10. RECEIVING ONSHORE ENVIRONMENT: UPSTREAM FACILITIES AND ONSHORE PIPELINES

10.1 Introduction and Terms

This chapter provides a description of the onshore physical and biological environment associated with the upstream facilities and onshore pipelines for the PNG LNG Project. The upstream project area encompasses the highlands and gulf region.

10.1.1 Study Area

The upstream project area falls mainly within the northwest–southeast orientated Kikori catchment from the high northern landscapes of the geological Papuan Fold Belt where Mount Dini rises to 3,056 m, to the Kikori River floodplain and delta of the Omati and Kikori rivers, which flows into the northern Gulf of Papua. The project area also encompasses the area around Juha in Western Province, which is located among lowland hills of less than 1,000 m and in an upper catchment of the Strickland River. The upstream project area is extremely diverse in its geology, geomorphology, soils, habitats, flora and fauna.

More specifically, the former Kikori Integrated Conservation and Development Project (KICDP) area, now termed the Kikori River Program (KRP), was the basis for defining the project area; however, it does not encompass all potential upstream PNG LNG Project components. Gas development in the Juha area will extend the project beyond the Kikori River drainage and into the drainage of the Strickland River in Western Province. Therefore the upstream project area has been defined based on extending the former KICDP area westwards to encompass the Juha area. This extension does not encompass the entire catchment of the Strickland River, but attempts to follow catchment-based approaches by including the catchment of the Liddel River, the southern catchment of the Burnett River and the northern catchment of the Wai Asia River. Therefore the potential impact areas that might feed into the Strickland River have all been included (Appendix 1, Biodiversity Impact Assessment).

This project area has been used for the biodiversity and hydrology studies, for example, whereas studies relating to noise, air quality and groundwater have focussed more on the proposed facility locations.

Information relating to the Hides, Kutubu, Gobe, Agogo, and Moran gas fields within the upstream project area has been sourced from previous assessments undertaken from 2005 to 2006 for the PNG Gas Project and draws extensively on information from the KRP. The KRP is a collaboration between the Kutubu oil producing companies and the World Wildlife Fund for Nature (WWF). Researchers associated with the KRP have been studying terrestrial and aquatic biodiversity in the Kikori River catchment since the early 1990s. The KRP area encompasses the infrastructure of the existing petroleum production facilities and the majority of the facilities proposed for the PNG LNG Project.

Additional information has been sourced from specialist studies commissioned for this project to assess the physical and biological environment of the areas around Hides and the Hides to Juha segment where new wells, gathering systems, production facilities, pipelines and roadways are proposed (see Figure 1.6, which lists the specialist studies provided as appendices to this report).

10.1.2 'Baseline' and 'Monitoring'

The IFC's (2006b) social and environmental impact assessment guidelines provide for 'appropriate social and environmental baseline data' that should be 'relevant to decisions about project location, design, operation, or mitigation measures'.

The guidelines also provide for 'procedures to monitor and measure the effectiveness of the management program' that should be 'commensurate with the project's risks and impacts'.

These two requirements have different purposes, but both rely on 'baseline' data, that is, information about the project environment prior to project development.

This EIS has therefore adopted the following terminology:

- Characterisation baseline: corresponds to the IFC meaning set out in the first paragraph of this subsection, that is, information on existing conditions 'relevant to decisions about project location, design, operation, or mitigation measures'. This information will typically be broad enough to capture for assessment the areas of potential impact.
- Monitoring baseline: is implicit in the IFC guidelines, and is here used to describe data comprising the 'before' or 'control' component of a monitoring program set up to track the project's ability to manage and mitigate its impacts in line with the predictions in the EIS. Selection of sampling locations for this monitoring is dependent upon finalisation of project design and the completion of impact assessment procedures, including the setting of conditions.

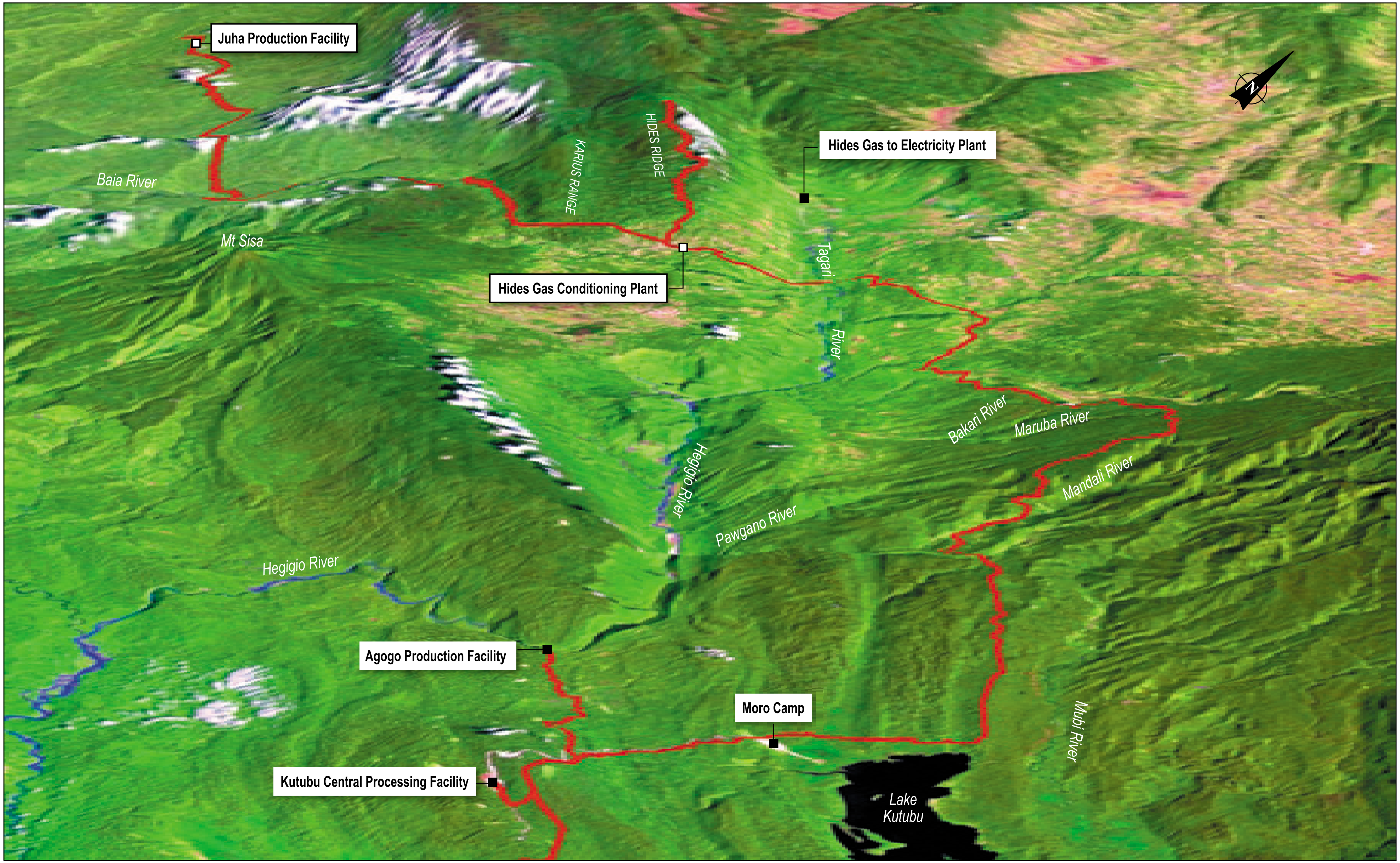
The monitoring baseline typically will be narrowly focused on indicators of change identified by the impact assessment. Characterisation data may be directly applicable to the monitoring baseline, but often needs to be supplemented, especially if there is to be statistical analysis of the data.

10.2 Physical Environment

The onshore physical environment of the upstream project area is described by location and geomorphology (Section 10.2.1), landforms (Section 10.2.2), tectonic setting and regional seismicity (Section 10.2.3), geology and hydrogeology (Section 10.2.4), soils (Section 10.2.5), climate (Section 10.2.6), river systems and hydrology (Section 10.2.7), water quality (Section 10.2.8), noise (Section 10.2.9) and air quality (Section 10.2.10).

10.2.1 Location and Geomorphology

Figures 10.1 and 10.2 show digital elevation models for the upstream project area.



Note:
Vertical exaggeration x 2.
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

PNG LNG	Job No: 1284	Esso Highlands Limited	Digital elevation model: Juha to Kutubu	Figure No: 10.1
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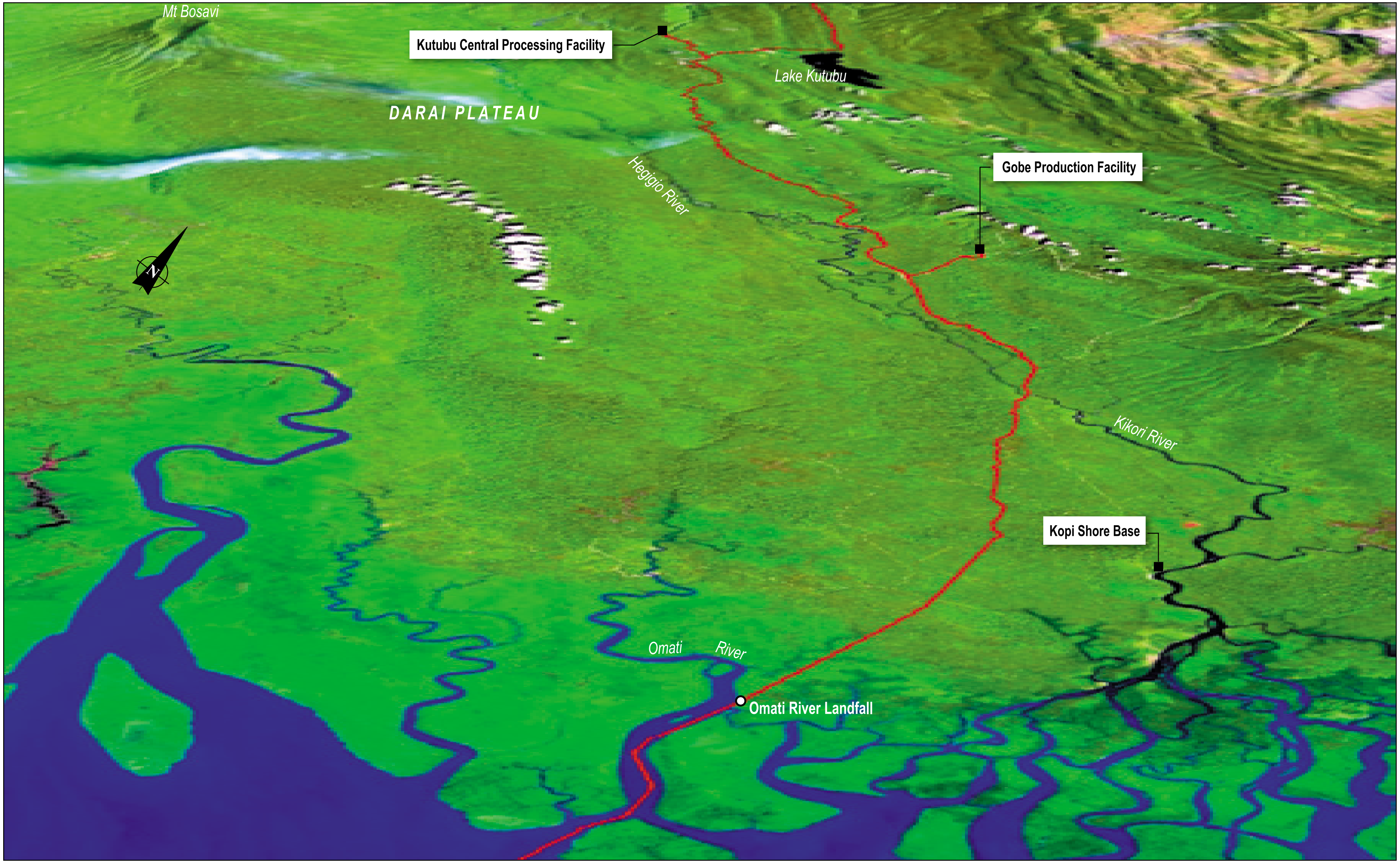

Note: Vertical exaggeration x 2. Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.	PNG LNG	Job No: 1284	Esso Highlands Limited	Digital elevation model: Kutubu to Omati River Landfall	Figure No: 10.2
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10.2.1.1 The Kikori Catchment

The Kikori catchment is one of the more remote areas of Papua New Guinea. It stretches from the alpine grasslands of Doma Peaks in Southern Highlands Province to the extensive mangrove wetlands of Gulf Province.

The structural history of the Kikori catchment is strongly reflected within the geomorphology of the upstream 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, folding is more prominent, 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, a complex environment of mixed karst, dolines, rock towers and sharp-edged escarpments, all covered in dense lowland forest.

Thrust and secondary faults are associated with several of the ridges and valleys of the upstream project area (see Section 10.2.3, Tectonic Setting and Regional Seismicity).

10.2.1.2 The Hides to Juha Area

The Hides to Juha area is an extension of the northern part of the KRP area to the Burnett River (encompassing the northern karst region) and from Mount Sisa west to the east bank of the Strickland River. The northern part of this area (Juha Production Facility) includes the Karius Range, with heights of up to 2,700 m. The southern part of this area is comprised of mainly sedimentary lowlands and foothills with mixed lowland forest.

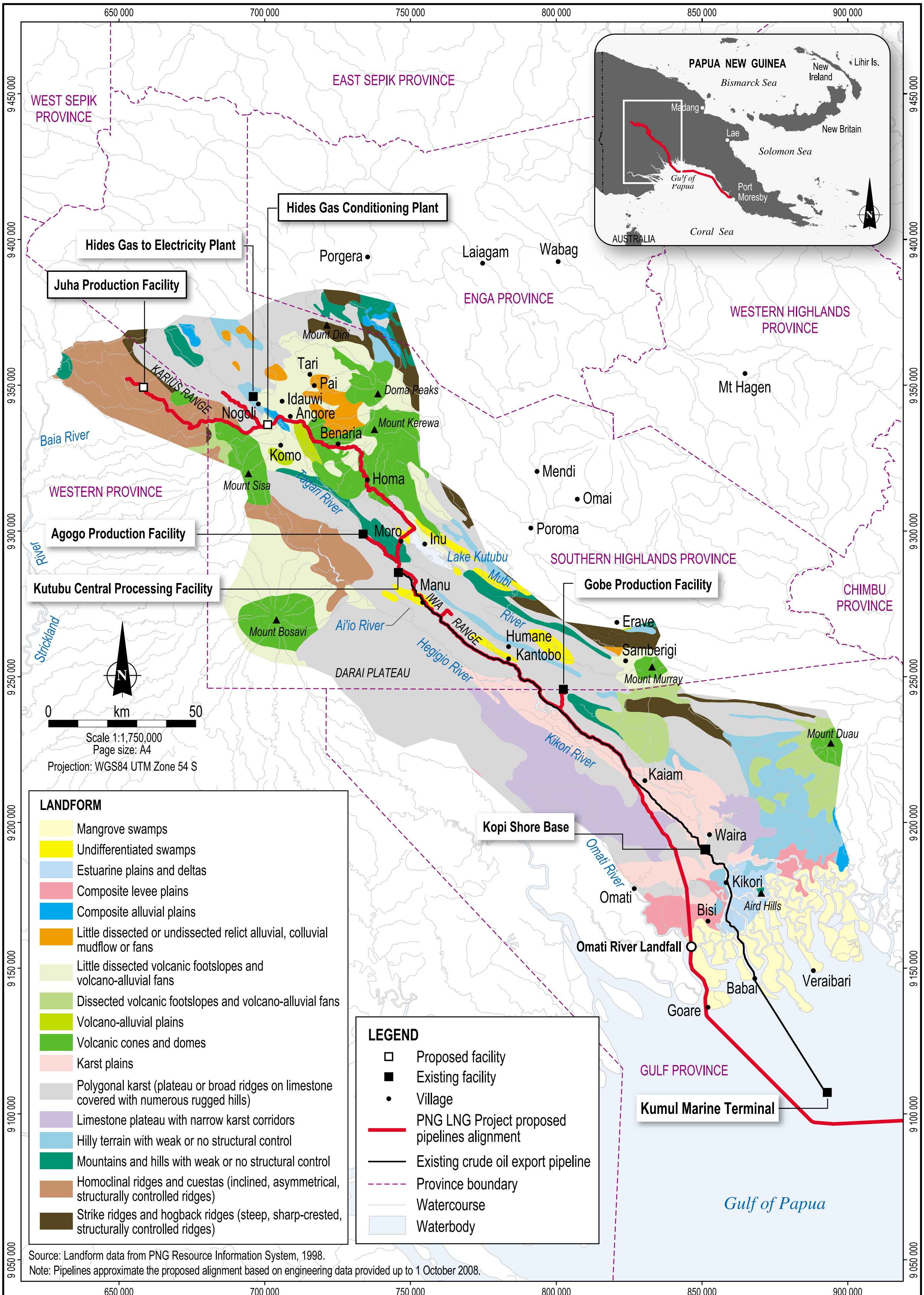
10.2.2 Landforms

Landforms in the upstream project area are dominated by a system of limestone ridges, valleys and plains running in a northwest to southeast direction from the central cordillera of New Guinea. They form part of the extensive southern fold mountains that cover some 2,000,000 ha between the Gulf of Papua and the West Papua border. Descending from Hides and Kutubu at elevations of 2,700 m ASL and 1,500 m ASL respectively, the terrain becomes progressively gentler southeastwards across the limestone Darai Plateau to the floodplain and landforms of the Omati–Kikori delta as well as to the west into the lowlands of the Juha area and the Strickland River valley.

Figure 10.3 shows landforms of the upstream project area derived from the Papua New Guinea Regional Information System (PNGRIS) database.

10.2.2.1 Karst Landforms

Limestone is the dominant surface geological feature in the region. 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



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Landforms of the upstream project area

Figure No: **10.3**

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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 catchment, and Löffler (1977) distinguishes three major types: karst plains, limestone plateaux with karst corridors, and polygonal karst.

Karst Plains

Undulating plains of limestone occupy the central part of the Kikori catchment at approximately 40 to 100 m ASL. The Kikori River itself is confined to a channel cut in the coastal plains. These plains present a more or less uniform limestone pavement with the possible occurrence of local pinnacle and doline relief. The existence of subsurface caves is unlikely as karst plains are at the base level of erosion. Karst plains appear to underlie the depositional plains and fans that occur throughout the Kikori lowlands.

Limestone Plateaux with Narrow Karst Corridors

Flat-topped plateaux with narrow, often ill defined and discontinuous incised karst corridors occur extensively southwest of the lower sections of the upstream project area (around Kopi) and the southeastern section of the Darai Plateau. The corridors are in some cases 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 and extremely rugged 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 from 50 to 100 m in diameter and up to 50 m deep in the upstream project area (Dames & 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.

The Darai Plateau consists of cockpit karst (Plate 10.1), which is characterised by the presence of conically shaped residual hills with rounded tops and relatively steep, convex side slopes.

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 10.2). A typical karst pinnacle is an isolated hill or ridge consisting of an eroded remnant of limestone with vertical or near-vertical convex side slopes and commonly surrounded by an alluvial plain or deep rugged ravines.

Plate 10.1
Darai Plateau showing cockpit and cone karst countryside

Plate 10.2
Pinnacle and tower karst countryside

Plate 10.3
Emergence of subsurface waters from underground stream

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.

10.2.2.2 Volcanic Landforms

There are extensive areas of volcanic landforms in the north and northwest of the upstream project area. The major volcanic landform that dominates the landscape to the west of the oil facilities at Kutubu is the symmetrical cone of Mount Bosavi, a Pleistocene volcano, which rises to 2,530 m ASL in the far northwest of the Kikori catchment. Its fans and foot slopes extend over an area of approximately 200,000 ha north of the cockpit karst of the Darai Plateau. The Mount Sisa and the Doma Peaks volcanic landforms are located to the north and northeast of Mount Bosavi, respectively. Agricultural lands around Komo have been developed on the rich basalt soils of Mount Sisa, and the Doma Peaks provide an interesting landscape of remnant cones and volcanic domes, volcanic and volcano-alluvial fans and mudflows from eruptions that occurred hundreds of years ago.

10.2.2.3 Landforms of Fluvial Erosion and Mass Movement

The mountain systems to the north and east of the Kikori catchment and to the west of Kutubu and into Western Province north to Juha are a complex of karst and other landforms. The systems have been 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 strike rides and hogbacks, hills or mountains with no structural control, and homoclinal ridges and cuestas.

Strike Ridges and Hogbacks

Sharp-crested ridges (strike ridges) with structural control formed on highly tilted beds form a discontinuous rampart in the east of the Kikori catchment. There is also a narrow area of this landform in the northern part of the upstream project area in the vicinity of the proposed Juha Production Facility site. Hogbacks are homoclinal ridges where the bedding dip of the strata is steep but uniform (more than 30 to 40°) and in the one direction.

Mountains and Hills with No Structural Control

The strike ridges in the Kikori catchment are interspersed with limestone hills and mountains with no structure control. This steep landform has irregular slopes caused by intense gullying and has a highly complex drainage pattern. This landform occurs in the higher parts of the Kube Kabe, Wasuma, Iwa, Hurutami and Mosa ranges in the Kikori catchment between Lake Kutubu and the Mubi River. Peaks rise to 1,320 m ASL in the Iwa Range and on Mount Kemanagi to the southeast of Lake Kutubu. This landform also occurs in the Juha area, west of the proposed Juha Production Facility site.

Homoclinal Ridges and Cuestas

The homoclinal ridges and cuestas form where limestone is layered with harder, more resistant beds of rock. Homoclinal ridges are typically asymmetrical with a steep scarp slope and a more gentle dip slope. The dip slope lies at same or lesser 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°) and are produced by differential erosion of interbedded resistant and weak rocks. This landform is found on the eastern slopes of Mount Bosavi and the eastern slopes of Mt Sisa. It is also a landform characteristic of the lowland area of Juha.

10.2.2.4 Relict Alluvial Plains and Dune Complexes

Relict alluvial plains are found along both banks of the lower reaches of the Kikori and Omati rivers. Old dune complexes occur within the Omati–Kikori delta, forming thin layers of sediment over the underlying limestone plain.

10.2.2.5 Fluvial Plains, Fans and Swamps

Areas of fluvial deposition, comprising plains, fans, back plains and swamp, are most widespread in the lowland areas of the Kikori catchment surrounding the littoral plains and dune complexes to the east and west. Significant depositional areas also occur in perched valleys of the Ai'io and Mubi rivers at higher elevations.

10.2.2.6 Implications

Limestone landforms are often steep but otherwise favourable for civil construction. Slope instability is generally a reflection of surface weathering and so tends not to be deep-seated. Massive failures are therefore uncommon. Similarly, the irregular topography makes for incoherent surface drainage, and so fugitive sediment will tend to hang up or be contained close to its source.

