing oil and gas flowlines and pipelines[d]	GIS (approx 157 km x 30 m)	471	0
Oil and gas project access roads (Moro and Agogo to Kutubu CPF, Moran, Gobe) [d]	GIS (approx. 105 km x 30 m)	315	0
Public roads	GIS (approx. 167 km x 30 m)	492	110
Public roads under construction (eastern link)	GIS (approx. 100 km x 30 m)	300	0
Logging roads – Turama Block 1	Approx. 251 km x 30 m[e]	753	970[f]
Logging roads – Kikori Block 2	Approx. 246 km x 30 m[e]	738	1,680 [f]
Logging roads – East Kikori	Approx. 224 km x 30 m[e]	687	0 [f]
Logging roads – Nogoli	GIS PNGRIS	0	160 [f]
Logging roads – Hekiko	GIS PNGRIS	0	2,000 [f]
Logging roads – Kutubu-Poroma	GIS PNGRIS	0	130 [f]
Logging roads – Pi Tukere	GIS PNGRIS	0	40 [f]
Logging roads – Bosavi	GIS PNGRIS		460 [f]
PNG Gas Project (+ RoWs completed as public roads)	This EIS	0	600[g]
Future oil and gas expansion[d]	This EIS		350[h]
Total (rounded)		**132,000**	**14,250**
[Total oil and gas		*1,382*	*950]*
Total Kikori River basin area is approximately 2,160,000 ha			

[a]Applies only to existing forest loss estimate. [b]Most of this clearing is in the Nogoli and Komo areas in Southern Highlands Province. [c]Only limited reliance can be placed on this estimate. It is derived from two sources (1) gardening along the road where it has been assumed that up to 200 families might settle along the road, with clearing at a rate of 0.75 ha/household per three years (upper value adopted here) and (2) an expansion of cash cropping assumed to be 5% of existing clearing. [d]Oil and gas values summed for convenience – note different data sources. [e]Roading system digitised from satellite imagery TM/Pan using edge technique UTM Zone 54S WGS84 ETM 98/64 (acquired 7-Aug-01), ETM 98/65 (acquired 1-Dec-02), ETM 99/65 (acquired 24-Sep-91), ETM 99/64 (acquired 4-Jul-02). [f]Analysis of roads from satellite imagery indicates approximately 0.018 km of access roads per hectare in production forests. Remaining loggable areas within concessions inside the KICDP area were estimated from areas of volcanic alluvial or mixed sedimentary geology on low slopes from PNGRIS data. Areas calculated were as follows: Kikori Blk 2 – 93,850; Turama Blk 1 – 54,314; Hekiko – 114,819; Kutubu–Poroma – 7582; Nogoli - 9253; Pi Tukure - 2116; Bosavi – 25,720. Estimated hectares cleared have been rounded. [g]Mid-point of estimates in Section 13.7. [h]Based on 100-km x 30-m RoW and 50 ha for wells and facilities.

16.4 Associated Impacts

Associated impacts are those related to developments lying outside the project area that could be/are facilitated by the existence of the PNG Gas Project. These activities are the initiatives of other parties and would require their own environmental impact assessments as per applicable legislation before proceeding.[4]

The PNG Gas Project is not in a position to be able to prevent or mitigate any of the associated impacts discussed in Sections 16.4.1 to 16.4.3.

16.4.1 Cement Manufacture

A cement plant currently exists at Lae. Gas from the PNG Gas Project offers a fuel option for a new cement works, with the local and abundant Darai limestone as the feedstock. The location of such a plant may be on or close to the upgraded public road system associated with the project, since this would facilitate the transport of manufactured cement to customers.

16.4.2 Natural Gas Pipeline to Port Moresby and the Construction of a Methanol Plant

It is a policy objective of the State to add value to the nation's natural gas. In addition, under the Gas Agreement, the PNG Gas Project's sales gas pipeline must incorporate a connection at Kopi to enable domestic offtake of gas in the future.

A potential development in view of this policy objective and requirement (but that is beyond the scope of the PNG Gas Project) would involve the construction of a lateral pipeline from the sales gas pipeline running offshore east across the Gulf of Papua to a landfall some 20 km west-northwest of Port Moresby, and then along existing roads to a new methanol plant site in the existing oil refinery complex at Napa Napa. Such a development might also enable natural gas-fired power generation in Port Moresby.

The impacts associated with this development would need to be analysed by the proponents of such a development as part of the environmental impact assessment process for that development.

16.4.3 Project Impacts in Australia

16.4.3.1 Facilities

The Australian section of the sales gas pipeline and ancillary scraper, compression and control systems have been the subject of an environmental impact assessment approved by Australian Commonwealth and Queensland ministers in 1998. APC is responsible for implementing the approval conditions as the Australian pipeline project moves through front-end engineering and design.

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[4] Such developments would also be expected to comply with all applicable national, provincial/state, and local legislation and other appropriate/applicable requirements.

The approved pipeline runs from the PNG–Australian border to Townsville and Gladstone. New lateral pipelines running from the main pipeline to Weipa, Gove, Ballera/Moomba and Mt Isa are currently the subject of feasibility studies. These pipelines will be subject to their own environmental impact assessment processes as dictated by applicable Australian legislation.

16.4.3.2 Gas Consumption

The gas supplied to Australia by the PNG Gas Project will enable existing energy users to transfer to clean-burning natural gas from coal (44 PJ/year) and fuel oil (46 PJ/year).

This will have the effect of reducing carbon dioxide emissions from these sources by approximately 1.8 million tonnes of CO_2 per year (with a net reduction, after taking into account the gas production-related emissions, of approximately two-thirds of this amount).

17. Waste Management

This chapter describes how the PNG Gas Project will manage wastes produced during its construction and operations phases. The project's waste management strategy and an overview of the waste management procedures that the project will prepare for the construction and operations phases are presented (Section 17.1) along with a preliminary listing of the project's anticipated wastes (Section 17.2). Section 17.3 discusses the waste management facilities or capabilities associated with the existing oil operations and outlines the types of waste management facilities or capabilities that may be established by the PNG Gas Project. The chapter also concludes with a brief description of the cleaner production and energy balance aspects of the project (Section 17.4).

17.1 Waste Management Strategy

The project and its contractors will comply with applicable PNG legislative requirements related to the management of wastes, and appropriate industry waste management standards and practices will be implemented in the absence of such requirements.

The project's waste management objectives are as follows:

- Utilise to the maximum extent possible the waste management facilities or capabilities that have been put in place by the existing oil operations.
- Establish and operate new fit-for-purpose waste management facilities or capabilities to augment the existing facilities and capabilities.
- Optimise the selection and use of materials in order to avoid or reduce the production of wastes.
- Reuse or recycle certain waste materials to the extent practical.
- Properly and prudently treat or dispose of non-reusable or non-recyclable wastes and waste treatment residues.
- Classify or characterise wastes, and then store, handle, transport, and track wastes appropriately.

This waste management strategy will evolve into construction and operations waste management plans that will be incorporated into the construction and operations modules of the Environmental Management Plan (see Chapter 18). These waste management plans will feature the following:

- Waste characterisation criteria.
- Overall waste storage, inventory, transportation, and tracking requirements.
- A waste-by-waste listing including:

- Definition of the waste type and source.
- Waste-specific storage, handling, and transportation requirements, including safety considerations.
- Reuse or recycling and treatment options (if appropriate).
- Waste disposal options.

17.2 Waste Types

The types of wastes potentially generated by the PNG Gas Project during its construction and operations phases are listed below:

- Used lubricating oils.
- Oily debris, e.g., oil filters, oily rags from vehicle and equipment maintenance.
- Contaminated soil as a result of accidental, small-volume releases, spills or leaks of hydrocarbons and chemicals.
- Separator or vessel sludges and pigging wastes.
- Drilling fluids and cuttings.
- Domestic waste or trash.
- Domestic wastewater, sewage and sludge.
- Empty barrels, drums, containers, and gas cylinders.
- Batteries (lead acid and other types).
- Construction debris, e.g., wood, metal, glass, insulation.
- Ash from waste incinerators.
- Unused, spent, expired and contaminated solvents, chemicals, and additives.
- Spent molecular sieves and mercury removal bed material.
- Medical wastes.
- Hydrotest water.
- Produced water.
- Stormwater from under or around operating equipment (potentially contaminated with hydrocarbons).
- Paint.
- Plastic.

- Scrap metal.
- Tyres.

Quantities of these wastes will be estimated during the preparation of the construction and operations phase waste management procedures. Not unexpectedly, the volumes of most wastes will be greater during the construction phase owing to the nature of the construction work and the large construction workforce.

17.3 Waste Management Facilities or Capabilities

17.3.1 Existing Oil Operations Facilities or Capabilities

There are four waste treatment and disposal sites (waste management areas) that service the existing oil operations; these are located at Hides, Kutubu, Gobe and Kopi. There are very limited opportunities for waste recycling and reuse in the project area, and it is logistically difficult to safely transfer wastes over long distances because of the restricted present-day road network in Papua New Guinea. Currently, most wastes produced by the oil operations, after neutralisation, volume reduction by incineration or other means, are disposed of using company-managed, controlled landfills located close to the oil processing facilities.

17.3.2 Potential PNG Gas Project Facilities or Capabilities

During the preparation of the waste management procedures for the construction and operations phases of the project, the types, sizes, locations, and specifications for the (new) waste management facilities or capabilities that will be established and operated by the PNG Gas Project will be defined. In addition to sewage treatment facilities at construction camps and production facilities, these waste management facilities could potentially include the following:

- Domestic trash incinerators.
- Engineered solid waste landfills.
- Innocuous solid waste dumps.
- Assorted waste processing equipment (e.g., shredders, compactors).

17.4 Cleaner Production and Energy Balance

The technologies proposed for the PNG Gas Project have been selected to achieve the project's design objectives in an environmentally responsible manner. With regard to electrical power generation, which will be the largest source of gaseous emissions in the operations phase (see Section 13.8), the use of gas turbines is the optimal approach from an environmental impacts point of view. Diesel fuel will be used for electrical power generation during the construction phase, since it is the safest and most practical fuel for portable equipment. Diesel fuel will be used in all mobile equipment in both the construction and operations phases for reasons of portability, manageability and safety.

Some PNG Gas Project design features that will lead to cleaner production and energy efficiency include:

- Smokeless flare tip design.
- Flaring limited only to start-up, commissioning and upset or emergency conditions.
- Natural gas–burning electricity generation turbines.
- Waste heat recovery from the electricity generation turbines (being considered to reduce the number of hot oil heaters and fuel gas use).
- Air emissions from the glycol reboiler will be flared to combust volatile organic compounds.

Energy (i.e., diesel fuel) usage will fluctuate during the construction phase depending on the nature of the works in progress.

18. Environmental Management, Monitoring and Reporting

This chapter describes the environmental management framework that will be implemented by the PNG Gas Project. A description is provided of the over-arching management system elements under which the project will be constructed and operated (Section 18.1), the documentation and schedule for environmental management (Section 18.2), the environmental management organisational structure (Section 18.3), proposed environmental performance standards and proposed mitigation measures to be implemented during project construction, operations and closure (high-level summary) (Section 18.4), and proposed environmental monitoring and reporting (outline) (Section 18.5).

An overview of the legislative requirements that are applicable to the environmental management of Level 3 activities (such as the PNG Gas Project) under the *Environment Act 2000* appears in Section 4.1.

18.1 Environmental Management System

The construction activities associated with the PNG Gas Project will be managed under the governance of an environmental management system. During operations, it is currently envisioned that a single operator, the arrangements for which are yet to be finalised by the project co-venturers, will manage the combined gas and oil operations. An environmental management plan will be developed and implemented to manage the PNG Gas Project's gas operations.

18.1.1 Environmental Policy

Operations will be conducted in a manner that is compatible with the balanced environmental and economic needs of the communities in the project area and with due regard for protecting the safety, health and security of employees, contractors, customers and the public.

18.1.2 Operations Integrity Management System

The project will utilise an appropriate operations integrity management system to provide the framework for the management of environment, health, safety and security matters and will abide by the requirements of the International Standards Organisation 14001 standard.

The EMP for the PNG Gas Project will be prepared and implemented within this operations integrity management framework.

18.2 Environmental Management Plan Development and Schedule

The project's EMP will comprise five modules (Table 18.1 and Figure 18.1) that will reflect its various phases. These modules will take into account the commitments made in this EIS, the conditions of approval stipulated by the State, and the requirements of any lending institutions associated with the project. These activity-based modules will direct workers to more detailed procedures, work instructions and guidelines that will be developed to manage all aspects of the PNG Gas Project.