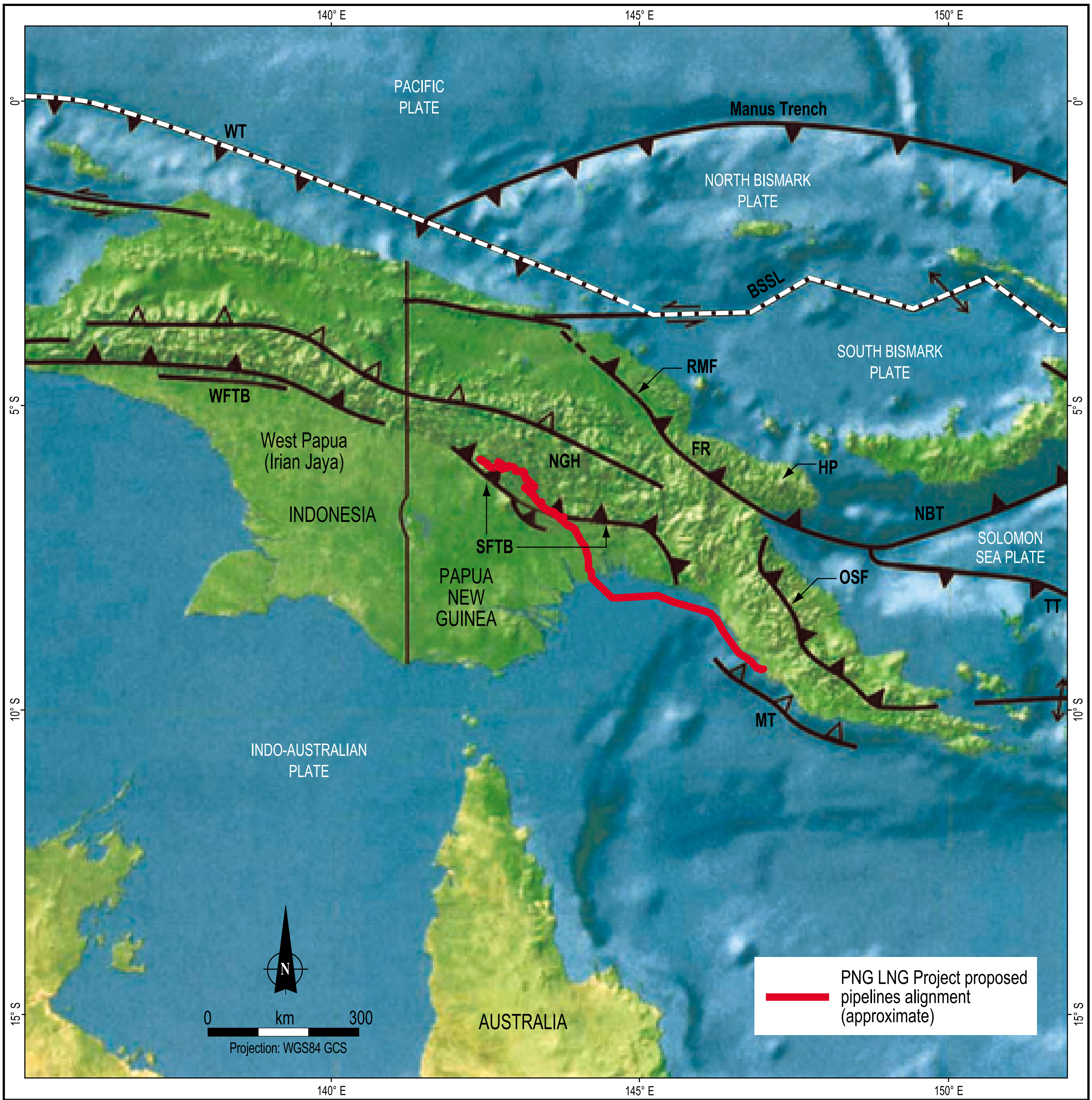
Volcanic landforms in steep terrain have conventional dendritic drainage patterns and so fugitive sediments report to local surface streams and rivers. These are erosional landforms and the construction-derived sediment is a short-term increment over what occurs naturally. Provided the period of fugitive sediment is finite, the impact will also be finite.

The deposition environments are inherently stable and once again, provided the perturbations of project construction are of finite duration, then the impacts will also be finite.

10.2.3 Tectonic Setting and Regional Seismicity

10.2.3.1 Tectonic Setting

The proposed upstream project infrastructure will be located on the northern portion of the Australian tectonic plate. Figure 10.4 shows the tectonic plates and major fault lines in the vicinity of New Guinea. The northeasterly moving Australian Plate is colliding with the southwesterly moving Pacific Plate, which lies to the north and east of the Australian 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/year based on global positioning satellite (GPS) geodetic surveys (URS, 2005).



EXPLANATION

Tectonic Features

SFTB - Southern Highlands Fold and Thrust Belt
MT - Moresby Trough
OSF - Owen Stanley Fault
RMF - Ramu Markham Fault
WT - Wewak (New Guinea) Trench
BSSL - Bismarck Sea Seismic Lineation
NBT - New Britain Trench
WFTB - Western Fold and Thrust Belt

Geographic Features

FR - Finisterre Range
NGH - New Guinea Highlands
HP - Huon Peninsula

Thrust fault (on land) or subduction zone (offshore); barbs are on upper plate; open barbs indicate fault is probably not active

Strike-slip fault; arrows show relative displacement

Spreading centre

Source: URS, 2005.
Note: Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

PNG LNG	Job No: 1284	Esso Highlands Limited	Geohazards study regional tectonic map	Figure No: 10.4
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The collision between the Australian and Pacific plates was initiated sometime between 55 and 34 million years ago, 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.

10.2.3.2 Regional Seismicity

Papua New Guinea's location over the converging Australian and Pacific tectonic plates means that it is seismically active.

The seismicity of the upstream project area is classified as Zone 3, which is moderate according to the Papua New Guinea building standards (PNGS, 1982). Figure 10.5 shows the location of all earthquakes recorded in the vicinity of Papua New Guinea from 1900 to 2008 and indicates that the upstream project components are located in an area in which seismic activity is generally less than that in other areas of Papua New Guinea.

Earthquakes off the north coast of Papua New Guinea in 1998 and 2002 resulted in tsunami activity along the northern coast of Papua New Guinea. The effects were devastating with many lives and villages lost and destroyed. Tsunami hazard zones in Papua New Guinea locate the upstream project area within Zone 3, classified as low frequency of a tsunami (University of Technology, undated).

A seismic hazard study was conducted as part of the 2005 PNG Gas Project (Geomatrix, 2005). It was discovered that active fault lines are present in the Kikori catchment, with a major fault in the vicinity of the Mubi River.

10.2.3.3 Implications

Although relatively quiet seismically by PNG standards, facilities in the upstream project area will need to be designed to withstand earthquake loadings.

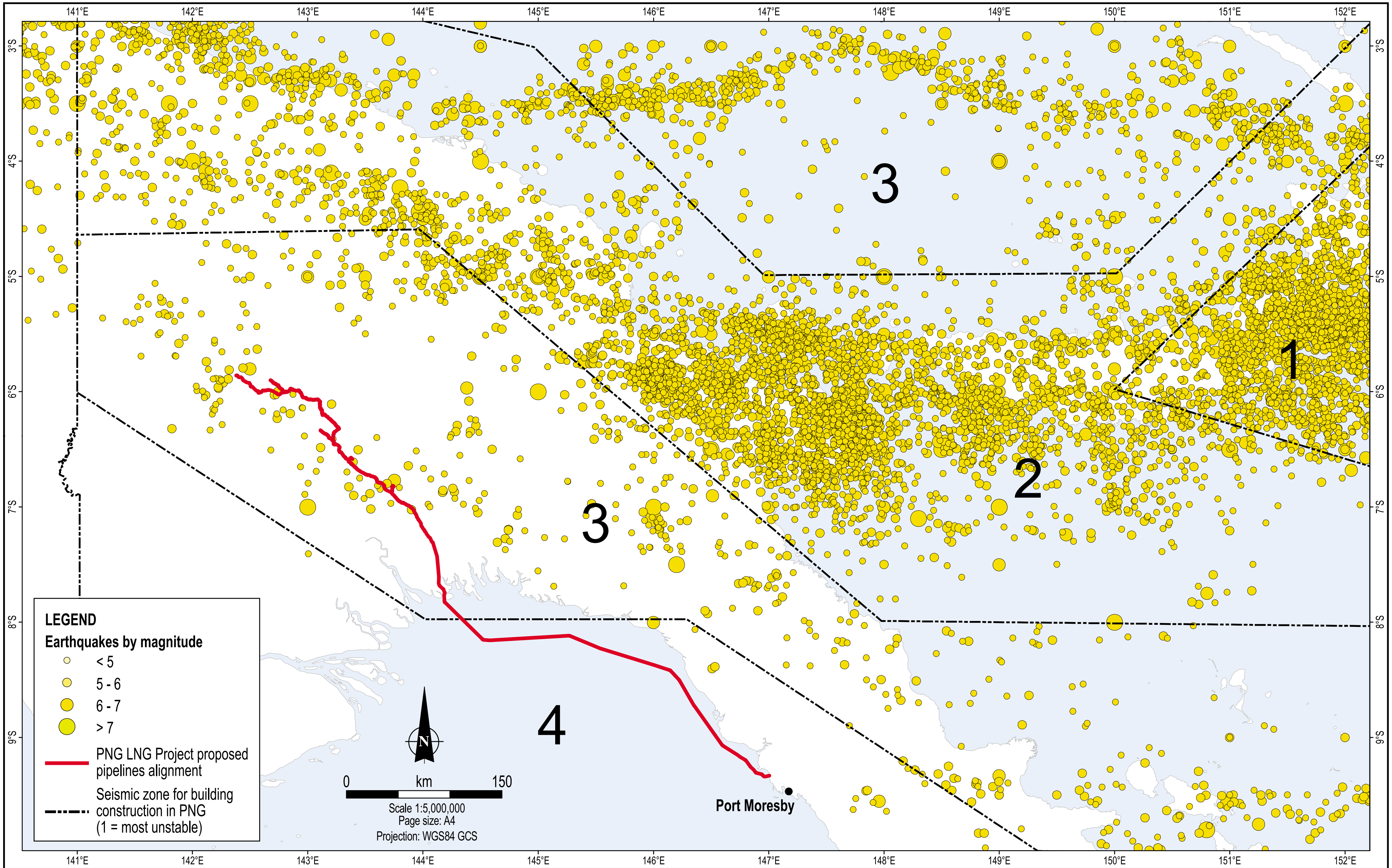
10.2.4 Geology and Hydrogeology

10.2.4.1 Geology

The proposed pipeline ROWs and roadways traverse the following four primary geological units, which are strongly representative of the physiography and geomorphology of the Kikori catchment and the Juha area (URS, 2005).

- Eocene to Miocene limestone.
- Miocene to Pliocene marine mudstones.
- Pleistocene volcanics.
- Holocene alluvium and colluvium.

The lithology and geology of the upstream project area is presented in Figure 10.6. The most extensive geological unit is limestone, which is a late Eocene to Miocene reef and bioclastic shelf carbonate. The strike ridges, anticlines and karstic landforms characteristic of the upstream project area are comprised of Darai Limestone.



Source:
Earthquake data from Geoscience Australia.

Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

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Earthquakes in the vicinity of Papua New Guinea (1900 to 2008)

Figure No: 10.5

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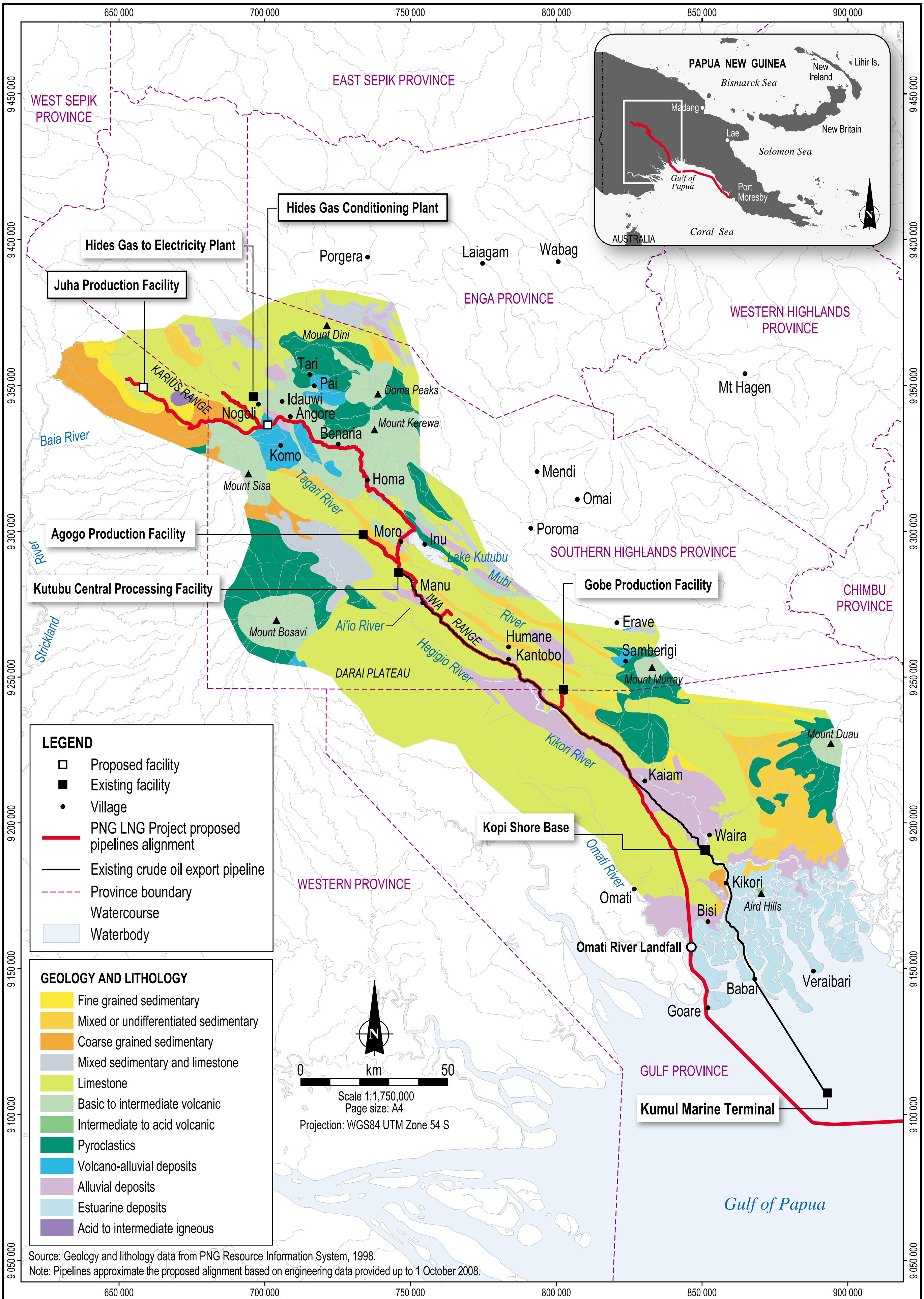

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Geology and lithology of the upstream project area

Figure No: **10.6**

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. Mount Kerewa, Mount Sisa and Mount Bosavi are located in the northwestern end of the upstream project area and Mount Murray and Mount Duau occur in the southeast (see Figure 10.6). These extinct or dormant volcanoes were responsible for the presence of a wide variety of basic to intermediate and intermediate to acid volcanic materials, including agglomerate, breccia and tuff, as well as extensive pyroclastic and volcanic alluvial deposits that form apron and valley fill deposits. The damming of its valley by volcanic ash and debris formed Lake Kutubu.

Pleistocene to Holocene sedimentary 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 and more extensively around the Juha area in the Western Province.

Alluvial deposits are largely found within the floodplain areas of the large rivers and, along with estuarine deposits, in the delta areas of the Kikori and Omati rivers.

10.2.4.2 Hydrogeology

Aquifers associated with karst terrain are expected to dominate the upstream project area. This makes for a complex hydrology, comprising many sinkholes and subterranean streams (Plate 10.3). These subsurface waters eventually emerge and augment the flows of surface waters, such as rivers and streams. Within the karst landscape, nearly all surface runoff is channelled directly or via short gully streams into sinkholes, with further runoff progress being subterranean. During major rainfall events, the sinkholes can flood rapidly, resulting in high inflows of water into the groundwater system, recharging the aquifers. The shallow soil profile of the terrain assists rapid recharge, apart from areas where significantly weathered limestone has formed low plasticity clays. It is probable that water overflow discharges back into the streams in flood recessions and is a very important source of stream flow during drier times of the year.

The movement of water through the limestone results in enlargement of bedding planes, faults and fractures, resulting in highly permeable aquifers with secondary porosity. The solutional enlargement of porosity results in the landscape that is typical of karst terrain.

It is expected that groundwater velocities within karst terrain are relatively high and that water quality is good with low salinity concentrations and slightly alkaline conditions (Appendix 6, Groundwater Impact Assessment). Examples around the world show that groundwater supply potential from karst aquifers is highly prospective.

10.2.4.3 Implications

The implications of the geology of the project area are discussed in Section 10.2.2, Landforms.

The hydrology of karst, with its underground streams and generally rapid groundwater flows, means that drilling fluid returns will be lost when new wells are being developed in these rock types.

10.2.5 Soils

10.2.5.1 Soil Types

Soil types within the upstream project area have been categorised as soil orders, as shown in Figure 10.7. The soil orders found within the path of the upstream project facilities are:

- **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 existing crude oil export pipeline ROW and the proposed LNG Project Gas Pipeline ROW between Gobe via Kopi to the Omati River Landfall.

- **Inceptisols.** Well-drained, very permeable soils with weakly developed subsurface horizons. This soil order occurs along the proposed ROW for the Hides–Kutubu Condensate Pipeline, and the LNG Project Gas Pipeline ROW between Homa and Angore where volcanic soil types prevail, and along a large percentage of the Juha–Hides pipeline ROW.

- **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 Processing Facility and Gobe, along the Agogo Gas Pipeline ROW from Kutubu to Agogo and also a section of the Juha–Hides pipeline ROW leading to the Juha Production Facility.

- **Alfisols.** Moderately weathered soils with an argillic horizon (a layer within the soil profile with higher clay content due to the movement of clay form the top to lower levels). This soil order occurs around Juha in areas of flat slope and ridges of less than 1,000 m (Appendix 8, Soils and Rehabilitation Impact Assessment)[1].

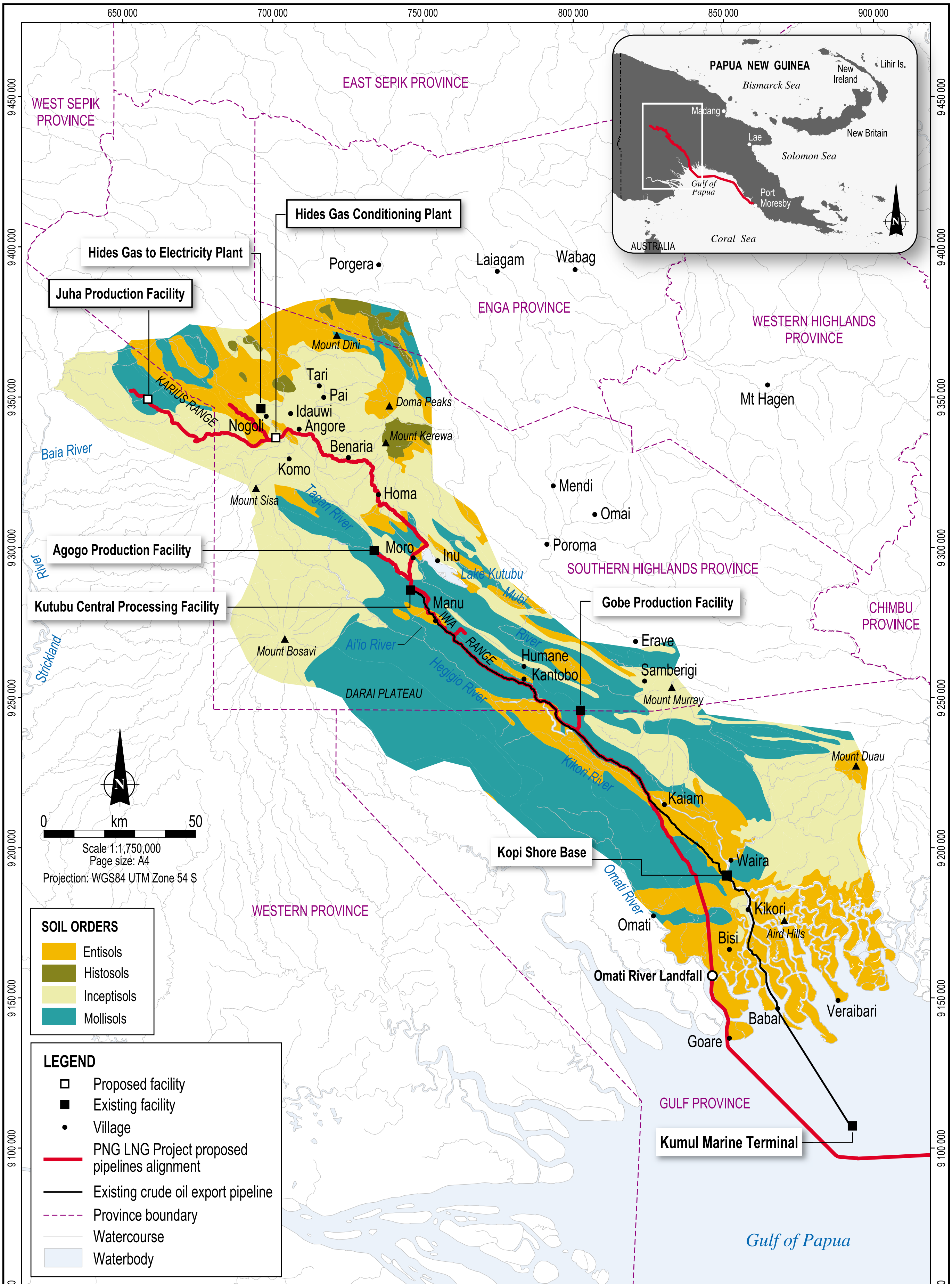
Histosols, which are soils comprised primarily of organic materials, exist in patches in the northern highlands around Mt Kerewa and Hides, but not within the path of the upstream project facilities.

Other more specific soil observations in the upstream project area include the following:

- A thin layer of terra rossa soil over hard and weathered limestone rock is found on the ridgeline and steep slopes of 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 Processing Facility and the Ai'io River and on the steep slopes north of the confluence of the Mubi and Hegigio rivers.

[1] This soil type has not been mapped in the PNGRIS information, possibly because PNGRIS tentatively identifies soil bases on broad scale 1: 50,000 mapping. For each soil-mapping unit, PNGRIS identifies up to three soil groups. Any soil occurring in less than 20% of a mapping unit is not listed (Booyong Forest Science, 2005).



Source: Soil orders data from PNG Resource Information System, 1998.
Note: Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.

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- 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 (Wage and Tibi creeks).
- Soils of the Kikori and Omati rivers 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 horizon high in organic matter. The subsoil is dark-brown or dark yellowish-brown silty clay loam or silty clay.

10.2.5.2 Implications

The soils of the upstream project area are generally able to support natural regrowth, although the skeletal organic soils on limestone pavement limit the size and longevity of trees (Plates 10.4 and 10.5). These areas will be a priority for rehabilitation as discussed in Section 18.2.4, Residual Impact Assessment.

10.2.6 Climate

The climate of the upstream project area is under the seasonal influence of the northwest monsoon (December to March) and the southeast trade winds (May to October). Both seasonal systems bring copious amounts of rain, mainly across the Kikori catchment, with mean annual precipitation rates in excess of 3,500 mm.

10.2.6.1 Rainfall and Humidity

Rainfall distribution varies over the upstream project area, with high falls being recorded along the coastal plain and lower falls in the high altitude areas. Figure 10.8 shows mean monthly rainfall across these differing altitudes.

Hides Ridge

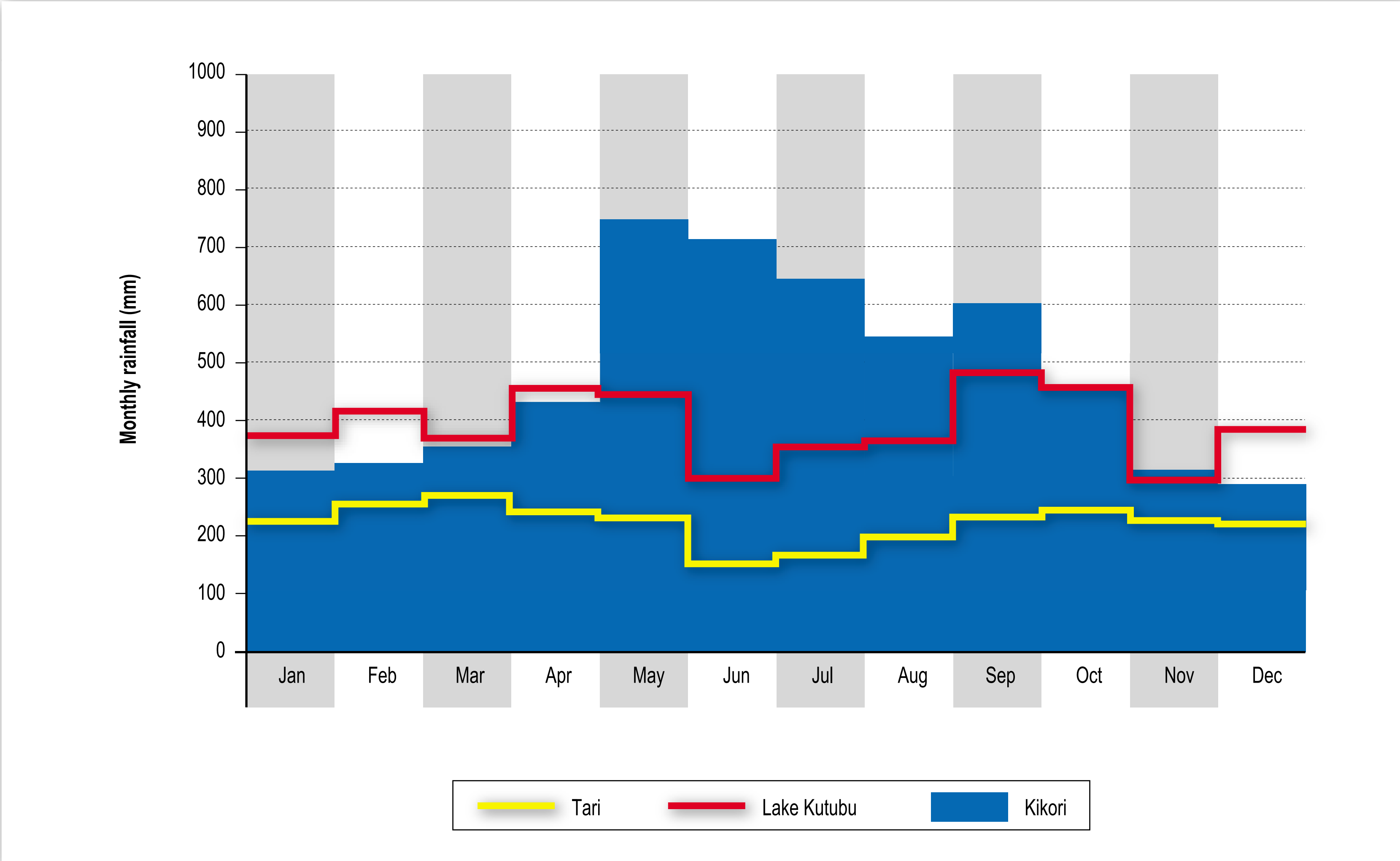
Mean annual rainfall at Tari, the nearest pluviograph station to Hides Ridge, is approximately 2,560 mm, with a maximum 24-hour rainfall of 120 mm. Mean monthly rainfall is consistent over the monsoonal season, with a drop in falls in June and July.

Humidity is generally high all year round, with mean relative values between 73% and 84%.

Plate 10.4
Limestone pavement and thin root mat of fallen trees

Plate 10.5
Wind-thrown patches of forest

Plate 10.6
Example of the unstable banks of the Baia River



Job No: 1284	Esso Highlands Limited	Mean monthly rainfall at Tari, Lake Kutubu and Kikori	Figure No: 10.8
File Name: 1284_09_F10.08 _HB	PNG LNG Project		

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, vegetation of 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. Mean monthly rainfall peaks occur in April and May and in September and October.

Humidity is consistently high throughout the year, with mean monthly values of between 85% and 90% at 9.00 a.m. and between 70% to 80% at 3.00 p.m.

Coastal Plain

In the lowland coastal plain at the town of Kikori, mean annual rainfall is 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.

Humidity is consistently high, with mean monthly values throughout the day of between 82% and 92%.

General meteorological data for the project area is given in Table 10.1.

Table 10.1 Meteorological data for the upstream project area

Feature	Hides 1 Well	Hides Gas Plant	Agogo Production Facility	Kutubu Central Processing Facility	Gobe Production Facility	Gobe Camp	Kopi	Omati River Landfall
Altitude and Barometric Pressure								
Altitude (m)	2,740	1,207	812	910	559	54	12	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

Table 10.1 Meteorological data for the upstream project area (cont'd)

Feature	Hides 1 Well	Hides Gas Plant	Agogo Production Facility	Kutubu Central Processing Facility	Gobe Production Facility	Gobe Camp	Kopi	Omati River Landfall
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

10.2.6.2 Wind

In the upstream project area, the wind regimes of the coastal plain differ from those in the mountainous hinterland.

Mountain Area

The southeast trade and northwest monsoon seasonal winds affect the mountains of the upstream project area. The higher winds experienced during the northwest monsoon season are accompanied by rain and thunderstorms. 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.

Coastal Plain

Southeast trade and northwest monsoon seasonal winds also affect the coastal plain, including the Omati–Kikori delta. During the southeast trade winds season, variable winds bring copious amounts of rain to the delta. Higher waves are also experienced during the southeast trade winds 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 (Enesar, 2005).

10.2.6.3 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 catchment 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, prior to the drought; it was 787 mm. Rainfall figures returned to expected levels of 717 mm after the drought in August 1988 (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).

10.2.6.4 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. They are therefore unlikely to reach land in Papua New Guinea.

10.2.6.5 Implications

The heavy and consistent rainfall of the upstream project area has been the main agent of the geomorphology and erosional and depositional landforms of the project area and of the prolific vegetation growth and cover. At the same time, droughts do occur, with frosts at higher altitudes. Droughts create the conditions for wildfires to burn uncontrolled, and have been the main cause of the extensive areas of fire disclimax grassland vegetation in Papua New Guinea. The management of project ignition sources and of fires spreading from adjacent areas will need to be a project mitigation priority (see 'Residual Impact of Fire' in Section 18.7.4.2, Indirect Impacts on Habitats, Flora and Fauna During Construction and Operations).

10.2.7 River Systems and Hydrology

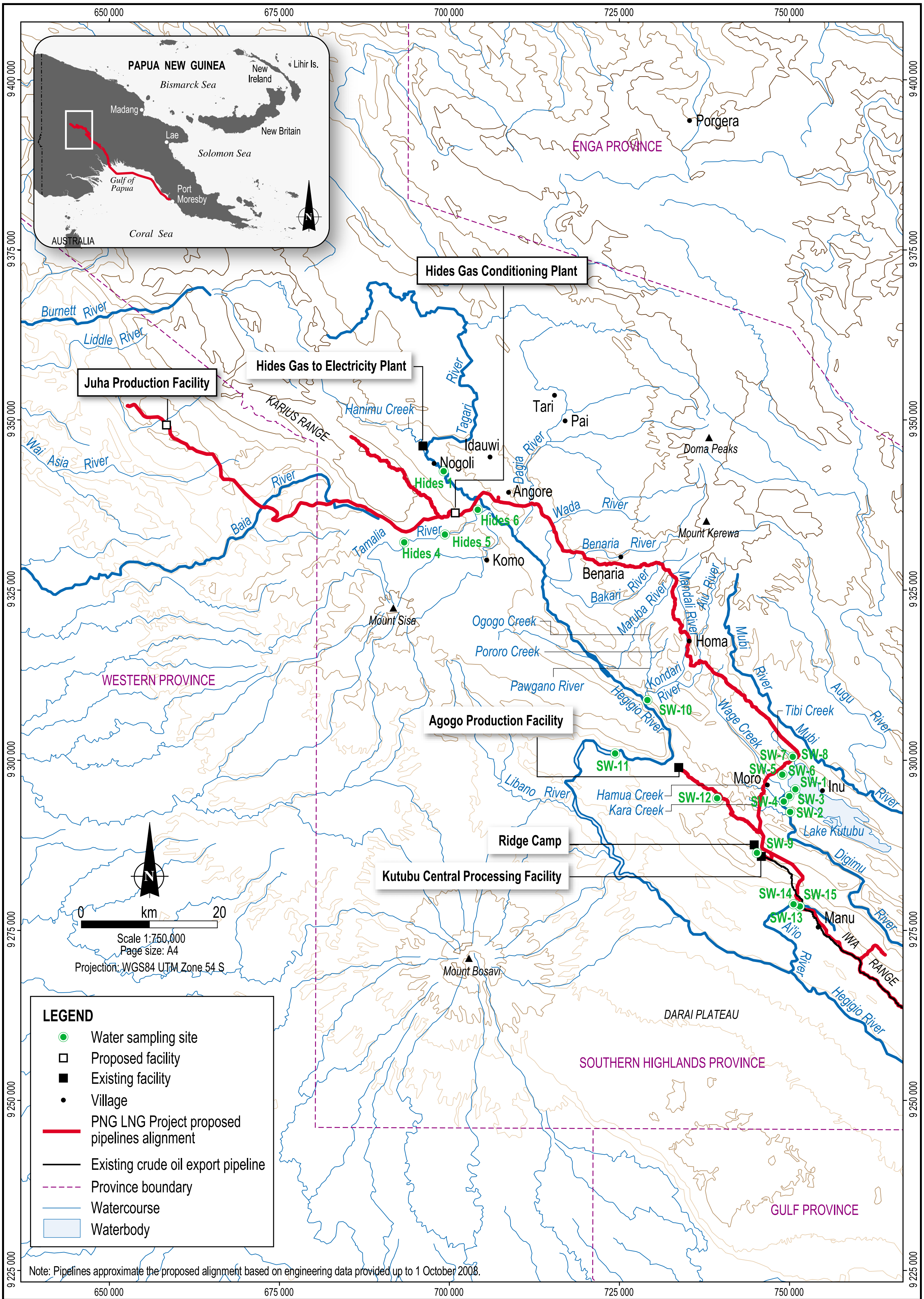
The upstream project area includes the Baia (which is a tributary of the Strickland River), Kikori and Omati river systems. The rivers and most streams within these systems are perennial, except during severe El Niño-Southern Oscillation droughts when smaller streams can dry up. Natural flow regimes of the river systems are dominated by surface runoff, which causes many rivers to have flow rates that increase sharply in response to regional rainfall. Figures 10.9 and 10.10 show the drainage system of the upstream project area.

10.2.7.1 Baia River System

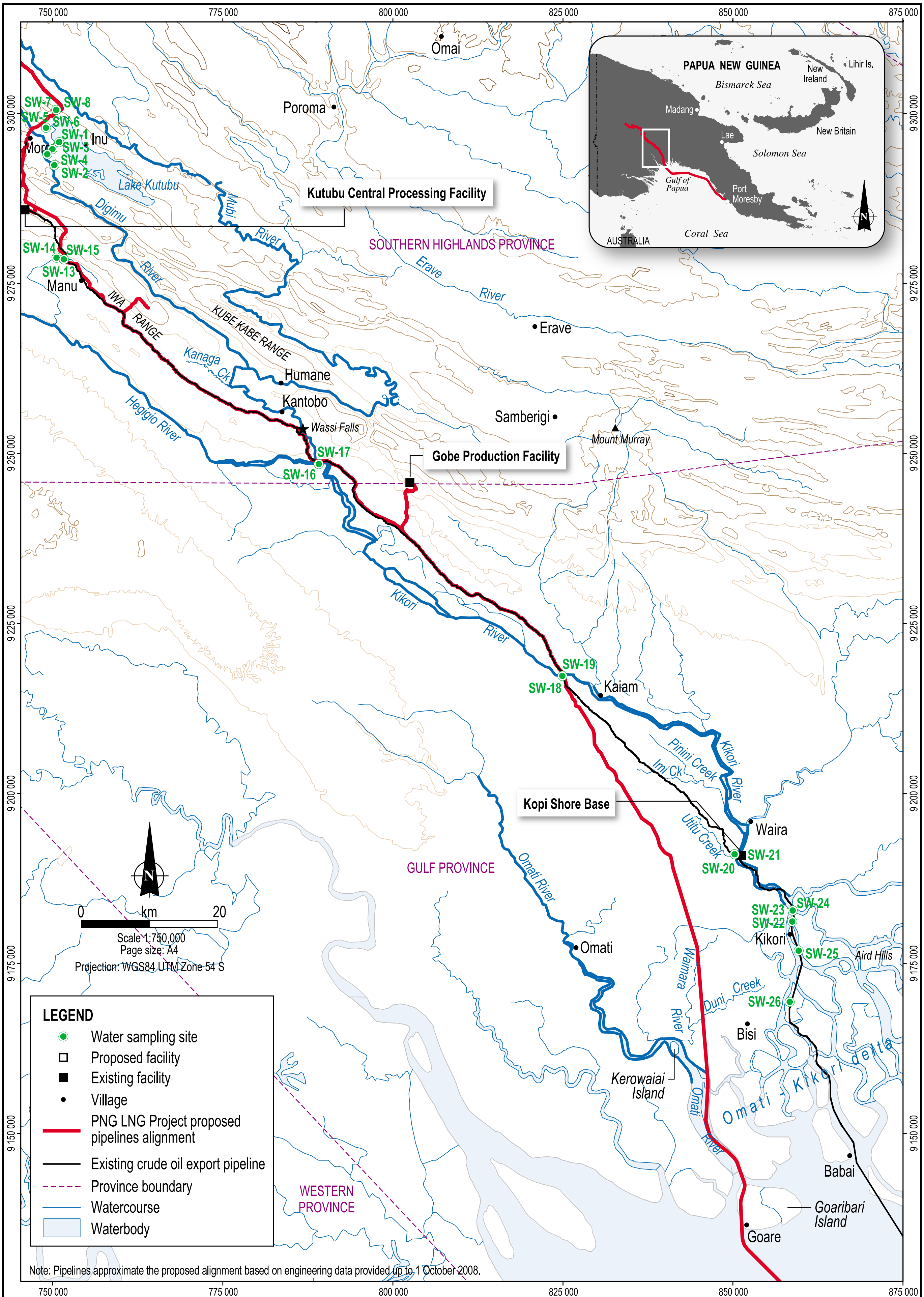
The Baia River flows north–south to the west of the Juha Production Facility. It is a partly confined channel with isolated floodplain pockets, dictated largely by the surrounding geology. Flow velocities are directly related to slope conditions of the river, with high velocity upstream at a slope of 0.0033 m/m (0.19° drop), and low velocity downstream where slope markedly decreases. The channel consists of high banks that are very unstable at many locations and are composed of a coarse fragment matrix surrounding non-consolidated fines that add to this instability (Plate 10.6). The river's unstable banks contribute high amounts of sediment to this naturally turbid river. Floodplain pockets to be crossed by the ROW within the Baia catchment have similar composition to the Baia River bank sediment composition.

The main channel width varies considerably between approximately 30 and 100 m, depending of the degree of confinement. The substratum of the riverbed consists of sands, gravel to cobble and large boulders.

The mean daily flow of the Baia River is estimated to be 156 m^3/s. Mean daily flows recorded monthly show little variation between seasons. Surface runoff dominates the river's natural flow regime.



PNG LNG	Date: 02.12.2008 MXD: PNG_LNG_Project_GIS.mxd File Name: 1284_09_F10.09_GIS_HB	Esso Highlands Limited PNG LNG Project	Drainage in the upstream project area (north)	Figure No: 10.9



PNG LNG	Date: 13.10.2008 MXD: PNG_LNG_Project_GIS.mxd File Name: 1284_09_F10.10_GIS_HB	Esso Highlands Limited PNG LNG Project	Drainage in the upstream project area (south)	Figure No: 10.10

The Karius Ridge area is the source of the headwaters of the Baia River, where the velocity is greatest and the water is colder and clearer.

10.2.7.2 Kikori River System

The Kikori River system is 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 River delta has remarkably few oxbows for a river of its size.

The high, median and low flows of the Kikori River at Kaiam are respectively 4,414 m^3/s (10% exceedence), 2,531 m^3/s and 670 m^3/s (90% exceedence).

The Kikori catchment comprises three subcatchments that are crossed by the pipeline ROWs. These are the Tagari–Hegigio subcatchment, the Lake Kutubu–Digimu–Mubi subcatchment, and the Kikori subcatchment.

Tagari–Hegigio Subcatchment

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 (see water sampling sites SW-16/SW-17 on Figure 10.10). At this point the Kikori River commences.

The Tagari River main channel varies in width (more than 100 m wide in parts) and experiences high velocities and highly turbid flow. The river is situated in a narrow floodplain, bounded by steep valley sides that restrict lateral movement of the main channel. Sinuosity of the river is variable, being somewhat dictated by the geology of the area. At the point of the ROW crossing, sinuosity was recorded at 1.36, and downstream of the crossing sinuosity was 1.3 (Appendix 4, Hydrology and Sediment Transport Impact Assessment). Riverbank sediments generally comprise silty sands or sandy clays with a matrix of cobble, and riverbank height is variable depending on sediment type and the channel's position in association with the valley sides. The substratum of the main channel bed consists of sands, gravel to cobble and large boulders.

The mean daily flow of the Tagari River is estimated to be 166 m^3/s. The river is perennial and can be affected by the December to March monsoon. However, mean daily flows recorded monthly show little variation between seasons. Surface runoff dominates the river's natural flow regime.

Field investigations (Appendix 4, Hydrology and Sediment Transport Impact Assessment) identified frequent undercutting and erosion of steep riverbanks and cliffs of rock and colluvium, resulting in sediment inputs directly to the river from both fluvial erosion and mass failures (Plate 10.7). Soil erosion also occurs in the vicinity of the river, and eroded sediments are transported towards the river via rainwater runoff.

Plate 10.7
Example of active bank failure along the Tagari River

Plate 10.8
Hegigio Gorge

Plate 10.9
View of Lake Kutubu

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 Mount Kerewa.

A tributary of the Hegigio River, the Ai'io River, drains the southern slopes of the Iwa Range. A section of the LNG Project Gas Pipeline will cross this river northwest of Manu (see Figure 10.9).

The mean flow of the Hegigio River just upstream of the Hegigio Gorge (Plate 10.8) is estimated to be 740 m^3/s for a catchment area of 3,600 km^2 (NEC, 2004).

Lake Kutubu–Digimu–Mubi Subcatchment

This subcatchment comprises Lake Kutubu, the Digimu River (which drains the lake) and the Mubi River of which the Digimu River is a tributary.

Lake Kutubu (Plate 10.9) is the largest perched lake 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 & Totome, 1992).

The lake is of volcanic origin and lies within karst terrain. It was formed originally as a result of volcanic-derived debris and ash blocking the valley in which it now lies. Fertile soils occur in the lake's catchment where volcanically derived soils have been 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. 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 level of Lake Kutubu is 800 m ASL. It is about 70 m deep with a thermocline of between 1.6 and 3 C° at depths of between 10 m and 30 m. There is a pronounced chemocline with elevated soluble reactive phosphorus and ammonium-, nitrite- and nitrate-nitrogen and very low levels of dissolved oxygen in the hypolimnion.

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 (see Figure 10.10) 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 Kube 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.

Discharge in the Digimu River has not been systematically gauged, but Rooke (1988b) 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 (Enesar, 2005)

Kikori Subcatchment

The Kikori subcatchment refers to the catchment of the Kikori River proper, which commences at the confluence of the Hegigio and Mubi rivers (see water sampling sites SW-16/SW-17 on Figure 10.10). (Note that the Kikori subcatchment should not be confused with the Kikori catchment, as the latter refers to the entire catchment of the Kikori River system.)

The Kikori River receives flows from numerous tributaries along its floodplain reach. The larger ones of these are the Utitu and Pinini creeks, which are crossed by the existing crude oil export pipeline ROW.

The lower reaches of this subcatchment are characterised by fluvial plains and fans and are part of the complex delta system, including the Omati River and Fly River. The dominant process of the lower reaches of the Kikori is accretion, which occurs episodically in response to runoff events, elevated sediment loads (e.g., from landslip) and channel changes. The sediment from the catchment is progressively sorted and deposited downstream as flow energy decreases, creating a myriad of channels and islands that form the delta system further south.

The safety issues of laying a second pipeline within the confines of the Kikori River have taken the proposed route of the pipeline outside the Kikori catchment west of Kaiam and into the drainage of the Omati River system at the Waimara River and Duni Creek area.

10.2.7.3 Omati River System

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. Despite these difficulties, the catchment area of the Omati River has been estimated to be 1,600 km^2 (Moroka, 2005). Elevations in the upper catchment area are around 600 m.

In the lower Omati River downstream of the proposed LNG Project 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 is 2.3 m, the highest astronomical tide is 4.9 m, the lowest astronomical tide is 0.0 m, and the tidal range is about 5 m (Enesar, 2005).

The lower Omati River is highly turbid, 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 riverbed overlain by a nepheloid layer of very fine suspended sediments (PMG-MHS, 1997). The nepheloid layer 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.

Discharge in the Omati River has not been systematically gauged, but estimated mean flow adjacent to the Omati River Landfall site is 243 m^3/s.

10.2.7.4 Implications

The hydrological implications of developing the project in the upstream project area are discussed in Section 10.2.8, Water Quality).

10.2.8 Water Quality

PNG environmental water quality guidelines are provided in Schedule 1 of the Environment (Water Quality Criteria) Regulation 2002 and outline the water quality criteria for protection of freshwater aquatic life. Any discharges to water associated with the project will be regulated under the PNG *Environment Act 2000* and require an Environment (Waste Discharge) Permit.

10.2.8.1 Previous Studies and Historic and Baseline Data

Monitoring of streams within the Kikori catchment 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 subcatchments. Sampling sites are identified in Figures 10.9 and 10.10.

Additional data is provided for the Tamalia and Tagari rivers (which are headwater tributaries of the Hegigio River) in the Environmental Baseline Report prepared for the Hides 4 Appraisal Well (NSR, 1997a). Data for the Ai'io River (which drains to the Hegigio River approximately 10 km northwest of Sisibia) and Wage Creek (which drains to Lake Kutubu) is also available from the Moran Project Environmental Assessment Report (NSR, 1997b).

Appendix 5, Water and Sediment Quality Impact Assessment, provides water quality baseline data for the Baia River and Karius Ridge areas, Juha area, Lake Kutubu, Kikori River system and lower Omati River.

10.2.8.2 General Riverine Water Quality

Baia River and Karius Ridge Areas

Water quality data for the Baia River and headwater streams draining the Karius Ridge area is given in Table 10.2. Metal concentration data is presented separately in Appendix 5, Water and Sediment Quality Impact Assessment.

Table 10.2 Water quality of the Baia River and Karius Ridge area

Date	Location	Site	Stream Type	pH	Temp[1]	Turb[2]	ORP[4]	SAL[5]	DO[6]	Cond[7]
					(°C)	(NTU)[3]	(mV)	(ppt)	(%sat)	(µS/cm)
14/2/08	Baia River area	BAI4	Tikawe Creek	8.05	21.6	156.9	315	0.03	98.4	0.0933
13/2/08	Baia River area	BAI4	Tikawe Creek	8.09	22.8	47.2	324	0.04	97.8	0.965
14/2/08	Baia River area	BAI5	Baia River	8.16	21.46	236.1	309	0.04	98.7	0.1031
12/2/08	Baia River area	BAI1	Baia River	8.09	21.8	81.3	337	0.09	98.7	0.1904
14/2/08	Baia River area	BAI1	Baia River	8.28	21.03	635	290	0.06	99.4	0.1325
14/2/08	Baia River area	BAI6	Baia River	8.24	22.02	362.3	313	0.07	99.8	0.1562
13/2/08	Baia River area	BAI2	Swamp	7.43	24.28	0	335	0.19	26.6	0.3864
14/2/08	Baia River area	BAI7	Forest stream	8.34	23.43	0	316	0.13	95.4	0.2674
14/2/08	Baia River area	BAI8	Forest stream	8.09	24.38	0	321	0.09	91.4	0.2045
21/2/08	Karius Ridge area	KAR1	Baia River headwaters	8.16	18.3	0	343	0.07	84.4	0.1636
21/2/08	Karius Ridge area	KAR2	Baia River headwaters	7.38	19.22	0	217	0.02	83.1	0.0745

[1]Temperature. [2]Turbidity. [3]Nephelometric turbidity units. [4]Oxidation-reduction potential. [5]Salinity. [6]Dissolved oxygen. [7]Conductivity.

Source: Appendix 5, Water and Sediment Quality Impact Assessment.

The Baia River main channel (site BAI1) was sampled on two occasions, once at a time of moderate flow (12 February 2008) and once after substantial rainfall (14 February 2008). Turbidity at the moderate flow was 81.3 NTU and that at high flow was 635 NTU, demonstrating the linkage between rainfall and sediment input in this system. Other sampling sites along the Baia River main channel also showed high turbidity following rainfall.

Samples taken from two headwater streams (sites KAR1 and KAR2) of the Baia River that drain the Karius Ridge area indicate the presence of colder and clearer waters with very low turbidity. The two watercourses sampled in this area showed differences in pH and conductivity, most probably reflecting the differing geologies in the catchment headwaters.

The swamp (site BA12) recorded very low dissolved oxygen concentrations (26.6% saturation) and low pH (pH 7.4), which represent more reductive conditions than other sites in the area.

Waters in the Baia River and KAR1 sampling area are considered to be of karstic origin with high levels of calcium and alkalinity. Dissolved metals levels are relatively low, generally below the limit of reporting (see Appendix 5, Water and Sediment Quality Impact Assessment).

Juha Area

Surface waters within the Juha area consist primarily of typical forest-shaded perennial streams and short streams that terminate in sinkholes. The water qualities of these two stream types are given in Table 10.3.

The typical forest-shaded streams generally have a neutral pH and lower conductivity than the sinkhole streams. Both stream types are well oxygenated and have low levels of turbidity and salinity.

The major anions and cations within the water column of both stream types are low. However, water samples from the sinkhole streams were observed to have higher pH, alkalinity and conductivities (associated with higher levels of calcium and calcium carbonate) than those of the typical forest-shaded streams. These waters are referred to as 'karstic' waters because of the elevated levels of dissolved limestone (as calcium carbonate).

Dissolved metal concentrations in the streams of the Juha area are given in Appendix 5, Water and Sediment Quality Impact Assessment. All dissolved metal concentrations were low and below their analytical reporting limits, with the exception of manganese, iron and aluminium. The highest concentration of manganese (0.011 mg/L) was recorded in one of the sinkholes (JUH3), but it was still well below the stipulated guideline limits of 0.5 mg/L in the *PNG Environment Act 2000* and 1.2 mg/L in ANZECC/ARMCANZ (2000) for the protection of 99% of aquatic species. Iron and aluminium levels were higher in the typical streams, with JUH2 having the highest level of iron at 100 mg/L, and JUH6 having aluminium levels higher than the 95% protection limit of ANZECC/ARMCANZ (2000).