Table 18.1 EMP summary

EMP Module	Project Element(s)
Module 1: Early Works Environmental Management Plan	PNG Gas Project
Module 2: Onshore Construction Environmental Management Plan	Well drilling Wellhead installation Construction of gas facilities: Hides, Kutubu, Agogo, Kopi, Gobe Construction of onshore pipelines and access ways
Module 3: Offshore Construction Environmental Management Plan	Offshore pipeline installation Construction of the pipeline landfall crossing and installation of the pipeline at the landfall crossing
Module 4: Operations Environmental Management Plan	PNG Gas Project (gas operations)
Module 5: Closure Plan	PNG Gas Project (facility-by-facility decommissioning)

The EMP modules will include the following components:

- Identified issues and impacts.
- Performance targets.
- Mitigation and management measures.
- Monitoring requirements and activities.
- Implementation schedules.
- Responsibilities.

The current timetable for the preparation of the EMP modules is as follows:

- Modules 1 to 3 – March to July 2006.
- Module 4 – 2008.
- Module 5 – at an appropriate time during operations, 1 to 3 years prior to the commencement of decommissioning activities.

18.3 Organisational Structure and Reporting

The composition and reporting relationships of the project's environmental management plan implementation and monitoring group for the construction and operations phases of the project will be described in the EMP.

The EMP will summarise the responsibilities of this group, which will include:

- Assist the project and its contractors regarding the implementation of the EMP.
- Evaluate/monitor the project's implementation of the EMP.

- Monitor defined parameters regarding the project's environmental and sociocultural impacts.
- Review project plans, designs, strategies, etc. in relation to environmental and sociocultural considerations.
- Maintain environmental management systems and documentation.
- Prepare and submit various reports regarding environmental and sociocultural matters to relevant government agencies and lenders.
- Interface with government environmental authorities.

18.4 Performance Standards and Mitigation Measures

18.4.1 Environmental Performance Standards

Environmental management of the PNG Gas Project, and the design of facility and other equipment, will be governed by performance standards defined by applicable PNG legislation, by Australian and applicable international industry standards, and by the World Bank Group Pollution Prevention and Abatement Handbook (World Bank, 1998), as appropriate.

The environmental performance standards that the project proposes to adopt are presented in Chapter 13 as appropriate for the following areas: water quality (Section 13.5.1.2); air quality (Section 13.8.1); and noise (Section 13.9.1).

18.4.2 Engineering Performance Standards

Section 2.5 discusses the proven engineering design and management principles that underlie the project development. These include investigations to understand site conditions (Section 2.5.2), adherence to appropriate engineering design codes and standards (Section 2.5.3 and Attachment 1), and the implementation of appropriate quality assurance procedures. Adherence to these management principles will ensure that the range of environmental constraints identified is properly considered and that the environmental effects of the project are limited.

18.4.3 Mitigation Measures

In addition to the environmental performance standards and project and engineering design features discussed above, the PNG Gas Project will implement appropriate mitigation measures throughout the preconstruction (early works), construction, operations and decommissioning phases of the project, and these measures will be documented in and activated through the EMP. Proposed mitigation measures are described in Chapters 13, 14 and 15. The implementation of these proposed mitigation measures in combination with adherence to project environmental and engineering design performance standards will ensure that potential impacts of the PNG Gas Project are limited.

18.5 Monitoring and Reporting

Monitoring programs will be developed with appropriate modifications as the project advances through the permitting and detailed design phases. These programs will be developed for the construction and operations phases of the project in consultation with the State and will define:

- Monitoring locations.
- Variables to be measured.
- Sample collection and field measurement methods.
- Frequency of monitoring.
- Reporting.

It is anticipated that monitoring programs will be developed related to the following:

- Water and waste water.
- Solid waste.
- Sediment control.
- Rehabilitation.
- Key social effects.
- Pipeline integrity.

The PNG Gas Project will provide the State with the compliance reports stipulated in environment, water abstraction and waste discharge permits.

Regulatory authority and internal assessments of EMP implementation will occur, with the schedule for such assessments to be determined in consultation with DEC.

This will include mechanisms for reporting monitoring to DEC and other stakeholders, especially to directly affected stakeholder groups.

Incidents that occur as a result of an emergency, accident or malfunction or that cause or threaten serious adverse environmental impacts or are likely to adversely impinge on relations with local communities will be immediately reported to project senior management in addition to the relevant PNG regulatory authorities. Other lesser incidents will be reported within an agreed timeframe to the relevant PNG authorities.

19. Glossary

The following words and abbreviations are defined in the context of their use in this report. Some definitions have been adapted from Macquarie (1990), Baker (1983), Moore (1968), Uvarov et al. (1974), Meagher (1991), Whitten et al. (1979) and Webster (1976).

***n*H:*n*V** *abbr.* ratio of horizontal to vertical measure.

°C *abbr:* degrees Celsius.

°S *abbr:* degrees south.

µg *abbr:* microgram.

µm *abbr:* see micron.

A

A$ *abbr:* Australian dollars.

accretion *n:* the process whereby the size of a mass of sediment (e.g., a delta) is increased due to continual sediment deposition.

acoustic *adj:* pertaining to sound. Acoustic instruments use soundwaves to record measurements.

adventitious *adj:* occurring in an advantageous position or place (often by chance).

AGA *abbr:* Australian Gas Association.

AGL Petronas Consortium (APC) *n:* the entity responsible for the development of the Australian portion of the sales gas pipeline system; comprises The Australian Gas Light Company (AGL) and Petronas Australia Pty Ltd.

alluvial fan *n:* a fan-shaped mass of material deposited at a point along a river or stream where a sudden decrease in the gradient occurs.

alluvial material *n:* material, mainly sand and silt, that a river has carried in suspension and then deposited.

alluvial plain *n:* a plain formed by the deposition of alluvial material over a long period of time.

anchored laybarge *n:* a type of pipelaying vessel.

ANSI *abbr:* American National Standards Institute.

anthropogenic *adj:* originated by humans or from human activity.

anticline *n:* a fold in the earth that is upwardly convex.

artefact *n:* anything made by human workmanship, particularly by previous cultures (such as a chipped or modified stone used as a tool).

AS *abbr:* Australian Standard.

ASL *abbr:* above sea level.

associated gas *n:* natural gas found in association with crude oil in a reservoir, either dissolved in the oil or as a cap above the oil.

AS *abbr:* Australian Standard.

ASME *abbr:* American Society of Mechanical Engineers.

atoll *n:* a ring-shaped or horseshoe-shaped coral island enclosing a lagoon.