Nitrogenous compounds were detected at JUH2 and JUH6 mostly in the form of ammonia and total Kjeldahl nitrogen (TKN), a measure of organic nitrogen and ammonia, but occurred at low levels. Total organic carbon (TOC) is also at low levels across all sample sites.

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). Clarity within the water column was recorded using secchi disc depth readings (depths at which the secchi disc disappears from view in the water column). These 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 of the lake and a low phytoplankton biomass as a consequence and, secondly, to the low and ephemeral TSS loads of inflowing streams (water sampling sites SW-5/SW-6 and SW-7/SW-8). The largest of these streams, Wage Creek, enters the northwest end of the lake after passing through extensive marshes and swamp forest where reduced water velocities settle out entrained solids.

Table 10.3 Water quality of streams in the Juha area

Date	Location	Site	Stream Type	pH	Temp[1] (°C)	Turb[2] (NTU)[3]	ORP[4] (mV)	SAL[5] (ppt)	DO[6] (%sat)	Cond[7] (µS/cm)	Alk[8] (mg/L)	Cations				Anions				
												Ca	Mg	Na	K	HCO_3[9]	SO_4	Cl	NO_3	PO_4
												(mg/L)								
19/2/08	Juha area	JUH2	Typical	6.85	20.62	0	332	0	76.1	0.0277	17	4	1	1	1	17	1	1	0.3	0.01
18/2/08	Juha area	JUH3	Sinkhole	7.85	20.32	0	357	0.07	85.4	0.1592	84	30	3	1	1	84	2	6	0.1	0.01
18/2/08	Juha area	JUH5	Sinkhole	7.98	20.39	0	345	0.05	89.7	0.1265	61	24	1	1	1	61	4	3	0.1	0.01
19/2/08	Juha area	JUH6	Typical	7.23	20.12	0	369	0	86.4	0.0227	17	4	1	1	1	17	1	1	0.2	0.01
20/2/08	Juha area	JUH8	Typical	6.80	20.14	0	371	0	80.8	0.0222	14	3	1	1	1	14	1	1	0.1	0.01
22/2/08	Juha area	JUH9	Typical	7.91	20.54	0	327	0.04	89.7	0.1085	14	3	1	1	1	14	1	2	0.1	0.01

[1]Temperature. [2]Turbidity. [3]Nephelometric turbidity units. [4]Oxidation-reduction potential. [5]Salinity. [6]Dissolved oxygen. [7]Conductivity. [8]Total alkalinity as $CaCO_3$. [9]Bicarbonate alkalinity as HCO_3.

Source: Appendix 5, Water and Sediment Quality Impact Assessment.

Osborne and Totome (1992) identified a thermocline between the 10-m and 25-m water depth. Above this thermocline, dissolved oxygen levels were high; 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.

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 & Totome, 1992). Although Lake Kutubu's stratification appears to be generally stable, the lake does equilibrate and mix from time to time. The frequency of major turnovers appears to be at intervals of between 10 and 20 years, but minor upwellings are more common. Reportedly, the upwelling does not affect the entire lake but only areas corresponding to the deepest parts. The episodes of mixing and upwelling follow droughts in the highlands, where frosts under clear night skies cool the surface waters and eliminate the thermocline. Anoxic bottom waters well up, causing water discoloration and an unpleasant smell, massive fish deaths by asphyxiation and an influx of birds feeding on the dead fish.[2] The upwelling of nutrients into the epilimnion also triggers phytoplankton blooms (Osborne & Totome, 1992).

Kikori River System

The main channel water quality of the rivers of the Tagari–Hegigio and Lake Kutubu–Digimu–Mubi subcatchments are typical of other 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^{-}) (Table 10.4). These constituents 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, 1997b).

[2] There are various reports of the frequency of lake mixing and upwelling. The web page at Aquatic Community (undated) says that there is 'massive upwelling' every two years, but the Kutubu Petroleum Development Project Environmental Plan (NSR 1990) questioned the local people on this issue and found that it had been 12 years since the previous turnover in 1978 (with no reports of upwelling during the drought of the early 1980s), Totome and Osborne (1999) reported upwellings in 1960 and 1990 (after cold weather) and Trevor Shearson's novel *White Lies* (1977) introduces a dramatised account of a turnover with two Kutubu men talking: 'We (have) both (seen it), when we were little boys…'. Shearson had lived at Lake Kutubu and does not seem to be implying that the last turnover had been less than two years earlier. In other words, there seem to have been larger episodes of upwelling in Lake Kutubu in 1960, 1978, 1990 and 1998 and a number of minor ones.

Table 10.4 General water quality of upstream project area rivers in the Kikori River catchment

Site	Site Description	N*	pH	Conductivity (µS/cm)	Hardness* (mg/L)	Turbidity (NTU)	TSS*	TDS*	Alkalinity	Cation (mg/L)			Anions (mg/L)					
										Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	PO_4
Streams in Tagari River Catchment †																		
Hides 1	Tagari River	1	8.2	260	140	-	12	-	140	47	5.5	1.1	0.36	-	2.0	0.75	-	-
Hides 4, 5 and 6	Tamalia River	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																		
SW-10#	Upper Hegigio River (immediately d/s of Kondari River)	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
SW-11#	Upper Hegigio River (approx. 22 km d/s of SW10)	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	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 #																		
SW-5/SW-6	Wage Creek	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
SW-7/SW-8	Tibi Creek	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 #																		
SW-1	Lake Kutubu outlet	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
SW-2	Doromora Creek	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
SW-3	Hamua Creek	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
SW-4	Kara Creek	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
SW-14/SW-15	Ai'io River	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 10.4 General water quality of upstream project area rivers in the Kikori River catchment (cont'd)

Site	Site Description	N*	pH	Conductivity (µS/cm)	Hardness* (mg/L)	Turbidity (NTU)	TSS*	TDS*	Alkalinity	Cation (mg/L)			Anions (mg/L)					
										Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	PO_4
Streams Crossed by Kutubu Pipeline																		
SW-16/SW-17#	Mubi River	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
SW-18/SW-19#	Kikori River	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
SW-20/SW-21#	Utitu Creek	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
SW-22/SW-23#	Howoi Creek	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
SW-24#	Lower Kikori River	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
SW-25††	Lower Kikori River	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
SW-26††	Lower Kikori River	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

N = the number of TSS samples; the number of samples for other water quality parameters may vary from this number. TSS = total suspended solids. TDS = total dissolved solids.

** Reported as $CaCO_3$. NSR (1997b).

† NSR (1997a).

NSR (1991, 1992, 1993a, 1993b, 1994, 1995 and 1997c).

†† NSR (1991, 1992 and 1997c).

Water hardness in all rivers except the Aiu 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.

Trace metal concentrations in the rivers and streams were uniformly low (NSR, 1997a, b, d). 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 subcatchments are generally of low turbidity (less than 2 nephelometric turbidity units (NTU)), with correspondingly low concentrations of total suspended solids (TSS), which are generally less than 2 mg/L. However, the main channel of the upper Hegigio River is highly turbid with high total metal and 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 (water sampling sites SW-10 and SW-11) have been sampled.

Tributary streams in the lowland area of the Kikori subcatchment have higher TSS concentrations than tributary streams in the upper subcatchment 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 medians ranging between 20 and 43 mg/L at the three sampling sites SW-24, SW-25 and SW-26). Note that median TSS concentrations are lower at these three downstream sites than at the sites near Kaiam village (water sampling sites SW-18 and SW-19) 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 (water sampling sites SW-24 to SW-26) has been used. 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 indicates that prevailing turbidity and TSS concentrations in the Omati River could be significantly higher.

10.2.8.3 Implications

The climate and hydrology acting on the central cordillera of New Guinea has created the dynamic and complementary erosional and depositional landforms of the upstream project area.

Heavy rain, large rivers, high rates of weathering and erosion have removed large quantities of material from the highlands and deposited them in the sedimentary environments of the gulf lowlands. It is these processes that make containment of fugitive sediment difficult. At the same time, the sediment impacts of construction are an increment over what naturally occurs and, as has been noted in Section 10.2.2.6, Implications, if this process is finite, then the impacts too will be finite.

The surface waters of Lake Kutubu are of exceptional clarity. At the same time, the lake receives sediment from its major tributary, Wage Creek, which forms a bird's foot delta extending out onto the northwestern end of the lake. The lake also undergoes the infrequent but severe impact of major upwelling every 10 to 20 years. The implications for the PNG LNG Project are as follows:

- Fugitive sediment from construction is of finite duration and will mimic, and be an increment over, the normal catchment yield. It will in this respect be similar to historic roadworks in the catchment. Its effects can likewise be expected to be limited to the period of construction and shortly thereafter.
- The lake survives the infrequent but major perturbations of upwelling and is unlikely to be sensitive to fugitive sediments if the loading is small and the duration finite.

The Omati River feeds freshwater and sediment to a prograding delta. It is a dynamic sedimentary environment and is therefore unlikely to be sensitive to the localised and transitory remobilisation of recently deposited sediments that the project will generate.

The water chemistry reflects unmineralised catchments, with alkaline waters and heavy metals present in low concentrations associated with particulate matter. The risk of metal mobilisation and toxicity from project-disturbed sediments is very low. Potential impacts on water quality in the upstream project area are discussed in Section 18.5, Water Quality.

10.2.9 Noise

Current noise levels within most of the upstream project area are expected to be low, as most of the proposed pipelines and facilities lie within remote environments. With a few exceptions around the existing oil and gas facilities, the pattern of population throughout this area of Papua New Guinea continues to be sparse. This is especially the case at Juha.

Noise monitoring and surveys were conducted in the Hides area at two locations close to the proposed project area in April 2008 to determine and characterise existing and ambient background noise levels.

The selected monitoring sites were:

- Residence A, Hides village, approximately 750 m west of the proposed Hides Gas Conditioning Plant site.
- Residence B, Hides village, approximately 1.2 km southwest of the proposed Hides Gas Conditioning Plant site.

In addition, a 24-hour period of background noise monitoring was conducted at a village in the Hides area in May 2005 as part of the noise impact assessment for the PNG Gas Project. This monitoring location was approximately 1 km to the northwest of the PNG Gas Project Hides

Processing Facility site, and is termed 'Hides: Historic' (see Appendix 10, Noise Impact Assessment).

The noises heard at the time of monitoring were mostly from birds and occasionally from domestic fowl. The sound of a distant river was present as a constant low-level background noise over a wide area and throughout the entire monitoring period. This noise was prominent at night when atmospheric conditions are more stable.

The monitoring results are presented in Table 10.5.

Table 10.5 Summary of ambient and background noise levels at Hides village

Location	Ambient Noise Level (dBA)^								
	Day (0700 to 1800)			Evening (1800 to 2200)			Night (1800 to 2200)		
	L_{90}	L_{10}	L_{eq}	L_{90}	L_{10}	L_{eq}	L_{90}	L_{10}	L_{eq}
Hides: Residence A	35	53	60	40	50	55	42	48	50
Hides: Residence B	38	54	57	42*	48*	51*	34	44	47
Hides: Historic#	43	47	50	45	51	48	46	50	48

^ For context, 30 dBA is considered equivalent to the level of noise inside a bedroom, 40 dBA to inside a private office, 50 dBA to inside a general office and 60 dBA to inside a department store.

Level estimated as entire period was strongly affected by local insect noise.

Results of Hides: Historic have been reprocessed since collection for the PNG Gas Project.

The results indicate that evening and night time background noise levels are generally higher than those during the day, and that the noise levels recorded from all sites were fairly consistent.

The background noise environment at all monitoring locations was similar in character, with natural sources (such as wind noise in foliage, insects, birds, periods of heavy rain and domesticated animals) and typical village activities being the main noise generators. A digital audio recorder was deployed alongside the noise logger to identify particular noise sources at night. The audio recordings indicate that high insect noise dominates the ambient noise environment during night hours. This is expected of the ambient environment all year as the tropical nature of the area, where there is little variation in temperature from season to season, supports a consistently high level of insect activity. While the prevalence and activity of individual insect species may vary slightly throughout the year, there is generally a consistently high level of overall insect activity all year round (Appendix 10, Noise Impact Assessment).

Operator-attended daytime surveys were also conducted at all background noise monitoring sites. The noise environment at all monitoring locations was generally similar in character, with the main noise sources being natural sources as listed above and typical village activities.

Ambient noise monitoring to date has been sufficient to enable target noise levels to be set and to model the ability of the project to meet those targets (see Section 18.9, Noise).

10.2.10 Air Quality

Ambient air quality monitoring data has not been conducted, because background air quality will reflect the virtually ubiquitous absence of industrial sources. Highly localised exceptions, albeit with very small zones of impact, are limited to the gas combustion emissions from the existing

Hides Gas to Electricity Plant and the petroleum processing facilities at Hides, Kutubu. Agogo and Gobe (see Appendix 9, Air Quality Impact Assessment).

10.3 Terrestrial Biological Environment

This section describes the onshore terrestrial biological environment of the upstream project area and environs and includes descriptions of data sources (Section 10.3.1), bioregions (Section 10.3.2), vegetation and flora (Section 10.3.3), terrestrial fauna (Section 10.3.4), conservation areas (Section 10.3.5), conservation status of flora and fauna (Section 10.3.6), and noteworthy areas of terrestrial biodiversity (Section 10.3.7). Appendix 1, Biodiversity Impact Assessment, incorporates the individual biodiversity specialist studies, plus an overview summary, and has been used as a basis for this section.

10.3.1 Data Sources

The Kikori catchment was, until the petroleum developments of the early 1990s, one of the biologically least known areas of Papua New Guinea. There had been only one systematic survey in the Kutubu area, which recorded birds and bats during a Commonwealth Scientific and Industrial Research Organisation (CSIRO) land survey in 1961. A few mammal specimens had been collected elsewhere in the Kikori catchment but no reptiles or frogs.

In 1994, the WWF and Chevron (on behalf of the petroleum joint venture participants) established the KICDP, now called the KRP (see Section 10.1, Introduction and Study Area and 'Commercial Agriculture' in Section 10.5.1.1, Agriculture, Gathering and Hunting). The WWF carried out a number of surveys through the 1990s between the Kikori River delta and the Kutubu Central Processing Facility. More recently, this work has been supplemented by:

- Studies for the PNG Gas Project between Lake Kutubu and the Hides gas field, with flora and fauna surveys at Hides, Benaria and Nogoli.
- Flora and fauna surveys for the PNG LNG Project in the Juha area.

The Kikori catchment is biologically now one of the best-known areas of Papua New Guinea.

The combined geographic scope of these studies covers the entire Kikori River catchment and extends westwards to tributaries of the Strickland River around Juha.

A combination of primary and secondary data has been used to obtain an understanding of the project area. Primary data sources include the studies completed for the PNG Gas Project (i.e., between Hides and Kutubu from 2005) and the PNG LNG Project (i.e., between Hides and Juha, and also the Homa Deviation from 2008). Secondary data includes the WWF survey work from 1990, and also literature reviews. These data sources are described in detail in Appendix 1, Biodiversity Impact Assessment.

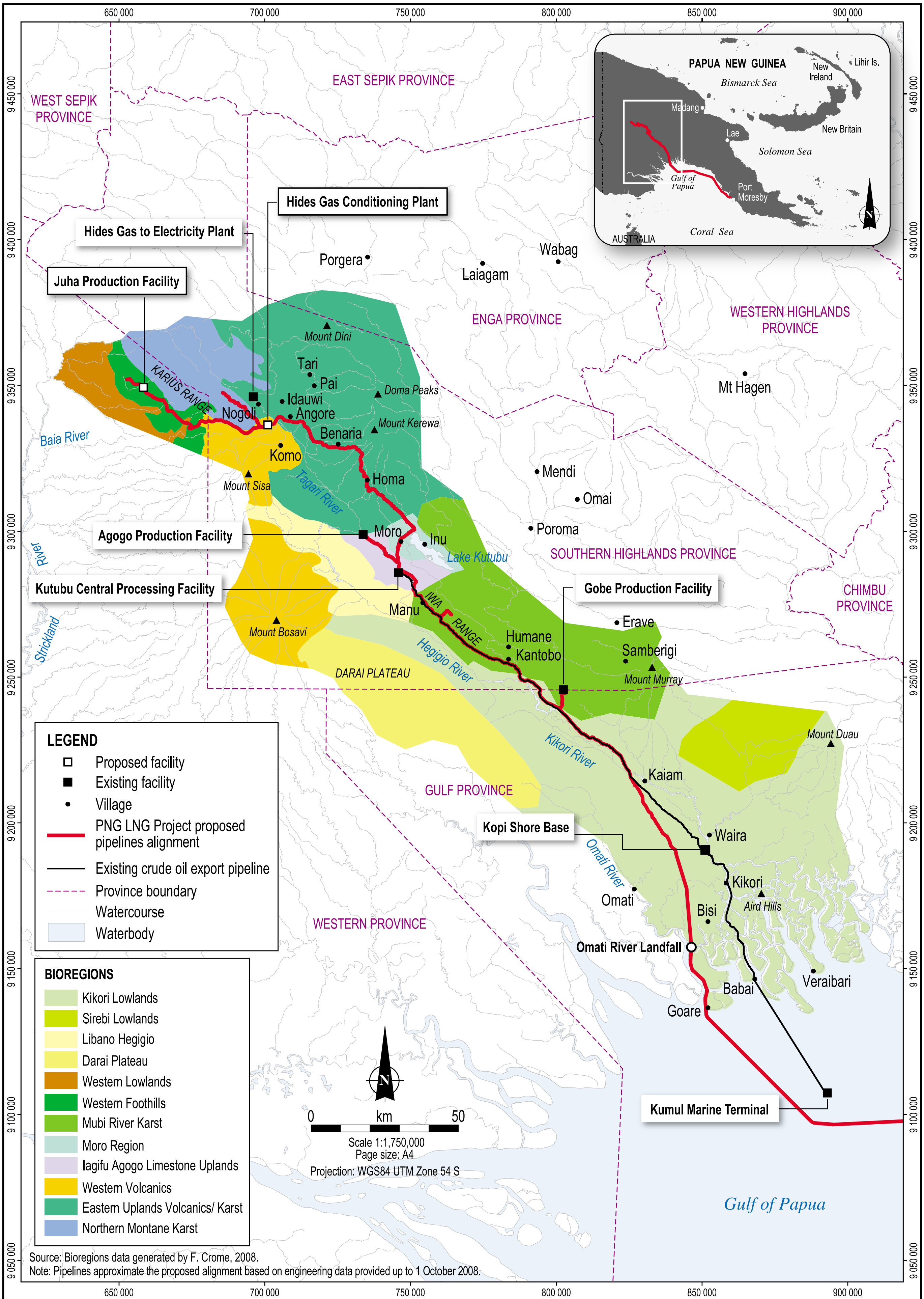
10.3.2 Bioregions

The upstream project area's physical diversity in terms of geology, topography, altitude, geomorphology and soils provides a highly heterogenous landscape with a correspondingly high habitat and biological diversity. The region is dominated by limestone, with volcanic rocks in the north. Altitude ranges from the Doma Peaks at 3,568 m ASL in the northeast of the KRP area to sea level on the coast at the head of the Gulf of Papua. The upstream project area reaches its highest elevation of around 2,800 m ASL at the Hides gas field.

Biota will generally reflect the physical habitat, so a framework of physiographically based bioregions has been adopted to deal systematically with this heterogeneous landscape (Table 10.6 and Figure 10.11). These bioregions have notional boundaries, with core features around the centroids blending with neighbouring bioregions near their respective boundaries.

Table 10.6 Bioregions of the upstream project area

Bioregion	Description
Kikori Lowlands	Floodplain of the Kikori River below about 200 m ASL consisting of limestone plateaus, karst plains and polygonal karst mangroves, swampland and some sedimentary hills.
Sirebi Lowlands	A complex lowland region in the southeast of the upstream project area in the drainage of the Sirebi River ranging from 40 m to 400 m ASL and consisting of mixed sedimentary hills, alluviums and polygonal karst and limestone ridges.
Libano Hegigio	Mixed sedimentary and limestone ridges and hills of the Libano and Hegigio rivers upstream of the Mubi–Kikori confluence ranging from approximately 200 m to 600 m ASL.
Darai Plateau	Rugged polygonal karst plateau from approximately 300 m to 1,100 m ASL.
Western Lowlands	Lowlands of the northern tributaries of the Strickland River between approximately 200 m and 400 m ASL consisting of sedimentary and limestone low hills and ridges. Some isolated hills rise to 700 m ASL.
Western Foothills	Western and southern foothills of the Karius Range from approximately 400 m to 1,200 m ASL consisting of mostly limestone ridges grading into sedimentary ridges in the southwest of the upstream project area.
Mubi River Karst	Karst and limestone plateaus from the Mubi River’s confluence with the Kikori River to Lake Kutubu covering most of the catchments of the Digimu and Mubi rivers. Elevation ranges from approximately 200 m to 1,300 m ASL.
Moro Region	The karst region around Lake Kutubu at about 800 m to 1,000 m ASL. Combined with the Iagifu Agogo Limestone Uplands bioregion for bird, reptile and frog surveys.
Iagifu Agogo Limestone Uplands	The high limestone and karst from about 1,000 m 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 bioregion for bird, reptile and frog surveys.
Western Volcanics	The Mount Bosavi and Sisa volcanic cones, plains and foot slopes and volcano-alluvial fans between approximately 280 m to 2,700 m ASL.
Eastern Uplands Volcanics/Karst	The upland region of mixed limestone and volcanic hills, ridges, cones and slopes in the northeast of the upstream project area, ranging from about 800 m to 1,800 m ASL.
Northern Montane Karst	The high limestone in the north of the upstream project area from 1,800 m to 3,268 m ASL that includes Karius Range, Hides Ridge and the high Levani Valley.



PNG LNG	Date: 5.09.2008	Esso Highlands Limited	Bioregions of the upstream project area	Figure No: 10.11
	MXD: PNG_LNG_Project_GIS.mxd			
	File Name: 1284_09_F10.11_GIS_HB	PNG LNG Project		

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10.3.3 Vegetation and Flora

10.3.3.1 Overview

Virtually the entire Kikori River catchment is covered in primary tropical forest, with structure and floristics influenced by altitude, climate, topography, soils, geology, degree of waterlogging and disturbance. 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, although this varies with local topography and relief.

In the uplands, the cooler climates, longer periods of rainfall and frequent fogs 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 longer periods since the last forest disturbance give trees time to develop great girths and where the substrate allows roots to penetrate.

10.3.3.2 Forest Structure by Terrain and Geology

Terrain and geology are the principal influences on the natural structure of forest in the upstream project area.

Limestone produces poor soils, with variable degrees of karstification affecting the quantity of soil and the capacity of trees to survive for long periods and attain large sizes.

The solid limestone pavement on the karst plains of the lowlands and on the tops of some upland ridges has only a few cracks and fissures in otherwise smooth, hard, featureless rock. There is little or no mineral soil and limited opportunity for roots to penetrate and gain a foothold in the limestone pavement, so the forest here must grow essentially in its own root mat (see Plate 10.4). These shallow-rooted trees are prone to wind throw, which peels sections of forest off the limestone pavement (see Plate 10.5). As these trees grow, their roots can only continue to spread laterally over the rock and their susceptibility to being blown over increases. These forests 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 short and direct, with the bulk of the nutrients tied up in the living biomass of 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 10.10).

In areas of polygonal karst, in upland karst corridors and in the decomposing rock of the upper ridge slopes, numerous fissures and weaknesses in the rock make root penetration easier. Trees have bigger crowns and boles, producing forests that are better developed overall and more like those on the richer valley alluvial soils.

Most of the limestone landforms are well drained, but there are areas of impeded drainage on the terra rossa clays of perched valleys in the uplands and where the watertable is close to the

Plate 10.10
Lichens and mosses on limestone pavement

Plate 10.11
Significant slumping in the middle Hegigio River

Plate 10.12
The Karius Range with steep scrub-covered sides

surface in the lowlands. In these locations, forest gives way to swamp forest or swamps and wetlands. *Pandanus* sp. and palms become more dominant, and specialist trees capable of surviving waterlogging occur. The small internal karst drainage basins in the Mubi River valley near Kantobo village can hold standing water for short periods after heavy rain but not long enough for swamp forest to develop.

Swamp forests tend to dominate the delta shorelines, giving way to mangroves on the more stable shores within the delta or nypa palms (*Nypa fruticans*) on the more active (prograding) landforms of the delta distributary streams.

Approximately one-fifth of the upstream project area comprises the volcanic and alluvial substrates that provide the best growing conditions for plants.

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 primary tropical forest, secondary forest and regrowth forest.

Rainfall in the Western Lowlands and Western Foothills bioregions is high, with otherwise montane plants growing at low elevations, such as around Juha (Appendix 1, Biodiversity Impact Assessment).

Disturbance determines the dynamics of all the forests in the upstream project area. 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 understorey are no longer constrained by shade, and grow to fill the gap. It is a matter of chance which species succeed, which is one mechanism that maintains the high diversity in tropical forests. Gaps are forming constantly and producing continuous low-level disturbance.