B

backfill *v:* to refill an excavation with the material previously removed from that excavation. *n:* the material used in backfilling.

backlimb *n:* the less steep of the two limbs of an asymmetrical anticlinal fold.

backwater *n:* a section of a stream or river, usually close to a bank, that is almost still or flows in the opposite direction to the main current due to localised conditions.

ballast *n:* liquid or solid material placed in a ship for stability at sea when it is not carrying a full cargo.

base flow *n:* water flow in a river or stream that does not arise directly from rainfall runoff.

bathymetry *n:* the science of measuring the depths of marine waters.

batter *n:* the backwards slope in the face of a wall.

Bbbl *abbr:* billion barrel(s).

bbl *abbr:* barrel(s).

Bcf *abbr:* billion cubic foot or feet.

bêche-de-mer *n:* a marine animal of the genus *Holothuria*, commonly known as sea cucumber or sea slug.

bedform *n:* the shape of the surface of a bed of granular sediment produced by the flow of fluid over it.

benthos *n:* animals and plants that live on or in association with the bed of a sea, lake or river.

berm *n:* 1. a low mound built over a pipeline to improve its structural stability and protect it from damage. 2. a mound or kerb made of earth, concrete, or some other material that provides containment for an area; also called a bund.

billion *n* or *adj:* one thousand million.

biocide *n:* a chemical that can kill animals or plants.

biodiversity *n:* the variety of all life forms; the different plants, animals and micro-organisms, the genes they contain, and the ecosystem of which they form a part.

bioturbated *adj:* process of reworking surficial sediments in a subaqueous environment by biological organisms such as worms.

blow down *v:* to produce both gas and oil from a reservoir, without reinjection of the gas, to maximise recovery of the remaining oil.

blowout preventer *n.* a large valve at the top of a well that may be closed if the drilling crew loses control of fluids in the reservoir.

borrow pit *n:* a small excavation providing earth to be used as a construction material.

brackish *adj:* fresh water which is mixed with saline water.

braided channel *n:* a river bed or stream bed consisting of a number of interwoven channels which shift through islands of alluvial material and sandbanks.

BS *abbr:* British Standard.

bund *n:* an embankment constructed around an area to prevent the inflow or outflow of liquids. Also called bunding.

butane *n:* the fourth hydrocarbon (C_4H_{10}) in the methane series, having the same formula but different structures (normal butane or isobutane). Used as a bottle gas fuel, amongst other things (*see* liquefied petroleum gas).

C

carbonate *n*: a group of oxide minerals comprised mainly of carbon and oxygen. Often composed of the skeletal remains of marine or freshwater organisms. Limestone is a common example of a carbonate mineral.

catchment *n:* the entire land area from which water (e.g., rainfall) drains to a specific watercourse or water body.

cathodic protection *n:* a method of protecting a metal structure from corrosion by making its surfaces cathodic and controlling the location of anodic areas so that corrosion damage can be reduced. *See also* corrosion control.

cavernicolous *adj:* cave dwelling.

cay *n:* a low, sandy island or low, exposed coral reef.

civil works *n:* earthworks to prepare a site for further construction work; roadworks; or bridge construction or reconstruction.

clay *n:* very fine-grained sediment or soil (often defined as having a particle size less than 0.002 mm, or 2 microns, in diameter).

CO_2 *form:* carbon dioxide.

CODE *abbr:* College of Distance Education.

colluvial deposit *n:* deposit of weathered material (soil and rock) transported by gravity.

compressor station *n:* equipment for compressing gas to drive it along a pipeline or to enhance recovery of gas from a reservoir.

competent *adj:* adequate, suitable for the purpose.

condensate *n:* a very light oil with an API gravity greater than 45° (*see* pentane).

consolidation *n:* the process or processes by which loose, soft or liquid earth materials (e.g., sand) become firm and coherent (e.g., sandstone).

construction spread *n:* a group of people and equipment engaged in pipeline construction activities that are spread out over several kilometres.

corrosion *n:* the destructive conversion of a metal to a metallic oxide through exposure to oxygen, moisture and/or chemicals.

corrosion control *n:* the measures used to prevent or reduce the effects of corrosion, such as cathodic protection, in which a galvanic or impressed direct electric current renders a pipeline cathodic, thus causing it to be a negative element in a circuit.

corrosion inhibitor *n:* a chemical substance that reduces or prevents corrosion from occurring in metal equipment.

crude oil *n:* unrefined liquid petroleum.

CSIRO *abbr:* Commonwealth Scientific and Industrial Research Organisation.

cubic foot *adj:* a non-metric measure of volume; 35.314 cubic feet equals 1 cubic metre.

culvert *n:* a large pipe or channel carrying water underneath a structure (e.g., a road or railway track) or underneath the ground.

cutter *n:* machine used to cut a trench during the laying of a pipeline on the ocean floor.

cyclonic wave *n:* a very large ocean wave caused by a tropical cyclone.

D

dB *abbr:* decibel; unit used to express sound intensity.

dBA *abbr:* decibels, A-weighted scale; unit used for most measurements of environmental noise; the scale is based upon typical responses of the human ear to sounds of different frequencies.

dbh *abbr:* diameter at breast height.

DEC *abbr:* Department of Environment and Conservation, PNG Government.

dehydration *n:* the removal of water or water vapour from natural gas or crude oil.

deltaic *adj:* of or pertaining to the deposits of sediments formed at the mouth of a river where it enters a lake or the sea.

deltaic mud *n:* very fine-grained sediments deposited in a delta.

demersal fauna *n:* animals which live under the sea.

dendritic *adj:* branching.

depauperate *adj:* scarce, lacking.

deplete *v:* to exhaust a supply. An oil and gas reservoir is depleted when most or all economically recoverable hydrocarbons have been produced.

dieback *n:* the progressive death of a plant, due to any of a number of causes, such as drought, salination, and insect or fungal attack.

dipterocarp *n:* tall, evergreen trees typical of a humid, tropical environment.

disjunct populations *n:* unconnected or separate populations.

diurnal *adj:* occurring daily.

doldrum *n:* a period or location of relatively calm weather.

doline *n:* a closed depression in an area of karst topography.

DPE *abbr:* Department of Petroleum and Energy, PNG Government.

drainage depression *n:* a shallow surface depression in which rainfall runoff collects.

dredge *n* or *v:* apparatus for, or action of, removing sediment from the bottom of a sea, river or lake (typically to increase water depth to allow shipping to pass).

E

easement *n.* a right (usually granted by a government) to use land owned by another party or parties.

ecologically sustainable development *n:* development that improves the quality of human life in a way that maintains the ecological processes on which life depends.

ecology *n:* the science dealing with the relationship between living things and their environment.

EIS *abbr:* environmental impact statement.

electrolysis *n:* the chemical decomposition of a dissolved or molten substance caused by an electric current passing through it.

EMP *abbr:* environmental management plan.

endangered species *n:* any plant or animal species that is likely to become extinct unless action is taken to remove the factors that threaten its survival.

Environmental Inception Report *n:* a document used to initiate the environmental impact assessment process in Papua New Guinea.

epibenthos *n:* plants and animals that are fixed to or crawl upon the sea floor.

epifauna *n:* animals living on the sea floor.

epiphyte *n:* a non-parasitic plant that grows on another plant.

epoxy *n:* resin used in glues and enamel.

erosion *n:* the process by which material (such as rock or soil) is worn away or removed (as by wind or water).

ethane *n:* the second hydrocarbon (C_2H_6) in the methane series; an odourless, colourless gas found in natural gas and used as a refrigerant, fuel and petrochemical feedstock.

exploration *n:* the search for reservoirs of crude oil and natural gas, including aerial and geophysical surveys, geological studies, core testing and test-well drilling.

F

facies *n:* the sum total of features (such as rock type, mineral content, bedding and structures) that characterise a sediment as being deposited in a specific environment.

FEED *abbr:* front-end engineering and design.

field *n:* the surface area overlying a subterranean oil or gas reservoir or reservoirs. Commonly, the term includes not only the surface area, but also the reservoir, production wells, and production equipment.

FIM *abbr:* forest inventory management system (PNG).

flare *n:* a physical structure used to combust gas. *v:* to dispose of excess gas by combustion.

floodplain *n:* a low-lying plain adjacent to a river, subject to occasional or frequent flooding and formed by the sediment deposited during flooding.

flow *n:* a current or stream of fluid.

flow regime *n:* the variation in flow characteristics, such as volume, for a particular stream over time.

fluid *n:* a substance that flows and yields to any force tending to change its shape. Liquids and gases are fluids.

fluvial *adj*: relating to, or formed by, a stream or river.

FMA *abbr:* forest management area.

fold belt *n:* a large-scale geological feature made up of folded rock strata caused by regional geological compression and uplifting (e.g., a mountain range).

formation *n:* a bed or deposit composed of substantially the same kind of rock or soil throughout.

fractionation *n:* the separation of a mixture into its component fractions, often by distillation, which relies on the different boiling points of the components to separate them.

fugitive sediment *n:* sediment that has escaped into the environment from an area of human activity (e.g., from a construction site).

G

galvanic anodes *n: see* sacrificial anodes.

gas *n:* a compressible fluid that completely fills any container in which it is confined.

gas cap *n:* a free-gas phase overlying a crude oil zone and occurring within the same producing formation as the oil. *See also* reservoir.

gas injection *n:* the injection into a reservoir of natural gas produced from the reservoir to maintain formation pressure and reduce the rate of decline of the original reservoir drive or to restore reservoir pressure and free trapped oil by miscible displacement.

gas reinjection *n: see* gas injection.

GDP *abbr:* gross domestic product.

geographic information system *n:* a computer-aided system for storing and reproducing information related to the earth's surface.

geomorphology *n:* the study of the form of the earth.

geotechnical *n:* a term currently employed to cover the fields of soil mechanics, rock mechanics and engineering geology.

GIS *abbr: see* geographic information system.

glycol *n*: a colourless liquid used, among other things, as an antifreeze and as a coolant.

glyphosate *n:* a systemic herbicide.

gorge *n:* a very deep and narrow valley, especially one with vertical or near-vertical sides.

groundwater *n:* water found below the surface of the ground, often in underground aquifers.

GPCSA *abbr:* Gas Project Co-operation and Sharing Agreement.

gubas *n:* short lived squalls of about one hour's duration.

H

h *abbr:* hours

ha *abbr:* hectare(s). 1 ha equals 10,000 square metres.

habitat *n:* the particular local environment of one or more organisms.

hardstand *n:* a compacted and solid base on which machinery can safely and efficiently operate.

hydraulic *adj:* 1. of or relating to water or other liquid in motion. 2. operated, moved, or effected by water or liquid.

hydrocarbons *n pl:* organic compounds composed of hydrogen and carbon, whose densities, boiling points, and freezing points increase as their molecular weights increase.

hydrogen sulfide *n:* a colourless, odorous gas (H_2S), which is a common component of natural gas.

hydrotest *n:* a pressure test of pipelines or other pressure-containing equipment using water as the pressure-test medium. *v:* to test a pipeline or other pressure-containing equipment using this method.

hydrate *n:* a compound which has water chemically associated with it.

I

IAC *abbr:* Independent Advisory Committee.

ICDP *abbr:* Integrated Conservation and Development Project.

IMO *abbr:* International Maritime Organisation.

inert gas *n:* a gas (e.g., helium, neon, argon) that does not react chemically at normal atmospheric temperature and pressure.

infauna *n:* those animals that live in or burrow into sediments.

ISO *abbr:* International Standards Organisation.

IUCN *abbr:* International Union for the Conservation of Nature and Natural Resources.

J

jetting *n:* the process of using directed high-pressure water streams to dig a trench in the sea-bed into which a pipeline is laid.

K

K *abbr:* kina, unit of PNG currency (1 kina = 100 toea). *See also* toea.

karst *n:* the characteristic landform of limestone regions, typically including underground streams, sinkholes, and steep-sided gorges. *See also* sinkhole.

KICDP area *n.* as used in Chapter 9 of this EIS, the 2.3 million ha area designated by the World Wildlife Fund as the Kikori Integrated Conservation and Development Program (KICDP) and covers the Kikori River catchment.

Kikori basin *n.* as used in Chapter 9 of this EIS, the entire catchment of the Kikori River and comprises three sub-basins that are crossed by the proposed pipeline RoWs and access way alignments: the Tagari-Hegigio sub-basin, the Lake Kutubu-Digimu-Mubi sub-basin, and the 'Kikori sub-basin.

km *abbr:* kilometre.

km^2 *abbr:* square kilometre(s); a metric measure of area.

knot *n:* a non-metric unit of speed of one nautical mile per hour.

KP *abbr:* kilometre point.

kSm^3/h *abbr:* thousand standard cubic metre(s) per hour.

Kumul Marine Terminal *n:* an offshore facility in PNG marine waters from which crude oil is loaded onto tankers; the destination of the Kutubu crude oil export pipeline.

kW *abbr: see* kilowatt.