On the other hand, catastrophic dynamics occur when large disturbances, such as landslides, floods, fire, frost, drought or clearing, devastate many hectares or even square kilometres of forest. The area then regenerates through succession, either to a similar forest type as before or, if the changes have been so great as to favour individual species, a forest that is no longer the same. For example, if the disturbance has exposed large areas of mineral soil, species that can germinate in such conditions and thrive in full sun are favoured over species that need organic soils and cannot tolerate open conditions. Catastrophic dynamic regimes are common in Papua New Guinea and are widespread in the Baia River and Homa region (Plate 10.11).

Fire is a potent force in forest dynamics, and even the wettest tropical forests can burn during drought. Swamp forests on peat and forests on limestone pavements are particularly susceptible to fire damage and may even give way to scrublands, grasslands or bare rock pavement if their organic substrates are burnt and lose their capacity to support trees. In most PNG forests, fire, extensive clearing and frost can allow grasses and other flammable species to establish. These invaders will burn repeatedly and indefinitely from lightning strikes and, especially, people lighting fires: the large areas of grasslands in the PNG highlands have been generated this way.

The naturally dynamic regime of tropical forests gives them a degree of resilience to human disturbance, because short-term, small-scale clearing will often mimic natural gap-phase or small-scale catastrophic dynamics (which is the ecological basis for sustainable tropical forestry). However, major interventions in natural processes (soil loss or destruction by large-scale clearing, continuous small clearings fragmenting the forest, disturbances being too frequent, fire and disease gaining a foothold, or changes to drainage) can cause a forest ecosystem to collapse. Of these, clearing and human fire lighting are the single biggest cause of forest loss in Papua New Guinea.

10.3.3.3 Vegetation Classification

The vegetation classification system used is a simplification of the PNG Forest Inventory Management System (FIMS). Seventy-five vegetation types or complexes have been mapped by the FIMS within the upstream project area. These have been grouped into 21 broad vegetation groups (BVG) and rivers or lakes for mapping and summarised in Table 10.7 and shown in Figure 10.12.

Table 10.7 Groupings of FIMS vegetation types used in EIS analysis

Broad Vegetation Group	Vegetation Type (fields in FIMS GIS)	
	Vegetation Type	Vegetation Type Description
Montane forest (>3,000 m) with/without grassland	Mo	Montane Forest – above 3,000 m – Very Small-crowned Forest
	Mo/Ga	Complex – Very Small-crowned Forest/Alpine Grassland
Grasslands	Ga	Grassland and Herbland – Alpine Grassland
	Gi	Grassland and Herbland – Subalpine Grassland
	Gri	Grassland and Herbland – Riverine successions dominated by grass
	Gri/Po	Complex – Riverine successions dominated by grass/Open Forest
	Gsw	Grassland and Herbland – Swamp Grassland
Scrub	Sc	Scrub – Scrub
Lower montane small-crowned forest	L	Lower Montane Forest – above 1,000 m – Small-crowned Forest
	L/Ls	Complex – Small crowned Forest/Very Small-crowned Forest
	L5	Lower Montane Forest – above 1,000 m – Small-crowned Forest
	L8	Lower Montane Forest – above 1,000 m – Small-crowned Forest
Lower montane small-crowned forest with conifers	Lc	Lower Montane Forest – above 1,000 m – Small-crowned Forest with Conifers
	Lc/Gi	Complex – Small-crowned Forest with Conifers/Subalpine Grassland
	Lc/Ls/Gi	Complex – Small-crowned Forest with conifers/Very Small-crowned Forest/Subalpine Grassland

Table 10.7 Groupings of FIMS vegetation types used in EIS analysis (cont'd)

Broad Vegetation Group	Vegetation Type (fields in FIMS GIS)	
	Vegetation Type	**Vegetation Type Description**
Lower montane small-crowned forest with *Nothofagus*	LN/LsN	Complex – Small-crowned Forest with *Nothofagus*/Very Small-crowned Forest with *Nothofagus*
	L/LN	Complex – Small-crowned Forest/Small-crowned Forest with *Nothofagus*
	LN	Lower Montane Forest – above 1,000 m – Small-crowned Forest with *Nothofagus*
	LN5	Lower Montane Forest – above 1,000 m – Small-crowned Forest with *Nothofagus*
	LN8	Lower Montane Forest – above 1,000 m – Small-crowned Forest with *Nothofagus*
Lower montane very small-crowned forest complexes	Ls	Lower Montane Forest – above 1,000 m – Very Small-crowned Forest
	Ls/L	Complex – Very Small-crowned Forest/Small-crowned Forest
Lower montane very small-crowned forest complexes with *Nothofagus*	Ls/LsN	Complex – Very Small-crowned Forest/Very Small-crowned Forest with *Nothofagus*
	Ls/LN	Complex – Very Small-crowned Forest/Small-crowned Forest with *Nothofagus*
	LsN	Lower Montane Forest – above 1,000 m – Very Small-crowned Forest with *Nothofagus*
	LsN/L	Complex – Very Small-crowned Forest with *Nothofagus*/Small-crowned Forest
	LsN/LN	Complex – Very Small-crowned Forest with *Nothofagus*/Small-crowned Forest with *Nothofagus*
	LsN/Sc	Complex – Very Small-crowned Forest with *Nothofagus*/Scrub
Medium-crowned to small-crowned forest complexes	Hm/Hs	Complex – Medium-crowned Forest/Small-crowned Forest
	Hm/Hs/Fsw	Complex – Medium-crowned Forest/Small-crowned Forest/Mixed Swamp Forest
	Hm8/Hs8	Complex – Medium-crowned Forest/Small-crowned Forest
	Hm9/Hs9	Complex – Medium-crowned Forest/Small-crowned Forest
	Hs/Hm	Complex – Small-crowned Forest/Medium-crowned Forest
Medium-crowned to small-crowned forest complexes with *Nothofagus*	HsN/Hm	Complex – Small-crowned Forest with *Nothofagus*/Medium-crowned Forest
Low-altitude large-crowned forest	Hl.N	Low Altitude Forest On Uplands – below 1,000 m – Large-Crowned Forest – presence of *Nothofagus* noted or suspected
	Hl8.N	Low Altitude Forest On Uplands – below 1,000 m – Large-Crowned Forest – presence of *Nothofagus* noted or suspected

Table 10.7 Groupings of FIMS vegetation types used in EIS analysis (cont'd)

Broad Vegetation Group	Vegetation Type (fields in FIMS GIS)	
	Vegetation Type	**Vegetation Type Description**
Low-altitude medium-crowned forest	Hm	Low Altitude Forest On Uplands – below 1,000 m – Medium-crowned Forest
	Hm.Ar	Low Altitude Forest On Uplands – below 1,000 m – Medium-crowned Forest – Presence of *Araucaria* noted
	Hm.N	Low Altitude Forest On Uplands – below 1,000 m – Medium-crowned Forest – presence of *Nothofagus* noted or suspected
	Hm8	Low Altitude Forest On Uplands – below 1,000 m – Medium-crowned Forest
	Hm8.N	Low Altitude Forest On Uplands – below 1,000 m – Medium-crowned Forest – presence of Nothofagus noted or suspected
	Hm9	Low Altitude Forest On Uplands – below 1,000 m – Medium-crowned Forest
	Hs	Low Altitude Forest On Uplands – below 1,000 m – Small-crowned Forest
	Hs8	Low Altitude Forest On Uplands – below 1,000 m – Small-crowned Forest
	Hm5	Low Altitude Forest On Uplands – below 1,000 m – Medium-crowned Forest
	Hm5/Hs5	Complex – Medium-crowned Forest/Small-crowned Forest
Low-altitude small-crowned forest with *Nothofagus*	HsN	Low Altitude Forest On Uplands – below 1,000 m – Small-crowned Forest with *Nothofagus*
Large-to medium-crowned lowland forest	Pl	Low Altitude Forest On Plains And Fans – below 1,000 m – Large-to medium-crowned Forest
	Pl9	Low Altitude Forest On Plains And Fans – below 1,000 m – Large-to medium-crowned Forest
Small-crowned lowland forest	Ps	Low Altitude Forest On Plains And Fans – below 1,000 m – Small-crowned Forest
	Ps/Hs	Complex – Small-crowned Forest/Small-crowned Forest
	Ps5	Low Altitude Forest On Plains And Fans – below 1,000 m – Small-crowned Forest
	Ps8	Low Altitude Forest On Plains And Fans – below 1,000 m – Small-crowned Forest
Open lowland forest	Po	Low Altitude Forest On Plains And Fans – below 1,000 m – Open Forest
	Po8	Low Altitude Forest On Plains And Fans – below 1,000 m – Open Forest
Open lowland forests and freshwater swamps	Po/Fsw	Complex – Open Forest/Mixed Swamp Forest
	Po/Fsw8	Complex – Open Forest/Mixed Swamp Forest
	Po8/Fsw8	Complex – Open Forest/Mixed Swamp Forest

Table 10.7 Groupings of FIMS vegetation types used in EIS analysis (cont'd)

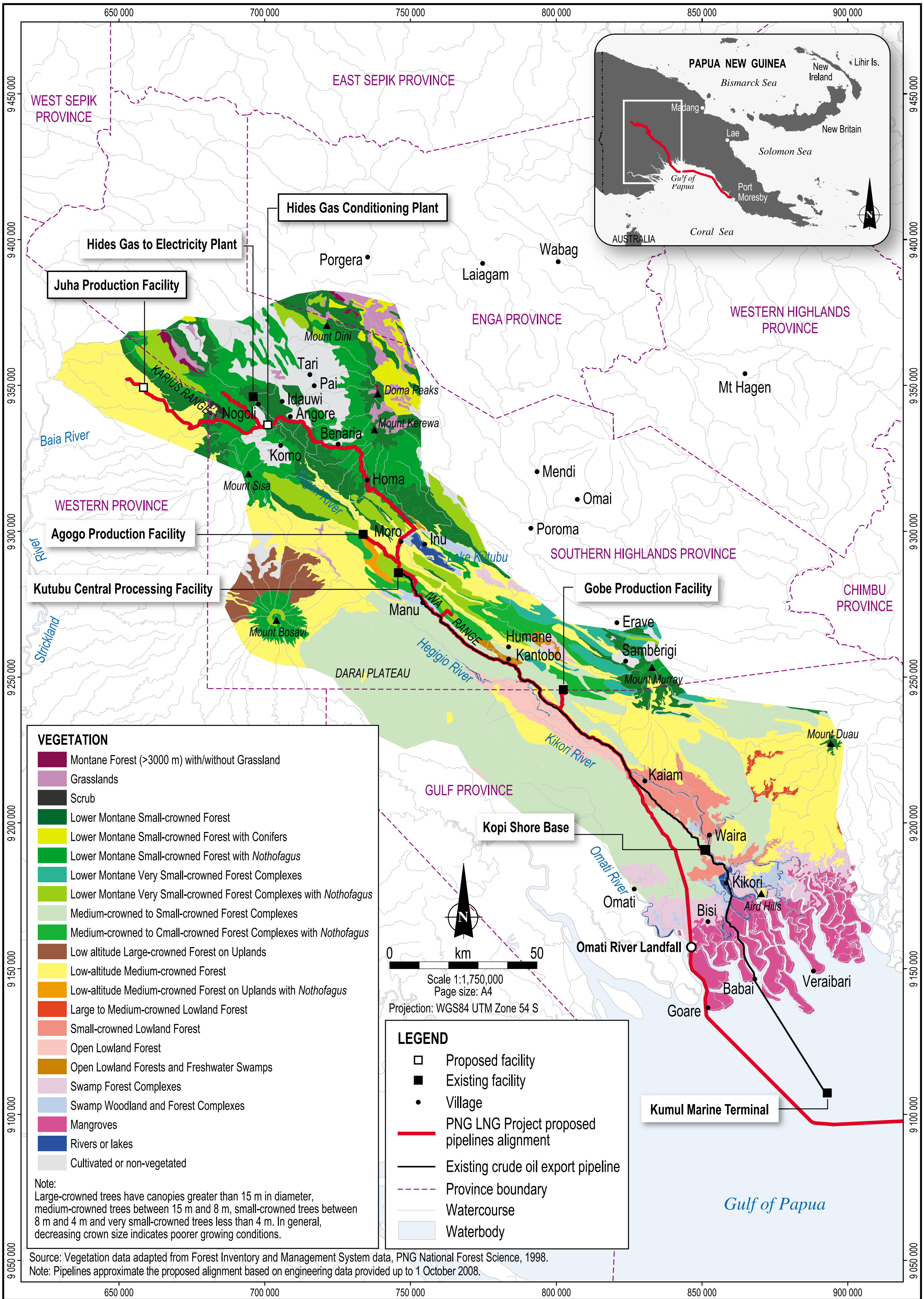
Broad Vegetation Group	Vegetation Type (fields in FIMS GIS)	
	Vegetation Type	**Vegetation Type Description**
Swamp forest complexes	Fsw	Swamp Forest – Mixed Swamp Forest
	Fsw/Gsw	Complex – Mixed Swamp Forest/Swamp Grassland
	Fsw/M	Complex – Mixed Swamp Forest/Mangrove
	Fsw/Wsw	Complex – Mixed Swamp Forest/Swamp Woodland
	Fsw/Wsw/M	Complex – Mixed Swamp Forest/Swamp Woodland/Mangrove
	Fsw5	Swamp Forest – Mixed Swamp Forest
	Fsw8	Swamp Forest – Mixed Swamp Forest
	Fsw8/Wsw	Complex – Mixed Swamp Forest/Swamp Woodland
	Hs/Fsw	Complex – Small-crowned Forest/Mixed Swamp Forest
Swamp woodland and forest complexes	Wsw	Woodland – Swamp Woodland
	Wsw/Fsw	Complex – Swamp Woodland/Mixed Swamp Forest
	Wsw/Fsw8	Complex – Swamp Woodland/Mixed Swamp Forest
	Wsw/M	Complex – Swamp Woodland/Mangrove
Mangroves	M	Estuarine Communities – Mangrove
Cultivated or non-vegetated	E	Other Non-vegetation and Areas Dominated By Land Use – Lakes and Larger Rivers
	O	Other Non-vegetation and Areas Dominated By Land Use – No Forest (Land use intensity classes 0-4)
	U	Other Non-vegetation and Areas Dominated By Land Use – Larger Urban Areas

Montane Forest (>3,000 m) With/Without Grassland. This includes FIMS types Mo and Mo/Ga of very small-crowned mossy forest ('elfin' forest) and alpine grassland complexes respectively. The forest is low (5 m to 15 m high) with thin crooked stems and no emergents. It only occurs in the far north of the upstream project area where there is no project infrastructure planned.

Grasslands. Grasslands in the Kikori catchment are mostly alpine grasslands above the tree line and to the north of the upstream project area where there is no project infrastructure planned.

Scrub. There are areas of rocky scrub on the steeper slopes of the Karius Range (Plate 10.12). No project infrastructure is planned within this vegetation type.

Lower Montane Small-crowned Forest. This BVG includes FIMS types L and L5 (both small-crowned forest) and generally occurs above 1,000 m ASL. This forest has an even to undulating canopy 20 to 30 m high and is very dense to almost closed. Beech (*Nothofagus*) is absent or very rare, but there are many emergent pines (*Araucaria*) in the forests on the ranges near Idauwi and Nogoli. Ferns and epiphytes are common. Trees tend to be thin, and oaks (*Castanopis* and *Lithocarpus*) are common, dominating in some areas. This forest type, while somewhat less diverse in tree species composition than other forests, can have a high diversity of smaller plants



PNG LNG	Date: 5.09.2008 MXD: PNG_LNG_Project_GIS.mxd File Name: 1284_09_F10.12_GIS_HB	Esso Highlands Limited PNG LNG Project	Distributions of broad vegetation groups within the upstream project area	Figure No: 10.12

PGGP-EN-SRENV-000001-001
Rev0

and epiphytes. At lower elevations in the river valleys, clearing for gardens has heavily disturbed this forest type. The project will cross this vegetation frequently at the eastern end of the Juha–Hides Rich Gas Pipeline and for a long length of the LNG Project Gas Pipeline between the Hides Gas Conditioning Plant and Lake Kutubu at elevations of approximately 1,200 m asl and above.

Lower Montane Small-crowned Forest with Conifers. This BVG only occurs at high elevations in the far northeast of the upstream project area as lower montane small-crowned forest with emergent conifers, including the genera *Dacrydium, Libocedrus* and *Phyllocladus* (FIMS types Lc and Lc/Gi). No project infrastructure is planned within this vegetation type.

Lower Montane Small-crowned Forest with *Nothofagus*. This mossy beech *Nothofagus* forest includes FIMS types Ln (small-crowned forest with *Nothofagus*) and Ln/LsN (complex of small-crowned forest with *Nothofagus* and very small-crowned forest with *Nothofagus*). The closed, even to slightly undulating canopy is 20 m to 30 m high, with *Nothofagus pullei* and *N. rubra* dominant along ridgelines and subcrests.

In the drainage subcatchments, the canopies are usually lower, and the mixed communities typical of Papuasian[3] habitats become more apparent. Natural gap-phase dynamic processes, such as wind throw and tree senescence, have produced small patches of seral growth, which are scattered through the forest.

The forests on Hides Ridge and around Homa reflect the classic processes of patch dynamics and spatial rotation of forest units in different stages of maturation (Appendix 1, Biodiversity Impact Assessment). The effects of fire are apparent in the Homa area.

On Hides Ridge, the *Nothofagus* forest characteristically contains large numbers of epiphytic ferns and orchids (Plate 10.13), which may represent up to 75% of the plant diversity (Appendix 1, Biodiversity Impact Assessment).

The main occurrences of this BVG are as extensive stands on the Doma Peaks and Mount Sisa, Hides Ridge and between the Benaria and Kondari. The eastern end of the pipelines between Juha and Hides will traverse this vegetation type, and the pipelines between Hides and Kutubu will cross large expanses of this forest above 1,600 m between the Benaria and Kondari Rivers and sporadically at higher elevations between the Kondari River and Lake Kutubu.

The Hides wells and gathering system and Hides Spineline are mostly in this BVG on Hides Ridge.

Lower Montane Very Small-crowned Forest Complexes. This BVG includes FIMS types Ls (very small-crowned forest) and Ls/L (complex of very small-crowned forest and small-crowned forest) and occurs on the central eastern boundary of the upstream project area northeast of Gobe. No project infrastructure is planned in this area.

[3] Papusia is an area that extends from Indonesian New Guinea to Vanuatu.

Plate 10.13
Epiphytes in lower montane small-crowned forest with *Nothofagus*

Plate 10.14
The Ai'io River swamp forest complexes

Plate 10.15
Arenga sp. and *Galubia* sp. palms typical of less inundated areas

Lower Montane Very Small-crowned Forest Complexes with *Nothofagus*. This vegetation group includes FIMS types LsN (very small-crowned forest with *Nothofagus*) and LsN/L (complex of very small-crowned forest with *Nothofagus* and small-crowned forest) and is concentrated in the uplands surrounding Kutubu. The forest has a dense, evenly textured, dark-toned canopy 5 m to 15 m high. Around Kutubu, *Nothofagus* dominates along ridges but is far less obvious than in the higher regions to the north. There are fewer ferns but more vines in this vegetation type.

The existing Kutubu Central Processing Facility is located within this BVG and a small section of the pipelines between Hides and Kutubu either side of the Kutubu Central Processing Facility will traverse it. The South East Hedinia spineline also traverses this BVG.

Medium-crowned to Small-crowned Forest Complexes. This BVG covers large areas of the southern and central parts of the upstream project area and includes several FIMS complexes of medium- (Hm) and small-crowned trees (Hs). This vegetation type has a canopy 25 m to 30 m high with 60% to 80% closure. The medium-crowned forest has emergents up to 40 m high. The small-crowned forest has thinner trees and a more even canopy with no emergents and tends to develop on the more difficult pavement sites. The PNG LNG Project Gas Pipeline will pass through a long section of this vegetation between Manu and to south of Kantoba, i.e., the crossings of the Ai'io and Mubi rivers, and between the Kikori River crossing and Omati. The Gobe Gas Pipeline and the South East Hedinia Spineline also encounter this BVG.

Medium-crowned to Small-crowned Forest Complexes with *Nothofagus*. This vegetation group includes FIMS type HsN/Hm (complex of small-crowned forest with *Nothofagus* and medium-crowned forest) and occurs in the central eastern part of the upstream project area. The canopy is 25 m to 30 m high with 60% to 80% closure and is a mixture of medium- 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. The South East Hedinia Spineline crosses some of this BVG and the LNG Project Gas Pipeline crosses large areas between the Kutubu Central Processing Facility and the Ai'io River.

Low-altitude Large-crowned Forest on Uplands. This includes FIMS type Hl.N (large-crowned forest in which the presence of *Nothofagus* is noted or suspected) and occurs on the slopes of Mount Bosavi. It has an uneven canopy 30 m to 35 m high and 80% closure with emergents to 40 m. No project infrastructure is planned within this vegetation type.

Low-altitude Medium-crowned Forest. This includes various FIMS complexes of Hm (medium-crowned forest) and occurs widely in the upstream project area. The canopy is 25 to 30 m high with 60% to 80% closure and emergents up to 40 m high. Species composition varies widely according to altitude and substrate. In the Juha area, this BVG has many upland forest features, and plants other than trees may dominate the flora. The project mostly encounters this vegetation at Juha and along the Juha–Hides Rich Gas Pipeline and again sporadically between Lake Kutubu and the Gobe turnoff where this BVG merges into open lowland forest (Po) on the edge of the karst pavements.

Low-altitude Small-crowned Forest on Uplands with *Nothofagus*. This vegetation group includes a range of FIMS types with Hm (medium-crowned forest) dominating and includes Hm.N (medium-crowned forest in which the presence of *Nothofagus* is noted or suspected). It has a fairly even canopy approximately 30 m high with emergents up to 35 m. Tree crowns average between 8 m and 15 m in diameter, and larger crowns are rare. Orchids and figs are very common, ferns are moderately common, and palms and *pandanus* sp. are sparse. The understorey is generally open, and there is a ground layer of seedlings, ferns, moonlight fern (*Selaginella)* and gingers. Conifers such as *Papuacedrus* spp. and *Phyllacladus* spp., become abundant; and oaks (*Castanopis* and possibly *Lithocarpus*) are common. The Agogo Gas Pipeline will cross the single occurrence of this vegetation type east of the Kutubu Central Processing Facility.

Large- to Medium-crowned Lowland Forest. This vegetation group includes FIMS types Pl and Pl9 and occurs in small areas in or near the Sirebi Lowlands bioregion on alluvial fans. The forest is tall (30 m to 35 m) with emergents to more than 50 m. No project infrastructure is planned within this BVG.

Small-crowned Lowland Forest. This vegetation group includes FIMS type Ps (small-crowned forest), which has a canopy 25 m to 30 m high of dense small crowns and no emergents. Single species, such as *Intsia* sp. and dipterocarps, are often dominant. This type of forest often occurs on badly drained or very poor substrates, such as limestone pavements. Small areas of this BVG will be traversed by the southern section of the PNG LNG Project Gas Pipeline as it approaches the Omati River Landfall.

Open Lowland Forest. This vegetation group includes FIMS type Po (open forest). The canopy is approximately 30 m high and consists of small- and medium-crowned trees with large crowned emergents up to 40 m. Frequent tree falls on the limestone pavements create an uneven canopy profile with many large gaps. There are a variety of palms, and climbing rattans are common. Stands of sago palm develop in low-lying areas, and broad-leaved trees can reach great sizes (greater than 100 cm dbh) in some places. While the FIMS does not map it as such, the forest at Baia River is of this type. The PNG LNG Project Gas Pipeline will traverse this BVG, where it merges with low altitude medium-crowned forest in, in the vicinity of Gobe.

Open Lowland Forests and Freshwater Swamps. This vegetation group includes FIMS type Po (open forest) and Fsw (mixed swamp forest) and is a complex of open forest and mixed swamp forest. The LNG Project Gas Pipeline crosses this BVG several times either side of the Gobe turnoff.

Swamp Forest Complexes. This BVG includes a range of FIMS type Fsw (mixed swamp forest) complexes and occurs patchily but widely on impeded drainage in the upstream project area (Plate 10.14). Trees can be large (up to 100 cm dbh) and up to 30 m tall. Thick and thin lianas are common, and epiphytes are abundant. *Selaginella* (moonlight fern) is common on the forest floor and palms are abundant. Sago palms can form almost pure stands where flooding is common (FIMS type Wsw (swamp woodland)). Sago palms dominate in the small hollows or dolines where karst has produced local relief within these otherwise flat basins or plains, with medium-crowned or small-crowned lowland hill forest on the limestone ridges. Other palms, such as *Arenga* sp. and *Galubia* sp., are dominant where inundation is less frequent (Plate 10.15).

There are large areas behind the mangroves of the Kikori River delta and scattered patches towards the centre of the upstream project area. The swampy lands at the South Karius survey area are of this BVG but not mapped by FIMS as such. The LNG Project Gas Pipeline traverses large areas of swamp forest complexes approaching the Omati River.

Swamp Woodland and Forest Complexes. This vegetation group includes FIMS type Wsw (swamp woodland) and complexes with Fsw (mixed swamp forest) and occurs around the north of Lake Kutubu, near Kantobo and behind the Kikori River delta mangroves. 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 m to 30 m high and an understorey of sago palms visible in gaps in the canopy. The variable density of sago and other trees give this forest type a very patchy appearance. The LNG Project Gas Pipeline crosses this BVG to the north of Lake Kutubu and in the Ai'io River valley.

Mangroves. The mangrove vegetation group (FIMS 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 Omati River Landfall of the PNG LNG Project Gas Pipeline (see Plate 6.28; a close-up is shown in Plate 6.29). The LNG Project Gas Pipeline does not cross any mangrove vegetation except for a fringe of nypa palms at the landfall.

Non-forested Areas. These areas usually occur on the better soils and indicate human settlement. The project has sited infrastructure to be in cleared areas where practicable.

10.3.3.4 Flora

Floristic Diversity

The island of New Guinea has one of the world's richest floras, with more than 25,000 species of vascular plants, over 3,000 species of fern, and over 2,800 species of orchids. It also has the highest numbers of indigenous and endemic plant species within the Malesia[4] floristic province, and the proportion of endemics may exceed 70%. New Guinea ranks fifth in the world for flowering plant diversity and first for ferns.

A full botanical inventory of the 2.16 Mha of the KRP area would take many years to prepare, but the work to date in Papua New Guinea generally and in the KRP allows certain inferences to be drawn about the upstream project area. The WWF surveys investigated broad-scale patterns of vegetation composition and forest ecology based on small study plots, and the results confirm that the KRP area has high floristic diversity. It has been estimated that 1.8 ha of a typical Kikori River catchment forest contains 372 tree species that attain a 10-cm dbh or greater. Over 1,000 species of plants in nine survey areas were recorded in the north of the upstream project area. Of these, 72% were collected at only one site and 97% at only two sites, indicating the wide heterogeneity of the flora. Overall, the upstream project area may hold between 6,000 and 12,000 species of plants.

The forests on limestone appear to be the most diverse and the highest diversity areas sampled were the limestones of the Darai Plateau, with 271 species collected from limestone sites compared with 170 species from volcanics. However, more species were collected at alluvial sites and most species (522) from sites with mixed soil types (alluviums and limestones). The upstream project area does not appear to have its own specialist karst flora, which is consistent with the broad distribution of specialist karst plants in Papua New Guinea.

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[4] The Malesian botanical region encompasses the islands of New Guinea and Indonesia and the Malayan Peninsula.

Altitude, local conditions and forest type can all influence floral richness. Species diversity increases in the sequence of lowland forest, mid-montane forest, and lowland alluvial hill forest to lowland limestone karst. At Juha, however, high rainfall has brought many montane elements to the lowland and foothill flora. Ecotones, such as the geological transition at Juha South, and forest edges will often have the combined elements of the adjacent habitats (and hence higher diversity).

Over 150 families of tracheophytes have been recorded in the upstream project 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. Collections in the northern part of the upstream project area found that 76 families were represented by two species or less. The Rubiacea and Moracea were the most species rich, with 77 and 52 species respectively. These 2 and the other 10 families represented by more than 20 species each (Grammitidaceae, Meliaceae, Aspleniaceae, Piperaceae, Poaceae, Elaeocarpaceae, Myrtaceae, Ericaceae, Euphorbiaceae *sens. lat.* and Polypodiaceae) accounted for only 41% of the total species, demonstrating little dominance in the flora.

The data from the WWF surveys and general understanding of forest composition do allow the lowland, lowland hill and upper hill zones (below 1,200 m ASL) to be floristically characterised. In the medium- and small-crowned forest of the upper hill zone between 600 m and 1,200 m ASL around 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 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 KRP area, are more common in wetter forests of the lowlands and intermontane swamps. No endemic species or genera of palms have been found to date in the lowlands of the KRP area.

The issue for the PNG LNG Project is whether that, within the broad and ubiquitous floristic diversity of the KRP forests, certain forest types, plant groups or species might be concentrated in small areas along the pipeline ROWs, to the point where clearing would have a disproportionate impact on their conservation status. The evidence available is that this is unlikely: 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 ASL has a flora typical of the New Guinea highlands in general. Moreover, 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 evidence from botanical surveys (Annexes 1 and 2 in Appendix 1, Biodiversity Impact Assessment) considers the lack of botanical exploration rather than restricted distribution is responsible for the apparently patchy distribution of some plants. Also, there are no highly restricted forest types (BVGs) in the project area (see Figure 10.12 and Annex 4 in Appendix 1, Biodiversity Impact Assessment).

Epiphytes

Forest inventories concentrate on tree species, but epiphytes and ferns may dominate the flora overall. For example, 225 of the 1,030 species recorded in the northern part of the upstream project area are ferns. Orchids, most of which are epiphytic, may be the most species-rich family in the upstream project area.

High-altitude forests are the least known. The PNG Gas Project studies conducted in 2005 found 13 species new to science in the Hides Ridge area, including a tree fern (*Cyathea* sp.) and three unusual calcium-depositing ferns (Plates 10.16 and 10.17). The recent botanical surveys of the northern part of the upstream project area (Juha and Hides) have produced 31 species new to science and 31 range extensions. Takeuchi (Annexes 1 and 2 in Appendix 1, Biodiversity Impact Assessment) recommended no species specific protective actions. Although nearly all of the novelties were seen only once, or at most a few times, this is not sufficient cause for presuming that the plants are at risk. While it is tempting to assume that these species have managed to evade detection because of extreme rarity, a more rational and plausible approach is to view the discoveries within their historical context as improving knowledge within one of Malesia's most poorly documented areas.

Epiphytes and ferns can make up 75% of the floristic diversity in upland forests above 1,800 m ASL. 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.

10.3.3.5 Weeds

Surveys of the Hides Ridge (Hides 3 well survey area) indicate that the area was almost free of invasive weeds, with only two alien – but otherwise harmless – herbs found in construction rubble at helipads. One of these, *Passiflora ligulata* (passionfruit), may have been planted by construction workers. The survey areas in 2008 between Hides and Juha were also in a floristically uncontaminated state. The survey areas at Baia River, Juha South and Juha North show only a few weed species, such as *Bidens pilosa* L. and *Ageratum conyzoides* L., probably brought in by working crews. These likely accidental introductions are low-growing annuals of limited forest-invasive capacity and are mainly a visual nuisance.

10.3.4 Terrestrial Fauna

10.3.4.1 Non-volant Mammals

Excluding the ubiquitous introduced wild pig, 89 species in 10 families of non-volant mammals have been found in the upstream project area, the 2005 and 2008 surveys having added 3 and 10 species respectively. Rodents (with 56% of the recorded species) are the most species-rich group, followed by possums (11 species, Plate 10.18), macropods (8 species), cuscuses (6 species, Plate 10.19) and marsupial carnivores (7 species).

Plate 10.16
Melodinus forbesii found on Hides Ridge

Plate 10.17
Agalymyla formosa found on Hides Ridge

Plate 10.18
Plush-coated ringtail

In New Guinea, altitude is a major determinant of distribution for non-volant mammals, with a peak in species richness (over 50 species) between 1,000 m and 2,000 m ASL.

Non-volant mammal diversity within bioregions reflects this relationship, with the richest being the Western Volcanics and the Eastern Uplands Volcanics/Karst. These bioregions include the optimal altitudinal belt and have volcanic soils, which are more productive and provide a more resource-rich forest for mammals. The bioregions with the lowest species richness were Sirebi Lowlands, the Moro Region and the Iagifu Agogo Limestone Uplands with two, one and two species respectively. Table 10.8 shows the number of species from each family recorded in each bioregion. Prior to the 2008 survey, the Mubi River Karst was the richest bioregion after the uplands with five sample sites producing 41 species, and the highest diversity recorded at any sample site was 27. The single sample site at the Juha South survey area produced 30 species, and an additional 13 species were considered highly likely to occur following discussions with local people.

Table 10.8 Number of non-volant mammal species in the bioregions of the upstream project area

	Kikori Lowlands	Sirebi Lowlands	Libano Hegigio	Darai Plateau	Western Lowlands	Western Foothills	Mubi River Karst	Moro Region	Iagifu Agogo Limestone Uplands	Western Volcanics	Eastern Uplands Volcanics/Karst	Northern Montane Karst
Upper elevation of bioregion (m ASL)	200	400	1,100	600	400	1,200	1,300	1,000	1,400	2,700	1,800	3,300
Lower elevation of bioregion (m ASL)	0	40	300	200	200	400	200	800	1,000	280	800	1,800
No of sample sites	8	2	3	1	2	1	5	1	2	4	4	1
Family												
Tachyglossidae			2	2	1	1	1			1	1	1
Dasyuridae			5	2	4	4	3		1	6	6	2
Peroryctidae	4		2	2	3	3	4			4	3	3
Phalangeridae	4		4	3	3	6	3		1	6	5	5
Macropodidae	2		3	4	1	4	5			5	5	3
Burramyidae							1			1	1	
Pseudocheiridae	1				1	2	3			5	5	3
Petauridae	2		2	1	2	2	2			4	3	1
Acrobatidae	1		1	1	1	1	1	1		1	1	1
Muridae	10	3	11	8	19	20	18	4	6	38	28	6
Total species	**24**	**3**	**30**	**23**	**35**	**43**	**41**	**5**	**8**	**71**	**58**	**25**

Plate 10.19
Mountain cuscus

Plate 10.20
Megachiropteran bat *Nystimene aello*

The mammal fauna of New Guinea is highly endemic: 70% of the species are restricted to New Guinea and its offshore islands, and 75% of the species recorded from the KRP area are New Guinea endemics. Within the upstream project area, 18 species of the total of 89 were recorded in only one site; however, as knowledge of the area increases, it is anticipated that these will be found at more and more sites. This has been the pattern of mammal discoveries in the study area during the long history of biodiversity surveys since 1996 (Appendix 1, Biodiversity Impact Assessment). No species except those new to science are restricted to the upstream project area. An analysis of endemicity within the upstream project area indicated that it increases with altitude (Table 10.9).

Table 10.9 Endemicity of non-volant mammals in the bioregions of the upstream project area

Region	No. of Species within Each Endemicity Rating*					Total Species	Endemicity Score† (%)	No. of Survey Sites
	1	2	3	4	5			
Kikori Lowlands	11	3	1	7	2	24	37.5	8
Sirebi Lowlands	1	1			1	3	33.3	2
Libano Hegigio	5	3	2	10	3	23	56.5	3
Darai Plateau	9	4	3	12	2	30	46.7	1
Western Lowlands	9	4	4	15	3	35	51.4	2
Western Foothills	9	5	3	23	3	43	60.5	1
Mubi River Karst	11	3	2	20	5	41	61.0	5
Moro Region	1	2		2		5	40.0	1
Iagifu Agogo Limestone Uplands#	1			4	2	7	85.7	2
Western Volcanics#	12	4	4	41	9	70	71.4	4
Eastern Uplands Volcanics/Karst#	8	4	3	36	6	57	73.7	4
Northern Montane Karst	3	2	2	17	1	25	72.0	1

Endemicity Rating: 5 – Endemic to mainland Papua New Guinea, 4 – Endemic to New Guinea and its satellite islands, 3 – Endemic to New Guinea and its satellite islands and the Aru Islands, 2 – Endemic to New Guinea and its satellite islands and New Britain and/or New Ireland and/or the Loisiades, 1 – Occurs widely through Australia, Indonesia, the Solomon Islands or the Pacific.

† Endemicity Score: the percent of species with endemicity ratings of 4 and 5.

This table excludes unidentified *Rattus* species.

10.3.4.2 Bats

Bats fall into two major groups Megachiroptera and Microchiroptera. The Megachiroptera comprises about 20% of Papua New Guinea species and contains a single family, the Pteropodidae, which includes the large- to medium-sized frugivorous flying foxes and the small nectivorous blossom bats (Plates 10.20 and 10.21). These species use vision to navigate. The five remaining families of bats belong to the Microchiroptera (microbats), which are small- to medium-sized insectivorous species that forage on the wing and echolocate (Plates 10.22 and 10.23). The microbats are difficult, sometimes impossible, to capture and are best detected by recording their ultrasonic echolocation calls, which, like birdcalls, are mostly species-specific.

Plate 10.21
Megachiropteran bat *Paranyctimene* sp.

Plate 10.22
Microchiropteran bat *Rhinolophus euryotis*

WWF did not have this echolocation-detecting technology, so the biodiversity surveys prior to 2005 could not adequately sample the microbats. Automated electronic call recording was the primary data-gathering technique during the 2005 and 2008 surveys and provides the best estimate of the composition of the microbat fauna in any part of the upstream project area.

Forty-seven species of bats have been recorded in the upstream project area, and a further 28 species could occur. Table 10.10 presents data on the diversity of bat families in the upstream project area bioregions. The 2005 and 2008 surveys, in particular, have allowed a better understanding of the abundance, altitudinal variation and habitat of bats, from which the ecological implications of the project can be analysed.

Table 10.10 Number of bat species in the bioregions of the upstream project area

Family	Kikori Lowlands	Sirebi Lowlands	Libano Hegigio	Darai Plateau	Western Lowlands	Western Foothills	Mubi River Karst	Moro Region	Iagifu Agogo Limestone Uplands	Western Volcanics	Eastern Uplands Volcanics/Karst	Northern Montane Karst
Pteopodidae	9	5	7	5	6		8	4	3	5	6	1
Emballonuridae	1		4		1-2[1]	2-3[1]	2			4	2-3[1]	2-3[1]
Hipposideridae	5	1	3	4	6	3					1	
Rhinolophidae	1		2	1	5	5				5	5	2
Vespertilionidae	3	1			9-10[2]	4-5[2]	5		2	8	8	7
Molossidae					2	2				2	2	2
Total	**19**	**7**	**16**	**10**	**29-31**	**16-18**	**15**	**4**	**5**	**24**	**24-25**	**14-15**

[1] Calls of *Emballonura dianae* and/or *E. furax* recorded.

[2] Calls of *Miniopterus macrocneme* and/or *M. medius* recorded.

There is an inverse relationship between species diversity and altitude, with the Pteropodidae, in particular, having most species in the lowlands and at mid elevations. The lowlands also seem important for the rarer species.

The electronic detection methods have shown that several microbats previously thought to be rare are probably more common and widespread. The 2008 surveys confirmed this finding: of the 30 species of microbat recorded in 2005 and 2008, only 11 are now considered rare (that is, with less than 4 records and/or occurring at less than 2 survey areas). Of these, only two species were restricted to high elevations; the remaining nine were all recorded from elevations below 300 m ASL. These nine low-elevation species are slow flying and manoeuvrable bats that glean insects from substrates, forage for aquatic prey in the backwaters of rivers, or are species with specialised requirements for roost caves with very hot and humid microclimates.

The relative abundance of microchiropteran bats in major habitats during the 2008 surveys revealed that there were far fewer species utilising forest than many of the more open areas.

Plate 10.23
Microchiropteran bat *Aselliscus tricupidatus*

Plate 10.24
Superb fruit-dove

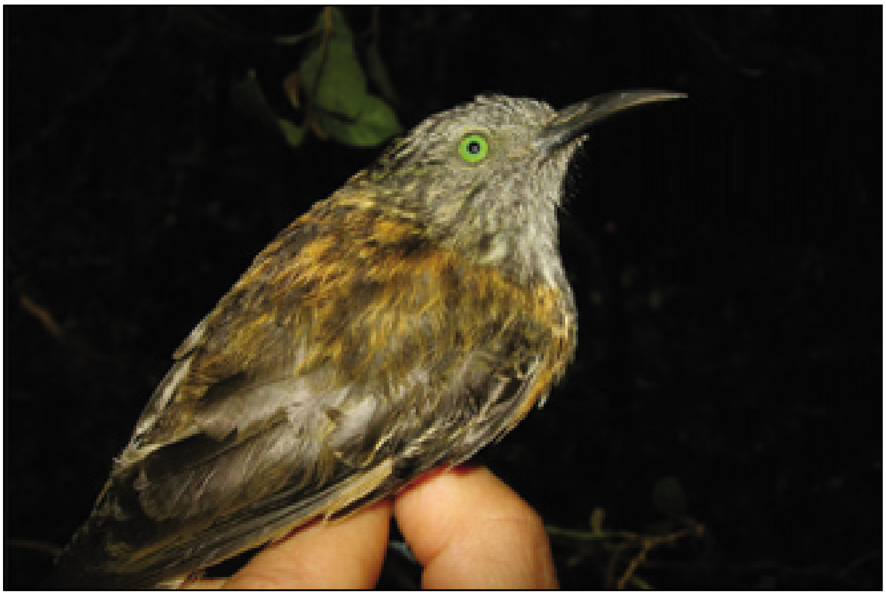

Plate 10.25
Rufous-backed honeyeater

The edges of rivers and major clearings or open areas were primary habitats, and more species were recorded along river edges than in any other habitat. At some survey areas, only 5 species were recorded in forest compared with 13 species at river edges. Also, activity (and relative abundance) in forest totalled 3,680 calls compared with 25,881 recorded in edge and open habitats. Of note is that 15 species were recorded in regrowth areas, nearly as many as in forest.

In general, the bat fauna of the upstream project area adapts well to foraging habitat disturbance; and, disturbance favours many species. However, species that roost or breed in caves or congregate in large colonies have sensitivities unrelated to the habitats within which they forage. Thirty-four of the species recorded or likely to occur in the upstream project area roost exclusively in caves. Although this area is extensively cavernous, this does not indicate that there are numerous caves to house bats, because most species have specific requirements of cave structure and microclimate.

Flying foxes (genus *Pteropus*) usually congregate in large colonies, particularly in the lowlands, and are very susceptible to hunting. Flying foxes that congregate in caves are particularly vulnerable, for which the loss (to hunting) of an entire colony of the critically endangered montane Bulmer's fruit-bat (*Aproteles bulmerae*) from a cave near the Hindenberg Wall in 1977 provides an example.[5]

While bats are generally tolerant of habitat disturbance, limiting both direct and indirect impacts on caves and colonial flying foxes will be an important project impact management consideration to maintaining the bat fauna of the upstream project area.

10.3.4.3 Birds

A total of 403 bird species have been recorded in the upstream project area, and a further 131 species could occur based on known distributions of these species in Papua New Guinea. Parrots, pigeons, honeyeaters and birds-of-paradise are the largest families and between them account for over 28% of the total species. Both lowland and mid-montane bioregions have more species than the higher montane areas.

New Guinea's forests support a high proportion of frugivores and nectarivores. The 16 species of fruit-doves (*Ptilinopus*) (Plate 10.24) and imperial-pigeons (*Ducula*), all specialist fruit eaters, are dispersers of seeds of forest trees, and the 14 species of brush-tongued lories and lorikeets are pollinators. The two species of cassowary disperse trees and vines, many with fruits too large to be dispersed by any other creature. Cassowaries are still abundant, particularly along the existing crude oil export pipeline in the Mubi River Karst bioregion and along the proposed route for the pipelines between Juha and Hides.

Many of the passerine families belong to a larger grouping with its centre of evolution in Australasia. Notably, the most species-rich groups include 33 honeyeaters (Meliphagidae; Plate 10.25), 17 warblers and scrubwrens (Pardalotidae) and 17 robins (Petroicidae; Plate 10.26). The Corvidae is a large passerine family (92 species recorded), and the upstream project area contains at least half of the 40 living species of birds-of-paradise (Paradisaeidae) and nearly two-thirds of the 31 species recorded in New Guinea and its islands. Many birds-of-paradise have

[5] During the 2008 survey, there were unconfirmed reports that a cave with Bulmer's fruit-bat may exist in the northern part of the project area.

restricted distributions (total area and/or altitude) and a number are of conservation value. A notable find in the 2005 survey was the greater melampitta (*Melampitta gigantea*) in the family Orthonychidae. This is one of New Guinea's most enigmatic birds, being restricted to rugged limestone country where it roosts and nests below ground; it has been recorded at Gobe and Agogo.

A total of 330 (some two-thirds) of the bird species of New Guinea and its satellite islands are endemic. Birdlife International (2008) has classified New Guinea into eight endemic bird areas (EBAs), each of which supports a high concentration of restricted-range species found nowhere else. In the global context, Papua New Guinea ranks fourth in numbers of restricted-range species (Birdlife International, 2008).

The upstream project area lies entirely within two of these EBAs: the Central Papuan Mountains and the South Papuan Lowlands. The former has the second-highest number of restricted-range species of all EBAs in the southeast Asian island region, includes nine endemic genera and ranks seventh of 128 EBAs world-wide for numbers of restricted-range species.

At the bioregion scale, the Kikori Lowlands and Sirebi Lowlands have the lowest endemicity in the upstream project area, reflecting the large number of more widespread wetland and secondary forest species. Details of endemicity in the upstream project area bioregions are provided in Table 10.11.

Forest birds dominate the upstream project area, particularly the passerines. Most can tolerate disturbance to some extent, and the majority can be found in secondary forests and sometimes scrublands and gardens. Primary forest specialists occur in all bioregions, but there is a tendency for numbers to increase in the mid-altitude bioregions. The montane bioregions contain by far the highest proportions of forest specialists, comprising almost 90% of the avifauna of the Northern Montane Karst. The Western Foothills (Juha region) has 80% forest specialists, yet it is of moderately low elevation at around 1,000 m ASL. A reason for the high percentage of specialists in these areas is the rarity of secondary habitats. (The proportion of forest specialists in a local avifauna declines as the amount of secondary habitat increases.)

A wide range of wetland and grassland species has also been recorded, with the greatest numbers in the lowlands and around Moro and Lake Kutubu. These include 23 waders, such as curlews, sandpipers and plovers (Scolopacidae and Charadriidae), 11 species of heron and egret (Ardeidae) and 11 species of the predominantly marine gulls and terns (Lariidae).

Over 86% of the species in the upstream project area are residents, meaning none or only part of the population migrates. Partial migration, which may be altitudinal and/or intra-country and has not yet been studied in Papua New Guinea, is well known in Asia and Australia. The few true migrants, where the entire population migrates, 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 upstream project area is relatively small.

Table 10.11 Endemicity of bird species in the bioregions of the upstream project area

Region	No. of Species within Each Endemicity Rating*					Total Species	Endemicity Score † (%)	No. of Survey Sample Sites
	5	4	3	2	1			
Kikori Lowlands	1	46	31	10	137	225	21	11
Sirebi Lowlands	1	13	19	4	37	74	19	1
Libano Hegigio	1	14	13	4	31	63	24	1
Darai Plateau	1	25	15	4	25	70	37	1
Western Lowlands	1	38	25	7	51	122	32	2
Western Foothills	1	34	10	8	29	82	43	1
Mubi River Karst	1	75	33	12	96	217	35	3
Moro Region#	1	74	31	12	102	220	34	3
Western Volcanics	16	94	7	6	47	160	63	3
Eastern Uplands Volcanics/Karst	7	69	10	8	57	151	50	4
Northern Montane Karst	3	47	3	2	9	64	78	1

Endemicity Rating: 5 – Endemic to mainland Papua New Guinea, 4 – Endemic to New Guinea and its satellite islands, 3 – Endemic to New Guinea and its satellite islands and the Aru Islands, 2 – Endemic to New Guinea and its satellite islands and New Britain and/or New Ireland and/or the Loisiades, 1 – Occurs widely through Australia, Indonesia, the Solomon Islands or the Pacific.

† Endemicity Score: the percent of species with endemicity ratings of 4 and 5.

Includes the Iagifu Agogo Limestone Uplands.

10.3.4.4 Reptiles

The herpetofauna are the least known group of terrestrial vertebrates in Papua New Guinea; and the WWF work and the 2005 and 2008 surveys have added considerably to overall knowledge of the PNG herpetofauna. Surveys in the upstream project area have concentrated on frogs, and the reptile fauna is considered under-sampled. In particular, the distribution of the freshwater turtles, a popular food item with locals, is very poorly known.

Table 10.12 shows the 61 species of reptiles recorded in the upstream project area by bioregion. Diversity decreases with increasing altitude. Not many reptiles in New Guinea tolerate the cold wet climates of the montane regions, and so in upland sites, reptile diversity can be very low.

Plate 10.26
Garnet robin

Plate 10.27
The gecko *Cyrtodactylus* sp.