L

lateral *n:* a small pipeline that branches off a larger pipeline.

laybarge *n:* a barge used for pipelaying.

laydown area *n:* sites at which pipe and other equipment and supplies may be stored prior to delivery to a right of way or a construction camp.

levee *n:* a raised natural river bank formed by the deposition of sediment during periods of flooding.

LIDAR *abbr: LIght Detection And Ranging.*

limestone *n:* sedimentary rock that consists mainly of calcium carbonate ($CaCO_3$), typically formed from the skeletal remains of marine or freshwater organisms.

liquefied natural gas *n:* the state of natural gas when it is refrigerated to below -160°C. Liquefied natural gas (LNG) is typically transported by special tankers to overseas markets, where it is regasified and reticulated by pipeline to industrial and domestic customers.

liquefied petroleum gas *n:* a liquid mixture of heavier, gaseous, paraffinic hydrocarbons, principally butane and propane. These gases, easily liquefied at moderate pressure, may be transported as liquids but converted to gases on release of the pressure. Thus, liquefied petroleum gas (LPG) is a portable source of thermal energy (e.g., as bottled gas) that finds wide application in areas where it is impractical to distribute natural gas. It is also used as a fuel for internal-combustion engines and has many industrial and domestic uses. Principal sources are natural and refinery gas, from which the liquefied petroleum gases are separated by fractionation.

liquid *n:* a state of matter in which the shape of the given mass depends on the containing vessel, but the volume of the mass is independent of the vessel.

liquid fuels *n:* fuels used in liquid form (e.g., petrol, diesel).

LLG *abbr:* local-level government.

LNG *abbr: see* liquefied natural gas.

LPG *abbr: see* liquefied petroleum gas.

M

m *abbr:* metre(s).

m² *abbr:* square metre(s).

m³ *abbr:* cubic metre(s).

m³/s *abbr:* cubic metre(s) per second.

mainline valve *n:* a valve used to control flow along a main pipeline.

mastic *n:* a type of resin.

megabenthos *n:* large animals or plants that live on or in association with the bed of a sea, lake or river.

megafauna *n:* large animals.

metamorphic rock *n:* a rock that has had its structural and chemical composition transformed by exposure to extremes of heat and/or pressure.

methane *n:* the first hydrocarbon (CH_4) in the methane series; a colourless, odourless gas.

mg/L *abbr:* milligram(s) per litre.

MHWS *n:* mean high water at spring tide.

microclimate *n:* a climate that is peculiar to a small area, particularly an area within a plant community that is sheltered from normal climatic conditions.

micron *n:* one millionth of a metre (one thousandth of a millimetre).

Miocene *n:* a geological epoch of the Tertiary period.

mL *abbr:* millilitre(s).

ML *abbr:* megalitre(s).

mm *abbr:* millimetre(s).

Mbbl *abbr:* millions of barrels.

Mscfd *abbr:* one million standard cubic feet per day.

MoA *abbr:* memorandum of agreement.

mobile bedforms *n:* features on the sea floor (e.g., sand waves) that are constantly shifting their shape and location due to the action of water currents.

MoU *abbr:* memorandum of understanding.

MRDC *abbr:* Mineral Resources Development Company Limited.

msl (or MSL) *abbr:* mean sea level.

Mt/yr *abbr:* megatonnes per year.

mudstone *n:* sedimentary rock composed of varying or undetermined proportions of clay, silt and sand particles.

N

NACE *abbr:* National Association of Corrosion Engineers.

naptha *n:* a general name given to mixtures of hydrocarbons in various portions obtained from paraffin oil, coal-tar and other sources.

natural gas *n:* a highly compressible, highly expansible mixture of hydrocarbons having a low specific gravity and occurring naturally in gaseous form. Besides hydrocarbon gases, natural gas may contain appreciable quantities of nitrogen, helium, carbon dioxide, hydrogen sulfide and water vapour. Although gaseous at normal temperatures and pressures, the gases comprising the mixture that is natural gas are variable in form and may be found either as gases or as liquids under suitable conditions of temperature and pressure.

NECL *abbr:* National Energy Company Limited.

New Guinea *n.* as used in Chapter 9 of this EIS, refers to the island of New Guinea, which contains the country of Papua New Guinea and the province of Irian Jaya in Indonesia. The term includes the immediately adjacent islands, such as Waigeo and Karkar.

NGO *abbr:* non-governmental organisation.

NO_x *abbr:* nitrogen oxides.

NTU *abbr:* nephelometric turbidity units. Units used to measure turbidity.

O

offgas *n:* a small, irregular release of gas from normal process fluctuations, which is typically disposed of by combustion in a small flare.

oil *n:* a simple or complex liquid mixture of hydrocarbons, which can be refined to yield gasoline, kerosene, diesel fuel and various other products.

Omati basin *n.* as used in Chapter 9 of this EIS, the catchment of the Omati River, which is crossed by a section of the sales gas pipeline RoW to reach landfall on the lower Omati River.

Omati River *n:* a distributary of the Kikori River.

P

padding material *n:* material suitable for backfilling the trench around a newly laid pipeline.

parent material *n:* the original rock material from which a soil has been derived.

PDL *abbr:* petroleum development licence.

pelagic *adj:* pertaining to underwater depths characterised by deposits of mud and ooze.

pentane *n:* the fifth hydrocarbon (C_5H_{12}) in the methane series.

permeability *n:* the characteristic of a porous medium that allows fluid to flow through it.

petajoule *n:* a derived SI unit of energy; one thousand trillion (10^{15}) joules. *See* joule.

petrochemicals *n:* substances industrially obtained from petroleum or natural gas.

petroleum *n:* a substance occurring naturally in the earth and composed mainly of mixtures of chemical compounds of carbon and hydrogen, with or without other non-metallic elements, such as sulfur, oxygen, and nitrogen.

Petronas *abbr:* Petroliam Nasional Berhad (Malyasia).

PHB *abbr:* Provincial Health Board.

phosphate *n:* a mineral compound characterised by a tetrahedral ionic group of phosphorus and oxygen.

phytoplankton *n:* small drifting plants near the surface of the sea, including algae, fungi and bacteria.

pig *n: see* scraper pig.

pipelay tractor *n:* a machine used to place a pipestring into a trench.

pipeline *n:* a system of connected lengths of pipe, usually buried in the earth or laid on the seafloor, that is used for transporting petroleum and natural gas from one place to another.

pipeline corridor *n.* as used in Chapter 9 of this EIS, generally the land 10 km on either side of the pipeline RoWs.

pipestring *n:* a series of line pipe lengths welded together into a single length, prior to lowering the string into a trench or onto the seafloor.