Plate 10.28
The agamid *Hypsilurus modestus*

Table 10.12 Number of reptile species in the bioregions of the upstream project area

	Kikori Lowlands	Libano Hegigio	Darai Plateau	Western Lowlands	Western Foothills	Mubi River Karst	Moro Region	Western Volcanics	Eastern Uplands Volcanics/Karst	Northern Montane Karst
Upper elevation of bioregion (m ASL)	200	1,100	600	400	1,200	1,300	1,000	2,700	1,800	3,300
Lower elevation of bioregion (m ASL)	0	300	200	200	400	200	800	280	800	1,800
Family										
Crocodylidae	1	1		1						
Agamidae	2	3	2	2	1				1	
Gekkonidae	2	4	2	4		1	2		1	
Scincidae	5	8	7	9	5			5	9	4
Varanidae	2	1		1						
Elapidae	3			1						
Pythonidae	2	2	1	2				1	3	1
Colubridae	4	2		2	1			1	2	1
Total Species	**21**	**21**	**12**	**22**	**7**	**1**	**2**	**7**	**16**	**6**

Sirebi Lowlands and Iagifu Agogo Limestone Uplands bioregions are not included as there are no records of reptiles in these bioregions from the surveys.

Most reptiles are small- to medium-sized skinks of the forest or forest clearings, and skinks are the only lizards found so far in the high montane karst areas. The more spectacular arboreal forest geckos (Cyrtyodactlyus; Plate 10.27), goannas and dragons (Agamidae; Plate 10.28) tend to have lowland to low montane distributions. Among the snakes, Boelen's python (*Morelia boeleni*; Plate 10.29) is a montane specialist.

Lowland sites have typical southern New Guinea reptile assemblages, with snakes far more common in the warmer conditions.

The most notable reptile in the upstream project area is the New Guinea freshwater crocodile, which the 2008 survey located in the Western Lowlands bioregion (see Section 10.4.6.2, Crocodiles).

Prior to this 2008 observation, the freshwater crocodile had been known in the upstream project area only from the Libano River. The much larger, more common and widely distributed saltwater crocodile (*C. porosus*) is known from several locations in the upstream project area.

Plate 10.29
Boelen's python *Morelia boeleni*

Plate 10.30
The ranid frog *Rana* cf. *grisea*

Plate 10.31
Tree frog laying eggs on a leaf above a sinkhole swamp

10.3.4.5 Amphibians

With 107 species, the frog fauna of the upstream project area amounts to a third of the New Guinea total and represents the most diverse assemblage of any catchment in New Guinea. Table 10.13 shows the species in each bioregion.

Table 10.13 Number of amphibian species in the bioregions of the upstream project area

Family	Kikori Lowlands	Libano Hegigio	Darai Plateau	Western Lowlands	Western Foothills	Mubi River Karst	Moro Region	Western Volcanics	Eastern Uplands Volcanics/Karst	Northern Montane Karst
Microhylidae	17	15	21	21	24	19	18	22	22	7
Hylidae	6	4	7	12	9	6	16	8	17	2
Myobatrachidae	1	1	1		1		1	1	1	
Ranidae	4	2	4	3	2	1	3	2	2	
Total species	**28**	**22**	**33**	**36**	**36**	**26**	**38**	**33**	**42**	**9**

Sirebi Lowlands and Iagifu Agogo Limestone Uplands bioregions are not included as there are no records of reptiles in these bioregions from the surveys.

The Hylidae and the Microhylidae completely dominate the amphibians. (The only other family with more than a few species is the Ranidae; Plate 10.30.) The Microhylidae are small terrestrial frogs. They have been able to breed extensively in the constantly moist montane habitats of New Guinea because they lay their eggs in terrestrial environments humid enough for their embryos to develop without free water. The Hylidae are tree frogs and occupy a range of specific microhabitats, such as streams, torrents, pools, stream edges and tree canopies. Some Hylidae lay their eggs in water that collects in stumps or dead branches, while others stick their eggs to leaves above pools, into which the tadpoles drop after hatching (Plates 10.31 and 10.32).

The richest survey area was Juha North, where 36 species, including some new to science, were recorded. This represents the highest of any survey area in New Guinea and identifies this locality as a management priority for construction and operations.

Altitude influences the distributions of most frogs. Most of the species of *Albericus* (Plate 10.33) live in the cool cloud forests, but temperatures at very high elevations are too cold for most species. The maximum frog diversity occurs in the low montane zone between 500 m and 1,500 m ASL.

The availability of standing water has a big effect on frog community composition. For example, 50% to 66% of species at each of the five 2008 survey areas, all of which had standing or flowing water, were Microhylidae, and 25% to 33% were Hylidae. By comparison, seven of the nine species at the Hides 3 well survey area, which is in polygonal karst with no flowing and little standing water but high ambient humidity, were Microhylidae.

Plate 10.32
Tree frog eggs on leaf where tadpoles will hatch and drop into a sinkhole swamp below

Plate 10.33
An undescribed species of microhylid *Albericus*

Plate 10.34
The tree frog *Litoria* cf. *arfakiana*

Most of the frogs occupy widespread habitats, but there are several species restricted to very clear, swift, mountain torrents. These include *Litoria* cf. *arfakiana* (a tree frog; Plate 10.34), *L. wollastoni* (a torrent frog; Plate 10.35), *Rana* cf. *grisea* (see Plate 10.30), *Nyctimystes pulcher* (a tree frog; Plate 10.36), *N. kuduk* and a further five species of *Litoria* and one species of *Nyctimystes* considered new to science.

10.3.5 Conservation Areas

Papua New Guinea 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. Much of this speciation reflects the physiographic diversity created by a complex geological and geomorphic history, particularly in the east of the island. Different mountain ranges can have different species, species replace each other along steep altitudinal gradients, and there are a number of super-species 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.

This biological complexity across large areas of little-disturbed forest has prompted the recognition of Papua New Guinea’s biodiversity status. Analyses of areas of high conservation value, covering most of Papua New Guinea, accorded particular significance to the Kikori catchment for its remoteness and intactness.

The Kikori River Programme is one of the world’s great wilderness areas and this status has been maintained alongside an existing oil project. Within it, there are five designated government conservation areas:

- Lake Kutubu Wildlife Management Area of 25,455 ha.
- Neiru/Aird Hills Wildlife Management Area of 3,963 ha southeast of Kopi.
- Libano–Arisai Wildlife Management Area of 3,964 ha on Libano Creek.
- Libano–Hose Wildlife Management Area of 7,736 ha adjoining Libano–Arisai.
- Sulamesi Wildlife Management Area of 86,451 ha on Mt Bosavi.

The Lake Kutubu Wildlife Management Area, the only wildlife management area that the project footprint intersects, is a Ramsar-listed wetland but does not have a specific wetland management plan. It is currently managed under the wildlife management area arrangement.

Eleven other areas of particular biodiversity significance in the southern section of the upstream project area have been identified by WWF (Table 10.14). These are described in Appendix 1, Biodiversity Impact Assessment. As yet none of these WWF significant biological areas has received official recognition as a reserve within Papua New Guinea.

This assessment predates the more recent of the WWF work and the 2005 and 2008 surveys, and it does not cover the northern section of the upstream project area. Nonetheless, the WWF work, on which this assessment was based, points to the high biological diversity status of the Kikori catchment as a whole. In this context, the designated areas are, in large part, a reflection of isolation and remoteness from human settlement.

Plate 10.35
The torrent frog *Litoria wollastoni*

Plate 10.36
A *Nyctimistes* sp. tree frog with road-map eyelids typical of the genus

Plate 10.37
Hides Wellpad E, site of the existing Hides 1 well

Table 10.14 WWF areas of biological significance in the upstream project area

Region	Description
Area 1: Lower Kikori-Omati River delta mangrove and swamp forest	Together with the Turama and Purari mangrove forests, this is one of the most extensive stands of mangroves in Papua New Guinea. A rich fish biodiversity and the importance of mangroves as breeding areas for fish and prawns warranted the designation of this area.
Area 2: Veiru Creek catchment and lower swamp forests	This area 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	This area has diverse and abundant mammal fauna, including rare bats.
Area 4: Upper Sirebi River and Lubu River	This area has cold waters from an extensive system of underground caverns and harbours a displaced upland aquatic insect biota. It also has high fish, bird and flora diversity.
Area 5: Darai Plateau and associated limestone karst country	This area has a large tract of tower limestone and, because the area is uninhabited, its fauna populations are largely intact.
Area 6: Mount Bosavi	This area has 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 aquatic insect fauna.
Area 7a: Kantobo/Wassi Falls and Gobe karst ridge system	This area has generally high biodiversity.
Area 7b: Blind fish habitat	This area has a new species of blind cave fish apparently restricted to the area.
Area 7c: Agogo and Iwa ranges	This area has generally high biodiversity.
Area 7d: Lake Kutubu Wildlife Management Area and catchment of Wage and Kaimari creeks draining into the Digimu River near Moro	This area is identified for the special values of Lake Kutubu and the endemic species therein and the generally high biodiversity of its environs.
Area 8: Mount Sisa	This area has a potentially rich mammal and moth fauna.

10.3.6 Conservation Status of Flora and Fauna

This section lists the plants and animals of conservation status within the upstream project area, from both an international and domestic (Papua New Guinea) perspective.

10.3.6.1 Flora

Eight flora species recorded in the upstream project area are listed on the International Union for the Conservation of Nature (IUCN) Red List of threatened species (Table 10.15).

These species are primarily threatened by unsustainable logging. Details of each species can be found in Appendix 1, Biodiversity Impact Assessment.

Table 10.15 Flora species of conservation significance in the upstream project area

Common Name	Scientific Name	IUCN Status[1]
Tree	*Halfordia papuana* Laut.	CR
Tree	*Bleasdalea papuana* (Diels) Domin	EN
Tree	*Flindersia pimenteliana F.v.M*	EN
Tree	*Arthrophyllum proliferum* Philipson	VU
Tree	*Helicia acutifolia* Sleum	VU
Tree	*Pterocarpus indicus*	VU
Tree	*Aglaia puberulanthera*	VU
Tree	*Myristica globosa*	NT

[1] IUCN status: CR = critically endangered, EN = endangered, VU = vulnerable, NT = lower risk but near threatened.

10.3.6.2 Non-volant Mammals

Twenty non-volant mammal species recorded in the upstream project area are listed on the IUCN Red List of threatened species, and two species listed under the PNG *Fauna (Protection and Control) Act 1966* have been recorded in the upstream project area (Table 10.16).

These mammals have the potential to be impacted by a range of factors, paramount of which is loss of habitat through clearing, edge and barrier effects and hunting. The most significant threat to them is the indirect effects of wildfire, exotic pests, weeds and diseases and increased hunting. Details of each species can be found in Appendix 1, Biodiversity Impact Assessment.

Table 10.16 Non-volant mammal species of conservation significance in the upstream project area

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Large leptomys	*Leptomys elegans*	CR	-
Fly River leptomys	*Leptomys signatus*	CR	-
Large pogonomelomys	*Pogonomelomys bruijni*	CR	-
Long-beaked echidna	*Zaglossus bartoni*	EN	-
Goodfellow’s tree kangaroo	*Dendrolagus goodfellowi*	EN	-
Greater small-toothed rat	*Macruromys major*	EN	-
New Guinea quoll	*Dasyurus albopunctatus*	VU	-
Stein’s cuscus	*Phalanger vestitus*	VU	-
Doria’s tree kangaroo	*Dendrolagus dorianus*	VU	-
Macleay’s dorcopsis	*Dorcopsulus macleayi*	VU	-
New Guinea pademelon	*Thylogale browni*	VU	-
Plush-coated ringtail	*Pseudochirops corinnae*	VU	-
Great-tailed triok	*Dactylopsila megalura*	VU	-
One-toothed shrew mouse	*Mayermys ellermani*	VU	-
Long-nosed murexia	*Phascomurexia naso*	DD	-
Ground cuscus	*Phalanger gymnotis*	DD	-
Lowland tree kangaroo	*Dendrolagus spadix*	DD	-
Lowland ringtail	*Pseudochirulus canescens*	DD	-

Table 10.16 Non-volant mammal species of conservation significance in the upstream project area (cont'd)

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Giant naked-tailed rat	*Uromys anak*	NT	-
Rock-dwelling giant rat	*Xenuromys barbatus*	NT	-
Short-beaked echidna	*Tachyglossus aculeatus*	-	R
Feather-tailed possum	*Distoechurus pennatus*	-	R

[1] IUCN status: CR = critically endangered, EN = endangered, VU = vulnerable, NT = lower risk but near threatened, DD = data deficient.

[2] Status under the PNG *Fauna (Protection and Control) Act 1966*: R = restricted.

10.3.6.3 Bats

Fifteen bat species on the IUCN Red List of threatened species have been recorded in the upstream project area, and a further 12 are likely to occur (Table 10.17). No species recorded were listed under the PNG *Fauna (Protection and Control) Act 1996*.

These bats are sensitive to the same impacts as non-volant mammals. They are generally tolerant of forest disturbance but not to disturbance of their breeding and roosting caves. Mitigation measures described in 'Caves' in Section 18.7.4.3, Direct and Indirect Impacts on Noteworthy Areas During Construction and Operations, specifically address this threat for project-related activities. The most significant threat to bats is the indirect effects of wildfire, exotic pests, weeds and diseases and possible increased hunting brought about by improving access to the area. Details of each species can be found in Appendix 1, Biodiversity Impact Assessment.

Table 10.17 Bat species of conservation significance in the upstream project area

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Bulmers' fruit-bat*	*Aproteles bulmerae*	CR	-
Thomas' big-eared bat*	*Pharotis imogene*	CR	-
Lesser tube-nosed bat	*Nyctimene draconilla*	VU	-
Moss-forest blossom bat*	*Syconycteris hobbit*	VU	-
Large-eared sheath-tailed bat	*Emballonura dianae*	VU	-
New Guinea sheath-tailed bat	*Emballonura furax*	VU	-
Papuan sheath-tailed bat*	*Saccolaimus mixtus*	VU	-
Telefomin leaf-nosed bat*	*Hipposideros corynophyllus*	VU	-
Fly River leaf-nosed bat*	*Hipposideros muscinus*	VU	-
Small-toothed big-eared bat	*Nyctophilus microdon*	VU	-
Greater big-eared bat*	*Nyctophilus timoriensis*	VU	-
Fly River trumpet-eared bat	*Kerivoula muscina*	VU	-
Papuan mastiff bat*	*Otomops papuensis*	VU	-
Mantled mastiff bat	*Otomops secundus*	VU	-
Lesser bare-backed bat	*Dobsonia minor*	NT	-
Greater tube-nosed bat	*Nyctimene aello*	NT	-
Round-eared tube-nosed bat	*Nyctimene cyclotis*	NT	-

Table 10.17 Bat species of conservation significance in the upstream project area (cont'd)

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Green tube-nosed bat	*Paranyctimene raptor*	NT	-
Raffray's sheath-tailed bat	*Emballonura raffrayana*	NT	-
Yellow-bellied sheath-tailed bat*	*Saccolaimus flaviventris*	NT	-
Southern sheath-tailed bat*	*Taphozous australis*	NT	-
Hill's leaf-nosed bat*	*Hipposideros edwardshilli*	NT	-
Greater leaf-nosed bat	*Hipposideros semoni*	NT	-
Wollaston's leaf-nosed bat	*Hipposideros wollastoni*	NT	-
Large-eared horseshoe bat	*Rhinolophus philippinensis*	NT	-
Papuan pipistrelle	*Pipistrellus papuanus*	NT	-
Watt's pipistrelle*	*Pipistrellus wattsi*	NT	-

* Species likely to occur but not yet recorded.

[1] IUCN status: CR = critically endangered, VU = vulnerable, NT = lower risk but near threatened.

[2] Status under the PNG *Fauna (Protection and Control) Act 1966*.

10.3.6.4 Birds

Of the bird species recorded and likely to occur in the upstream project area, 23 are listed on the IUCN Red List of threatened species, 37 are listed under the PNG *Fauna (Protection and Control) Act 1966* (Table 10.18) and an additional 10 are listed under both. These birds are impacted by habitat loss, edge effects and hunting and more rarely by barrier effects. The most significant threat to them is the indirect effects of wildfire, exotic pests, weeds and diseases and possible increased hunting brought about by improving access to the area. Details of each species can be found in Appendix 1, Biodiversity Impact Assessment.

Table 10.18 Bird species of conservation significance in the upstream project area

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Papuan whipbird*	*Androphobus viridis*	CR	-
Salvadori's teal	*Salvadorina waigiuensis*	VU	P
Black sicklebill	*Epimachus fastuosus*	VU	P
Blue bird-of-paradise	*Paradisaea rudolphi*	VU	P
Southern crowned-pigeon	*Goura scheepmakeri*	VU	P
Southern cassowary	*Casuarius casuarius*	VU	R
Pesquet's parrot	*Psittrichas fulgidus*	VU	R
New Guinea eagle	*Harpyopsis novaeguineae*	VU	-
Antarctic giant-petrel*	*Macronectes giganteus*	VU	-
Long-bearded melidectes*	*Melidectes princeps*	VU	-
Yellow-breasted bird-of paradise	*Loboparadisea sericea*	NT	P
Ribbon-tailed astrapia	*Astrapia mayeri*	NT	P
Gurney's eagle	*Aquila gurneyi*	NT	R
Black-necked stork*	*Ephippiorhynchus asiaticus*	NT	R
Dwarf cassowary	*Casuarius bennetti*	NT	-

Table 10.18 Bird species of conservation significance in the upstream project area (cont'd)

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Striated lorikeet	*Charmosyna multistriata*	NT	-
New Guinea flightless rail	*Megacrex inepta*	NT	-
Black-tailed godwit	*Limosa limosa*	NT	-
Asian dowitcher	*Limnodromus semipalmatus*	NT	-
Buff-breasted sandpiper*	*Tryngites subruficollis*	NT	-
Beach thick-knee	*Esacus giganteus*	NT	-
Doria's goshawk*	*Megatriorchis doriae*	NT	-
Forest bittern	*Zonerodius heliosylus*	NT	-
Archbold's bowerbird*	*Archboldia papuensis*	NT	-
White-bellied pitohui*	*Pitohui incertus*	NT	-
Olive-yellow robin	*Poecilodryas placens*	NT	
Yellow-eyed starling	*Aplonis mystacea*	NT	-
Blue-black kingfisher	*Todirhamphus nigrocyaneus*	DD	-
Papuan hawk-owl*	*Uroglaux dimorpha*	DD	-
Starry owlet-nightjar*	*Aegotheles tatei*	DD	-
Wallace's owlet-nightjar*	*Aegotheles wallacii*	DD	-
Chestnut-shouldered goshawk*	*Erythrotriorchis buergersi*	DD	-
Obscure berrypecker*	*Melanocharis arfakiana*	DD	-
Blyth's hornbill	*Aceros plicatus*	-	P
Palm cockatoo	*Probosciger aterrimus*	-	P
Osprey*	*Pandion haliaetus*	-	P
Little egret	*Egretta garzetta*	-	P
Great egret	*Ardea alba*	-	P
Intermediate egret	*Mesophoyx intermedia*	-	P
Papuan lorikeet	*Charmosyna papou*	-	R
Sulphur-crested cockatoo	*Cacatua galerita*	-	R
Pheasant pigeon	*Otidiphaps nobilis*	-	R
Little curlew*	*Numenius minutus*	-	R
White-bellied fish-eagle	*Haliaeetus leucogaster*	-	R
Eastern marsh-harrier	*Circus spilonotus*	-	R
Swamp harrier*	*Circus approximans*	-	R
Australian kestrel	*Falco cenchroides*	-	R
Oriental hobby	*Falco severus*	-	R
Australian hobby	*Falco longipennis*	-	R
Brown falcon	*Falco berigora*	-	R
Peregrine falcon	*Falco peregrinus*	-	R
Flame bowerbird*	*Sericulus aureus*	-	R
Crested bird-of-paradise*	*Cnemophilus macgregorii*	-	P

Table 10.18 Bird species of conservation significance in the upstream project area (cont'd)

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Loria's bird-of-paradise	*Cnemophilus loriae*	-	P
Glossy-mantled manucode	*Manucodia atra*	-	P
Crinkle-collared manucode	*Manucodia chalybata*	-	P
Trumpet manucode	*Manucodia keraudrenii*	-	P
Short-tailed paradigalla	*Paradigalla brevicauda*	-	P
Brown sicklebill	*Epimachus meyeri*	-	P
Black-billed sicklebill	*Epimachus albertisi*	-	P
Superb bird-of-paradise	*Lophorina superba*	-	P
Carola's parotia	*Parotia carolae*	-	P
Lawe's parotia	*Parotia lawesii*	-	P
Magnificent riflebird	*Ptiloris magnificus*	-	P
Magnificent bird-of-paradise	*Cicinnurus magnificus*	-	P
King bird-of-paradise	*Cicinnurus regius*	-	P
Stephanie's astrapia	*Astrapia stephaniae*	-	P
King-of-Saxony bird-of-paradise	*Pteridophora alberti*	-	P
Twelve-wired bird-of-paradise	*Seleucidis melanoleuca*	-	P
Raggiana bird-of-paradise	*Paradisaea raggiana*	-	P

* Species likely to occur but not yet recorded.
[1] IUCN status: CR = critically endangered, VU = vulnerable, NT = lower risk but near threatened, DD = data deficient.
[2] Status under the PNG *Fauna (Protection and Control) Act 1966*: P = protected, R = restricted.

10.3.6.5 Reptiles

Eleven species of reptile recorded in the upstream project area are listed under the PNG *Fauna (Protection and Control) Act 1966* (Table 10.19). None are listed on the IUCN Red List. These reptiles are sensitive to habitat loss, edge and barrier effects, but are mainly threatened by hunting and the indirect effects of wildfire, exotic pests, weeds and diseases. Details of each species can be found in Appendix 1, Biodiversity Impact Assessment.

Table 10.19 Reptile species of conservation significance in the upstream project area

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Saltwater crocodile	*Crocodylus porosus*	-	R
New Guinea freshwater crocodile	*Crocodylus novaeguineae*	-	R
Mangrove monitor	*Varanus indicus*	-	R
Gould's monitor	*Varanus dorianus*	-	R
Salvadori's monitor	*Varanus salvadori*	-	R
Ground boa	*Candoia aspera*	-	R
Pacific boa	*Candoia carinata*	-	R
Amethystine python	*Morelia amethistina*	-	R

Table 10.19 Reptile species of conservation significance in the upstream project area (cont'd)

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Boelen's python	*Morelia boeleni*	-	R
Green tree python	*Morelia viridis*	-	R
Olive python	*Liasis fuscus*	-	R

[1] IUCN status.

[2] Status under the PNG *Fauna (Protection and Control) Act 1966*: R = restricted.

10.3.6.6 Amphibians

Five amphibian species listed on the IUCN Red List were recorded in the upstream project area and are listed in Table 10.20. No amphibian species recorded were listed under the PNG *Fauna (Protection and Control) Act 1966*. These frogs are sensitive to habitat loss, edge and barrier effects. The most significant threat to them would be indirect effects of wildfire, exotic pests, weeds and diseases. In addition, sinkhole swamps in high altitude karst terrain, like on Hides Ridge, provide niche habitat for numerous frog species, including several new to science. Management measures to reduce impacts to these features, which largely relate to sidecast and fugitive sedimentation effects from earthworks, are described in 'Sinkhole Swamps' in Section 18.7.4.3, Direct and Indirect Impacts on Noteworthy Areas During Construction and Operations. Details of each species can be found in Appendix 1, Biodiversity Impact Assessment.

Table 10.20 Amphibian species of conservation significance in the upstream project area

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]
Frog	*Choerophryne allisoni*	DD	-
Frog	*Cophixalus cryptotympanum*	DD	-
Frog	*Hylophorbus richardsi*	DD	-
Frog	*Oreophryne notata*	DD	-
Frog	*Litoria majikthise*	DD	-

[1] IUCN status: DD = data deficient.

[2] Status under the PNG Fauna (Protection and Control) Act.

10.3.7 Noteworthy Areas of Terrestrial Biodiversity

The WWF work and the 2005 and 2008 surveys have enabled 10 areas to be nominated for special protective measures in any project development plan. The areas are listed below along with the reasons for which they have been nominated.

10.3.7.1 Juha

The 2008 survey established the significance of the Juha area in terms of:

- The remoteness of the region and the lack of human influence on the vegetation and fauna.
- The lack of weeds and other exotics in the area.
- No or low populations of wild pigs.
- The virtual absence of hunting.

- The occurrence in abundance of many bird and mammal species in abundance that elsewhere have been exterminated or severely reduced in populations.
- The richness of the frog fauna, the Juha South survey area being the richest site yet surveyed in New Guinea.
- The high diversity of mammals and birds.
- The occurrence of montane species of flora and fauna at very low altitudes.
- Ten species of plants new to science, some of them of particular botanical significance.
- Thirteen frogs in the upstream project area known only in this area.
- Six species of frogs new to science.

As for the Hides Ridge area (see below), the existing exploration wells have had no material impact in this area, and its ecological values are maintained by its difficulty of access. There are one or two tiny hamlets nearby but not within the area, and their impact has likewise been minimal to undetectable. The very high biodiversity values as evidenced by the 2005 survey results (see Annexes 1, 3, 5, 7 and 9 in Appendix 1, Biodiversity Impact Assessment) coexist alongside the existing infrastructure more so than occur in similar areas close to habitation.