PL *abbr:* pipeline licence.

plankton *n:* small drifting plants and animals near the surface of seas, lakes and oceans.

plateau *n:* a large, flat, elevated area of land.

plough *n:* a tool used to carve a trench in the sea floor.

ploughing *v:* method of carving a pipeline trench in the sea-floor using a surface vessel to pull along a plough.

plume *n:* a rising current in a marine environment.

PNG *adj:* Papua New Guinea.

PNGFA *abbr:* Papua New Guinea Forest Authority.

PNG Government *n:* The Government of the Independent State of Papua New Guinea.

PNG mainland *n.* as used in Chapter 9 of this EIS, that part of New Guinea that forms the country of Papua New Guinea.

PNGRIS *abbr:* Papua New Guinea Regional Information System.

PNGS *abbr:* Papua New Guinean Standard.

PPFL *abbr:* petroleum processing facility licence.

PPL *abbr:* petroleum prospecting licence.

pressure *n:* the force that a fluid (liquid or gas) exerts uniformly in all directions within a contained volume.

pressure maintenance *n:* the use of natural gas injection to provide additional formation pressure and displacement energy that can supplement and conserve natural reservoir drives.

PRL *abbr:* petroleum retention licence.

prodelta *n:* that part of the delta lying beyond the delta front.

producing formation *n:* geological structure that has accumulated hydrocarbons over time and that has been drilled to recover hydrocarbons.

production *n:* 1. the phase of the petroleum industry that deals with bringing well fluids to the surface and separating them and with storing, gauging, and otherwise preparing the product for transport by pipeline. 2. the amount of oil or gas produced in a given period.

prograding *n:* seaward building of a delta, beach or fan due to deposition of water-borne sediments.

project area *n.* as used in Chapter 9 of this EIS, this area extends from the Hides gas field to the Omati River and forms part the KICDP area.

project impact area *n.* the area used in the PNG Gas Project Social Impact Assessment, defined as some 98 census units, straddling Southern Highlands and Gulf provinces (see Section 11.3 for a figure showing this area).

propane *n:* the third hydrocarbon (C_3H_8) in the methane series; used as a bottled gas fuel (*see also* liquefied petroleum gas).

PZJA *abbr:* Protected Zone Joint Authority.

R

rare *adj:* a term applied to a species that is not often seen or found.

raw gas *n:* well head natural gas that is saturated with water.

reagent *n:* a substance used to detect or measure another substance or to convert one substance into another by the reaction it causes.

recontouring *n:* the process of re-establishing local topography and drainage (by grading or other means) following land disturbance.

reeve *v:* to pass a line or cable through a pulley to change the direction of tension.

regeneration *n:* the natural process by which plants within vegetation communities reproduce (either by seed or vegetatively) so that new individuals grow to replace the older plants when they die.

rehabilitation *n:* the measures and actions used to repair land disturbed by project construction or operations activities.

reinjection *n: see* gas injection.

reservoir *n:* a subsurface, porous, permeable rock body in which oil and/or gas can be located.

reservoir pressure *n:* the pressure that exists within a formation from which hydrocarbons or other fluids are produced.

revegetation *n:* the re-establishment and development of a suitable plant cover by either natural or artificial means; *natural revegetation* takes place without intervention and *active revegetation* takes place with intervention using such means as ground preparation, fertilisation, seeding or seedling planting.

rich gas *n:* a partly processed form of natural gas that is rich in heavier hydrocarbons. It is generally fully or partly dehydrated.

right of way *n:* the physical area over which an easement is held.

routing *v:* choosing the location of a linear entity, such as a pipeline, power line, or road.

RoW *abbr:* right of way.

S

sacrificial anode *n:* metal electrode that protects the metal structure on which it is placed by corroding in preference to the structure. Also called galvanic anode.

sand *n:* sediment composed of particles within the size range 63 microns to 2 millimetres.

sand wave *n:* a large ridge-like structure on the upper surface of a sedimentary bed that is formed by water currents.

SCADA *abbr: see* supervisory control and data acquisition system.

scraper pig *n:* a maintenance tool used in normal pipeline operations to clean the internal wall of a pipeline.

scraper station *n:* a facility located at the end points and at certain mid-points along a pipeline to allow scraper pigs to be placed into the flowing fluid and to be recovered at the end of each section.

seafloor *n:* the surface underlying the sea.

sediment *n:* unconsolidated, fine-grained material (typically derived from the weathering of rocks) that is transported and settles on the floor of seas, rivers, streams and other bodies of water.

seismic activity *n:* earth movement (e.g., an earthquake).

sheet pile *n* : a square or rectangular steel section, jointed on the edge and sometimes grooved and tongued, driven into the ground to provide a watertight and safe hole or excavation.

shoal *n:* a ridge of rock, mud or sand lying below the water level in rivers or seas, especially one that is exposed at low water.

SIA *abbr:* social impact assessment.

sidecasting *v:* putting material to one side, sometimes down a slope.

silt *n:* sediment with particles finer than sand and coarser than clay (i.e., 2 to 63 microns).

siltation *n:* the accumulation of very fine-grained sediments deposited by water currents in localised areas of channels, rivers, harbours and other water bodies.

sinkhole *n:* a hollow or hole into which surface water drains, especially such a hole worn through rock and leading to an underground channel.

skeletal soil *n:* a shallow soil that has minimal profile development and is dominated by the presence of weathering rocks and rock fragments.

SO_2 *form:* sulfur dioxide.

span rectification *n:* placement of material to fill an uneven seabed and prevent a pipeline from bridging across an open span.

species *n:* a grouping of organisms that are able to interbreed with each other, but not with members of other species.

specific gravity *n:* the ratio of the weight of a given volume of a substance at a given temperature to the weight of an equal volume of a standard substance at the same temperature.

spoil *n:* material removed during excavation (e.g., of a trench) or during site preparation.

spread *n: see* construction spread.

State *n.* the Independent State of Papua New Guinea.

stinger *n:* an inclined ramp that supports the pipestring as it leaves a pipelay vessel and thereby prevents excessive bending of the pipeline that could lead to buckling.

storm tide *n:* a larger than normal ocean tide caused by a storm.

subcatchment *n:* a smaller area within a catchment drained by one or more tributaries of the main watercourse.

subsea *adj:* below the surface of the sea and, in the case of a pipeline, resting on the seafloor.

substrate *n:* the material comprising the seafloor (e.g., sand, mud, rock).

supervisory control and data acquisition system *n:* a system for monitoring the performance of the pipeline, for notifying operators of anomalies and for controlling the pipeline system.

suspension *n:* supported by a fluid or gas. For example, a particle of sediment carried in suspension by a stream will travel for long periods without making contact with the streambed.

T

TCF *abbr:* trillion cubic feet.

terra rossa *n:* a reddish brown soil overlying limestone bedrock.

threatened *adj*: term applied to a species at risk of extinction.

tidal currents *n:* ocean currents caused by tidal forces.

tie in *v:* to join two sections of a pipeline.

toea *abbr:* unit of PNG currency (100 toea = 1 kina).

Torres Strait *n:* the stretch of ocean that separates Cape York Peninsula (Australia) from Papua New Guinea and across which the offshore portion of the PNG Gas Project's sales gas pipeline will run.

trap *n:* a sedimentary or tectonic structure where crude oil and/or natural gas has accumulated. Traps are structural highs where a porous rock unit is capped by an impermeable rock unit. Oil and gas trapped within the porous rock unit migrate to a high point in the structure because of their low density.

trawl grounds *n:* areas where trawl fishing is carried out.

treat *v:* to subject a substance to a process or to a chemical reagent to change (and often improve) its quality or remove a contaminant.

treated raw gas *n:* gas which has been dehydrated and processed to remove carbon dioxide and other gases (e.g., hydrogen sulfide).

trench plug *n:* an engineering structure used to intercept the flow of water along a pipeline in a trench after the trench has been filled in.

trench spoil *n:* material excavated from a trench when constructing a pipeline. *See also* padding material.

TSPZ *abbr:* Torres Strait Protected Zone.

TSPZJA *abbr:* Torres Strait Protected Zone Joint Authority.

TSS *abbr:* total suspended solids.

turbidity *n:* the optical property of water that prevents light from being transmitted through it. Increased turbidity, or muddiness, is caused by the presence of very fine suspended material, such as clay or organic matter.

turbidity plume *n:* a section of water containing sufficient suspended sediment to differentiate it visually from surrounding waters.

U, V

untreated raw gas *n:* Gas produced from an inlet separator prior to removal of carbon dioxide (and other gases) and dehydration.

US$ *abbr:* United States dollars.

valve *n:* a device used to control the rate of flow in a pipeline, to open or shut off a pipeline completely, or to serve as an automatic or semi-automatic safety device in a pipeline.

verge *n:* the edge of a road next to the made surface.

VOC *abbr:* volatile organic compound.

vug *n.* a cavity in an intrusive rock or carbonate sediment.

vulnerable species *n:* a species not presently rare or endangered but at risk of disappearing from the wild over a long period through continued depletion.

W

water vapour *n:* water (H_2O) in gaseous form (e.g., steam).

weld profile *n:* the bevel machined onto the end of a joint of pipe, prior to alignment for welding, to provide space for the deposition of weld metal.

well cellar *n.* a lined area dug out below the drill rig. The cellar serves as a cavity to receive drilling fluid returns from the well, which are pumped back to the surface drilling-fluid equipment

well fluid *n:* the fluid, usually a combination of natural gas, crude oil, water, and suspended sediment, that comes out of an oil reservoir.

wetlands *n:* low-lying areas regularly inundated or permanently covered by shallow water. Usually important areas for birds and other wildlife.

WHO *abbr:* World Health Organization.

winch *n:* a machine that pulls or hoists by winding a cable around a spool.

woodland *n:* a tract of land covered by trees that do not form a closed canopy.

WWF *abbr:* World Wildlife Fund and World Wide Fund for Nature.

X, Y, Z

x-ray inspection *n:* a method of non-destructively testing weld joint integrity.

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20.2 Personal Communications

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21. Study Team

Enesar Consulting Pty Ltd was commissioned by the Operator to assist in the preparation of this Environmental Impact Statement. Enesar engaged a number of specialist subconsultants and the EIS draws on their work. These contributions are gratefully acknowledged.

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L. David	Assessment report
R. Dehnert	Administration/report management
J. Gray	Studies coordination/report management/assessment report
D. Gwyther	Assessment report
J. Holmstrom	Administration/report production
J. McKechnie	Marine study field work

C. Monahan	Assessment report
D. Moriaty	Assessment report
J. O'Neil	Desktop publishing
D. Oram	IT specialist/DTM
K. Sutherland	Assessment report
G. Terrens	Assessment report
G. Young	GIS coordination
M. Wright	Assessment report

21.2.2 EOS Joint Venture

P. Thomson	Manager, Engineering Processes & Specialists
K. Jacobsen	Lead Project Engineer Constructability
V. Chiknaikin	Manager Infrastructure Engineering
V. Seto	Environmental Coordinator
P. Cox	Manager Onshore Pipelines

21.2.3 Biodiversity Consultants

Francis Crome Pty Ltd

F. Crome	Biodiversity studies team leader
I. Voxwold	Avifauna study

Greg Richards and Associates Pty Ltd

G. Richards	Bat study

WWF Kikori Integrated Conservation and Development Project

I. Enoch	Mammal Study
O. Gebia	Mammal Study
M. Kuduk	Mammal Study
T. Mamu	Mammal Study
R. Namo	Mammal Study
A. Ona	Mammal Study

Other Biodiversity Specialists

S. Richards	Herpetofauna study
W. Takeuchi	Flora study

21.2.4 Other Specialist Consultants

Apogee Imaging International

J. Douglas	Image analysis specialist
I. Lau	Image Analyst

Booyong Forest Science

H. Rogers	Forestry and RoW rehabilitation studies

David Balloch and Associates

D. Balloch	Onshore aquatic impact assessment

Liz Jacobsen Publishing Services

L. Jacobsen	EIS editor

Holmes Air Sciences

N. Holmes	Air quality, noise and greenhouse gas emissions

Laurence Goldman and Associates

L. Goldman	Social Impact Assessment team leader
N. Araho	PNG Museum Archaeology specialist
C. Ballard	Archaeology studies
B. David	Archaeology studies
J. Pappos	Administration
J. Weiner	Social Mapping

Mipela (GIS) Pty Ltd

H. McDonald	GIS specialist
E. Henry	GIS Specialist

Moroka Pty Ltd

J. Tilleard	Hydrologist

PDM Project Design and Management

Gary Simpson	Social and economic impact assessment

Peter Hallows and Associates

P. Hallows	Technical writer

21.2.5 Other Project Consultants

ACIL Tasman Australia Pty Ltd

G. Brownbill	Government relations and advice

APR GIS and Data Solutions

G. Mules	GIS specialist

Kramer Group Limited

Road Background Report