The remoteness, richness and mostly untouched condition of the forests warrant a management focus on access restrictions during construction and operations to prevent the indirect impacts of hunting, logging and settlement.

10.3.7.2 Hides Ridge

The features of Hides Ridge identified in the 2005 survey were as follows:

- Twelve of the 16 new plant species discovered were from Hides Ridge, including a new tree fern and three remarkable calcium-depositing ferns that are likely to be restricted to high-altitude karst
- High diversity of high-altitude birds-of-paradise.
- High concentration of limited-range, endemic, high-altitude birds, including the presence of the elusive and rare greater melampitta bird.
- An abundance of arboreal mammals.
- The occurrence of the rare rock-dwelling giant-rat.
- Potential for occurrence of caves of the critically endangered Bulmer’s fruit-bat.
- An abundance of high-flying, rare mastiff bats, occurrence of a new and unidentified species of vespertilionid bat, and the occurrence of the rare and elusive bat *Murina florium*.
- Three of the five IUCN-listed frog species in the upstream project area occur at Hides Ridge[6].
- The forests around Wellpad D are of high significance for conservation of poorly known frogs.

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[6] At least three species of frogs are known only from Mount Sisa and Hides Ridge and another four only from Mount Sisa, Hides Ridge and the pipelines route between Homa and the Hides Gas Conditioning Plant.

- The forest is largely undisturbed and only two exotic weeds were recorded, neither of which are a problem ecologically.

The gas wells, flowlines, helicopter pads and seismic lines cut for exploration have had little material impact on Hides Ridge (Plate 10.37), and its ecological values are maintained by its difficulty of access. As mentioned above in Section 10.3.7.1, in Juha, it has been shown that high biodiversity values exist alongside the existing infrastructure, more so than occur in similar areas close to habitation locations (Appendix 1, Biodiversity Impact Assessment). The epiphytes and ferns are the major component of plant biodiversity in this forest type, trees being the structure upon which these plants develop.

This forest on Hides Ridge is sensitive to fire, and the high altitude means slow growth rates and slow regeneration.

The Hides Ridge area warrants special erosion control and regeneration systems for construction, but controlling access to this area in the long term in order to eliminate indirect impacts of hunting and weed and pest invasion is the most important priority.

10.3.7.3 High-altitude Forest Above 1,800 Metres

The area above 1,800 m ASL on the pipelines between Homa and the Hides Gas Conditioning Plant has similar qualities to Hides Ridge. It is weed-free and has one of the highest mammal diversities in the upstream project area. However, it differs from Hides Ridge in two fundamental ways: it is not a pure karst area and hence has generally better soils; and it is crossed by the walking trail from Homa to Benaria.

Construction through this area will require similar erosion control and regeneration management as for Hides Ridge.

10.3.7.4 Caves

Caves are abundant in the karst of the upstream project area, but only some of them are important for conservation of the cave-dwelling bats as particular species require caves with very specific conditions and architecture, in which to roost and breed.

Caves in the uplands may support colonies of the extremely rare and critically endangered Bulmer’s fruit-bat.

10.3.7.5 Sinkhole Swamps

Sinkhole swamps are microhabitats of small pools or swamps (Plate 10.28) at the bottom of dolines or depressions in high-altitude karst, where falling leaf litter and other organic debris has impeded the drainage. These are the only habitats where tree frogs and other water-dependent frogs can breed in these karst areas, which tend to have few flowing streams.

Plate 10.38
Sinkhole swamp on Hides Ridge

Plate 10.39
The Maruba River near Homa

Plate 10.40
Riverine habitat (Baia River mainstream)

Sinkhole swamps have been identified as a special focus habitat requiring particular impact mitigation.

10.3.7.6 Upland Streams

Stream condition is important for maintaining populations of torrent-dwelling frogs and birds such as Salvadori's teal, torrent-lark and torrent robin. The torrent-dwelling frogs, in particular, require fast-flowing, clear water rocky streams with intact riparian vegetation (Plate 10.39). Such vegetation can also be a specialised habitat for hydromyine rodents and less commonly in these higher elevations, for birds.

10.3.7.7 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 freshwater turtles and crocodiles. Swamp forests tend to be resilient to physical vegetation disturbance but can be destroyed by fire in drought years and eliminated permanently by adverse changes to hydrology. Biologically, the upland swamp forests are of particular note.

Swamp forests are not always wet but are maintained by a drying and wetting regime. Drier conditions promote the growth of trees and a forest structure. Wetter conditions promote palms, particularly sago palms. Ponding converts them to freshwater swamps and, if there is seawater ingress, to mangroves. Dry conditions convert them to drier forest formations, scrublands or grasslands.

The dependence of these areas on inundation and restricted drainage mean that changes to hydrology may affect the wetland characteristics of these forests.

Fire can eliminate these complexes if they are developed on peat substrates, which can readily burn when dried out.

Swamp forests have been identified as a special focus habitat requiring particular impact mitigation.

10.3.7.8 Stream Refuges in Unstable Landscapes

Areas of mature habitat on stable substrates (for example, stream heads or small plateaux) are disproportionately important as regional fauna refuges in otherwise unstable and landslide-prone areas like the Baia River. Moreover, the dynamic hydrological conditions of major rivers in these unstable landscapes mean that the clearing, earthworks and sedimentation effects of construction add little damage to what occurs naturally. In these circumstances, it is appropriate to shift the emphasis of environmental management from its usual focus on river crossings to protecting the more stable back water refuge areas in the general vicinity (Appendix 1, Biodiversity Impact Assessment).

10.3.7.9 Lowland Rivers in Stable Landscapes

The lowland rivers in more stable landscapes provide the habitat for crocodiles and freshwater turtles. Within the upstream project area, there does not appear to be a specialised bird fauna restricted to riverine forest (as there is in gallery forests in dry woodlands). However, some species are particularly abundant, including kingfishers and shining flycatchers. In the lowlands, riverine forest supports a variety of large fruiting trees and is consequently particularly rich in pigeons and parrots. No species is restricted to this habitat, but many birds will take refuge in riverine forest during the drier parts of the year and at hot times of the day, particularly in the lowlands.

10.3.7.10 Off-river Waterbodies

The discovery of breeding New Guinea freshwater crocodiles in a small off-river waterbody alongside the Baia River during the 2008 survey identifies this habitat type in unstable lowland landscapes as a management priority. Such habitats are created by localised damming of runoff by landslides and should therefore be reasonably simple to maintain through construction.

10.4 Aquatic Biological Environment

This section describes the onshore aquatic biological environment of the highlands and gulf region within the upstream project area and includes data sources (Section 10.4.1), aquatic habitats (Section 10.4.2), aquatic flora (Section 10.4.3), fish fauna (Section 10.4.4), macroinvertebrate fauna (Section 10.4.5), and other aquatic fauna (Section 10.4.6).

10.4.1 Data Sources

A systematic survey program for freshwater fish and invertebrates in New Guinea was undertaken during the decade 1994 to 2004 by various research organisations, including the Bishop Museum, Smithsonian Institution, PNG National Museum and Gallery, and Conservation International. During the same period, the WWF also undertook several freshwater fish surveys as part of the former KICDP in concert with Chevron Niugini and Oil Search Limited. This work was focused largely on the upper catchment of the Kikori River.

A compilation of the aquatic biological surveys of highlands rivers was undertaken in 2005 for the previously proposed PNG Gas Project (NSR, 1998a; Enesar, 2005) and further studies were completed in 2008 (Appendix 2, Aquatic Fauna Impact Assessment) for the PNG LNG Project. The 2008 aquatic biological surveys targeted rivers and streams within newly defined upstream project areas, such as the Hides to Juha pipeline ROW and the Hides Gas Conditioning Plant. In addition, surveys were undertaken to provide supplementary aquatic biological data for areas that were not covered in detail in the PNG Gas Project EIS, such as the Tagari River and rivers and streams located within the Homa to Idauwi area. A summary of the data sources relating to the aquatic biological environment of the highlands and gulf region is as follows:

- Appendix 2. PNG LNG Project: Upstream Aquatic Impact Assessment. Report to Coffey Natural Systems.
- Enesar (2005). Onshore Aquatic Environmental Impacts. Supporting study to Enesar (2005) Environmental Impact Assessment. David Balloch and Associates.
- Enesar (2005). PNG Gas Project EIS. Report to Esso Highlands Limited.
- NSR (1998a). PNG Gas Project Environmental Plan. Existing Environment and Impact Assessment Sections. Report to Chevron Niugini Limited.

- Vui, R. (2003). A preliminary freshwater fish inventory report from Libano, a proposed wildlife management area (WMA), Southern Highlands Province. A report submitted to World Wildlife Fund for Nature, KICDP.
- Various WWF reports and papers on the Kikori catchment and Lake Kutubu fish fauna and aquatic resource use.

10.4.2 Aquatic Habitats

The upstream project area offers a wide variety of aquatic habitats that can be broadly categorised into riverine, clear water stream, sinkhole and subterranean stream, lacustrine, estuarine and mangrove habitats.

10.4.2.1 Riverine Habitats

The major rivers of the upstream project area (i.e., Tagari, Hegigio, Mubi, Digimu, Baia and Kikori rivers) are generally highly turbid and provide a variety of habitats for aquatic fauna (Plate 10.40). However, the high turbidity regimes in these major rivers preclude successful establishment of submerged aquatic macrophytes, benthic algae, periphytons and diatoms. In contrast, in non-turbid rivers (e.g., headwaters and tributaries), aquatic flora are represented by benthic algae, periphytons and diatoms.

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). These main channel habitats are characterised by high discharge and high concentrations of suspended sediments and associated turbidity. 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 numerous fish and macroinvertebrate species.

10.4.2.2 Clear Water Stream Habitats

Clear water streams are mainly those tributaries that generally terminate at rivers or within depressions or sinkholes and include many of the small tributaries of the Tagari, Hegigio, Wai Asia, Strickland and Baia rivers. Clear water streams are characterised by low concentrations of suspended sediments and associated low turbidity (Plate 10.41). Clear water streams share some characteristics with riverine main channel habitats, such as microhabitats of rocks, roots and fallen trees; however, they are generally smaller with less flow and limited suspended particulate matter.

10.4.2.3 Sinkholes and Subterranean Stream Habitats

Sinkholes and subterranean streams (Plate 10.42) occur in the limestone karst country (e.g., the Wai Asia, Strickland and Mubi rivers subcatchments) and provide habitat for a blind cave-dwelling fish, which is a type of gudgeon and is described in Section 10.4.4.4, Subterranean Fish Fauna.

Plate 10.41
Baia River clear water stream habitat

Plate 10.42
Standing groundwater sinkhole habitat

Plate 10.43
Blind cave gudgeon (*Oxyeleotris caeca*)

10.4.2.4 Lacustrine and Swamp Habitats

Off-channel waterbodies, lakes and swamps provide lacustrine habitats that are characterised by the presence of standing waters. Floodplain wetland habitats and swamps have high water tables and receive regular and seasonal flood flows from river main channels via permanent hydraulically connected channels or by overbank flow and some may receive groundwater flows. Most lacustrine habitats are associated with the off-channel waterbodies of the lower Kikori River floodplain in the gulf region. There are few large permanent lakes in the highlands region of the upstream project area, with the exception of Lake Kutubu. This lake is the second largest in Papua New Guinea after Lake Murray in Western Province.

Lake Kutubu provides a wide variety of aquatic habitats. The highly productive plant beds of Characeae (green algae that superficially resembles 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 fish species. The prevalence of Characeae is indicative of high water clarity (Enesar, 2005).

10.4.2.5 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 habitats 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 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, processes of erosion and accretion occur more-or-less continuously on the river bends and on the upstream/downstream areas in the deltaic islands.

The bed of the lower Omati River is an active zone of sedimentation; 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, providing a poor habitat of low structural diversity for bottom-dwelling fish and invertebrates.

10.4.2.6 Mangrove Habitats

While mangroves are extensive in the Omati–Kikori delta, none of this aquatic habitat type is actually traversed by the proposed pipeline ROW. Only a narrow fringing line of nypa palms (*Nypa fruiticans*) is present along the banks of the lower Omati River, including the riverbank crossing at the Omati River Landfall (see Plate 10.42). The submerged stems and roots of nypa palms provide microhabitats for estuarine macroinvertebrates, as well as for fish, such as mudskippers and gobies.

The nypa palm-lined tidal creeks of the Omati–Kikori delta also provide an important nursery and breeding habitat for a wide range of fish species from the Gulf of Papua and other offshore areas, such as the expansive network of coral reefs in northern Torres Strait.

10.4.3 Aquatic Flora

The aquatic flora of the highlands and gulf region of the upstream project area has not been studied to any significant degree. However, Lake Kutubu has received attention owing to its high conservation value and its listing as a Ramsar site (Osborne et al., 1990; Osborne & Totome, 1992).

10.4.3.1 Riverine Flora

Many of the rivers in the highlands and gulf region of the upstream project area are turbid, which precludes the establishment of submerged aquatic macrophytes, benthic algae, periphytons or diatoms.

10.4.3.2 Clear water Stream Flora

Clear water streams are found in the upper catchment of the Kikori River; tributaries of the Baia, Wai Asia and Strickland rivers; tributaries of the Tagari and Tamalia rivers; and tributaries of the Hegigio River especially where they drain karst terrain. Although benthic algae, periphytons and diatoms will be present in these streams, *in situ* (autochthonous) primary productivity is likely to be minor compared to the large inputs of organic matter from the forested catchments. This *ex situ* (allochthonous) terrestrial primary production forms a major portion of the food web in forest streams.

10.4.3.3 Lacustrine Flora

Examination of the habitats characterised by the presence of aquatic macrophytes in Lake Kutubu resulted in three vegetation groupings, or zones:

- **Tall emergent zone:** Forms 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 a 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*).
- **Aquatic mixed plant beds zone:** Comprises 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 occurred 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 single-species mat over the bottom of the lake. The aquatic Characeae plant beds zone generally occurred 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 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 has presented a weed problem to date. No other plant pest species 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 road access improvements.

10.4.4 Fish Fauna

The composition of the fish fauna of Papua New Guinea lacks primary freshwater groups (super-order Ostariophysi) and is similar to that of northern Australia. The fish fauna of both regions is largely derived from marine fish that entered fresh water in recent geological times. The PNG fish 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). These seven families account for about two-thirds of the freshwater fish fauna of Papua New Guinea.

The total fish fauna of the Kikori catchment comprises 115 fish species belonging to 55 genera distributed among 34 families. Appendix 2, Aquatic Fauna Impact Assessment and Enesar (2005) provide a detailed listing of the freshwater fauna of the Kikori catchment.

A total of 15 fish species are endemic to the Kikori catchment. The fish fauna of this catchment 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 floodplain) may dry out during severe El Niño-Southern Oscillation drought years.

No rare, endemic or endangered fish species was sampled or observed at any of the river or stream sites sampled during the 2003 and 2008 surveys (Appendix 2, Aquatic Fauna Impact Assessment).

Altitude, habitat type and sediment regime appear to be the primary factors controlling the diversity and abundance of fish and other aquatic fauna in the rivers of the upstream project area. Many of the highland rivers and streams sampled were at high altitude; and at the highest altitudes in, for example, the Juha area and the Karius area (up to 1,300 m in elevation), only one fish species was identified, namely, the fimbriated gudgeon (*Oxyeleotris fimbriata*). In lower-altitude rivers and streams, the fish assemblages were generally more diverse.

The riverine fish fauna of the highlands and gulf region of the upstream project area are described below.

10.4.4.1 Riverine Fish Fauna of the Highlands

The fish fauna of the highlands region (upper Kikori River catchment) of the upstream project area are given in Table 10.21 along with their locations and preferred habitat type. A total of 31 species of fish distributed among 11 families were sampled or observed during the fish surveys conducted by Vui (2003) and Hydrobiology (Appendix 2, Aquatic Fauna Impact Assessment); however, 5 species may have been misidentified by Vui (2003) and are unlikely to occur in the highlands.

The majority of the fish fauna listed in Table 10.21 have a broad distribution and are common species with wide distributions across highland rivers in southern Papua New Guinea.

Table 10.21 Fish fauna of the highlands region of the upstream project area

Family	Scientific Name	Common Name	Locations	Habitat
Cyprinidae	*Cyprinus carpio*[4]	Common carp	Hegigio	Riverine
	Shizothorax richardsoni[1.3.]	Snow trout	Hegigio	Riverine
Ariidae	*Arius uterus*[4]	Northern rivers catfish	Libano[2]	Riverine
	Arius latirostris[4]	Broad-snouted catfish	Hegigio	Riverine
	Arius taylori[3]	Taylor's catfish	Baia	Riverine
Plotosidae	*Neosilurus equinus*[3]	Southern tandan	Hegigio and Baia	Riverine
	Neosilurus ater[3]	Narrow fronted tandan	Tagari	Riverine and clear water
	Oloplotosus leteus[3]	Pale yellow tandan	Baia	Riverine
Hemiramphidae	*Zenarchopterus kampeni*[4]	Fly River garfish	Hegigio	Riverine
Atherinidae	*Craterocephalus nouhuysi*[3]	Mountain hardyhead	Hegigio and Tagari	Clear water
	Craterocephalus pimatuae[4]	Pima hardyhead	Hegigio	Riverine
	Craterocephalus lacustris	Kutubu hardyhead	Hegigio[2]	Clear water
Mugilidae	*Liza alata*[4]	Diamond mullet	Hegigio	Riverine
	Liza subviridis[4]	Greenback mullet	Hegigio	Riverine
Melanotaeniidae	*Melanotaenia catherinae*[4]	Weigeo rainbowfish	Libano[2]	Clear water
	Melanotaenia fredericki[4]	Sorong rainbowfish	Libano[2]	Clear water
	Melanotaenia sp.[4]	Unidentified rainbowfish	Hegigio	Clear water
	Melanotenia goldei[3]	Goldie River rainbowfish	Baia	Riverine and clear water
Apogonidae	*Gloassamia sandei*[4]	Sande's mouth almighty	Hegigio	Clear water
Teraponidae	*Hephaestus lineatus*[4]	Line grunter	Libano[2]	Clear water
	Hephaestus fuliginosus[4]	Sooty grunter	Hegigio	Riverine and clear water
	Hephaestus adamsoni[3., 4]	Adamson's grunter	Hegigio and Baia	Riverine and clear water
Eleotridae	*Oxyeleotris fimbriata*[3]	Fimbriate gudgeon	Hegigio, Baia and Tagari	Riverine and clear water
	Oxyeleotris wisselensis[4]	Paniai gudgeon	Hegigio	Riverine and clear water
	Mogurnda cingulata[3]	Banded mogurnda	Hegigio, Baia and Tagari	Riverine and clear water
Gobiidae	*Glossogobius concavifrons*[3]	Concave goby	Hegigio, Baia and Tagari	Riverine
	Glossogobius sp. [3.,4]	Mountain goby	Hegigio	Riverine and clear water
	Glossogobius sp. 6.[4]	Twinspot goby	Hegigio	Riverine and clear water
	Glossogobius sp. 11.[4]	Fly River goby	Hegigio	Riverine and clear water
	Glossogobius sp. 12.[4]	Kutubu goby	Hegigio	Riverine and clear water
	Glossogobius sp. 13.[4]	Bighead goby	Hegigio	Riverine and clear water

Source: Appendix 2, Aquatic Fauna Impact Assessment.

[1] Introduced species.

[2] Possible misidentifications by Vui (2003) as these species are not known from the Libano-Hegigio area.

[3] Species identified in the Hydrobiology survey (2008).

[4] Species identified by Vui (2003).

Juha Area

The fish fauna of the Juha area consisted of only one species, the fimbriate gudgeon (*Oxyeleotris fimbriata*).

Baia River Area

The fish fauna of the turbid main channel of the Baia River were dominated by sediment-tolerant forms, such as fork-tailed catfish (Ariidae) and eel-tailed catfish (Plotosidae). In contrast, the fish fauna of less turbid tributaries of the Baia River were dominated by clear water forms, such as rainbowfish (Melanotaeniidae), gudgeons (Eleotridae) and grunters (Teraponidae).

Libano River Area

In the area of the Libano River and Alisai Creek (both tributaries of the Hegigio River), Vui (2003) observed that the most frequently encountered fish were rainbowfish (Melanotaeniidae), gobies (Gobiidae), grunters (Teraponidae) and gudgeons (Eleotridae). Mullets (Mugilidae) were the dominant single species of fish, with large grazing schools of greenback mullet (*Liza subviridis*) observed in Alisai Creek. However, this is a migratory fish and may have been abundant because of the timing of the 2003 sampling event, which was in August; this species was not encountered during the 2008 survey, which was conducted in February and March.

Tagari River Area

The sampling of the fish fauna of the Tagari River, its main tributary (Tamalia River), and other smaller tributaries was hampered by high flows experienced during the 2008 aquatic fauna survey (Appendix 2, Aquatic Fauna Impact Assessment). However, sampling of main-channel-edge habitats revealed the presence of the concave goby (*Glossogobius concavifrons*) and introduced snow trout (*Shizothorax richardsoni*). However, fork-tailed catfish (Ariidae) and eel-tailed catfish (Plotosidae) are expected to be present. The Tagari's clear water tributaries harboured hardyheads (Atherinidae) and gudgeons (Eleotridae). All species caught are common and widespread in rivers and streams of the highlands.

Hegigio River Area

The Hegigio River was in flood at the time of sampling (Appendix 2, Aquatic Fauna Impact Assessment), and recourse to sampling the main channel at tributary confluences revealed the presence of concave gobies (*Glossogobius concavifrons*) and the southern tandan (*Neosilurus equinus*). In clear water tributaries, two species of gudgeon (Eleotridae) were caught. All these species are common and widespread in the rivers and streams of the highlands.

10.4.4.2 Riverine Fish Fauna of the Gulf Region

While the total number of freshwater fish species in the Kikori River catchment is currently estimated at 115, there are a significant number of estuarine fish species, including marine vagrants, which 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*).

The riverine fish fauna of the lower reaches of the Strickland River or Fly River are not described in this EIS because no effects are anticipated from the construction and operation of the Juha Production Facility and associated infrastructure, which are located several hundred kilometres upstream in the headwaters of the Baia River (a tributary of the Strickland River).

10.4.4.3 Lacustrine Fish Fauna

Table 10.22 lists the fish fauna of Lake Kutubu and their preferred habitat types. The lake is a Ramsar-listed site contains 18 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. Five of these endemics (*Hephaestus adamsoni*, *Mogurnda furva*, *M. spilota*, *M. variegata* and *M. vitta*) comprise up to 40% of the artisanal fishery and subsistence fish catches in the lake (Enesar, 2005).

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 Section 10.5.2, Aquatic Resource Use).

Table 10.22 Fish fauna of Lake Kutubu and 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.

Table 10.22 Fish fauna of Lake Kutubu and preferred habitat types (cont'd)

Fish Grouping	Scientific Name	Common Name	Preferred Habitat
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.
Poeciliidae	*Gambusia affinis*	Mosquito fish	Nearshore, calm habitats with some vegetation.

Source: (Enesar, 2005).

10.4.4.4 Subterranean Fish Fauna

The underground stream system of the karst country within the upper Kikori catchment is home to the blind cave gudgeon (*Oxyeleotris caeca*) (Plate 10.43). This fish was first found by people from Kafa village in a small creek of the Mubi River that drains a sinkhole at an elevation of about 650 m ASL. According to the people from Kafa, the blind cave gudgeon can be readily observed in sinkholes during the wet season. Note that alignment of the pipelines between Hides and Kutubu in this karst terrain is approximately 5 km 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. The blind cave gudgeon is the first specialised hypogean (cave-restricted) fish described from Papua New Guinea. There are only about 50 species known worldwide.

10.4.4.5 Conservation Status of the Freshwater Fish Fauna

Table 10.23 lists the freshwater fish fauna that occur or are likely to be present in the Kikori River catchment and that are listed as of conservation concern by the IUCN (IUCN, 2007). The meanings of the IUCN codes are presented in Appendix 1, Biodiversity Impact Assessment. Note that none of the fish listed in Table 10.23 was observed or sampled during recent aquatic fauna surveys.

Table 10.23 Fish fauna of the Kikori River catchment included in the IUCN 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, 2007.

10.4.4.6 Fish Endemism

Polhemus et al. (2004) as cited in Enesar (2005) recognises 40 areas of freshwater endemism in New Guinea and nearby islands, which are grouped into 6 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. This reflects the influence of Lake Kutubu: while 15 species are endemic to the Kikori River system, 12 of these are endemic to Lake Kutubu alone, including 5 species of freshwater gudgeons of the genus *Mogurnda*. The high lacustrine endemism shown by Lake Kutubu is due its isolation and unique habitats.

Table 10.24 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 10.24 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: Enesar, 2005.

10.4.4.7 Introduced Freshwater Fish

Twenty-one species of freshwater fish representing 19 genera, 11 families, and all six continents (with the exception of Antarctica) have been introduced into Papua New Guinea for various reasons (Enesar, 2005). The reasons include sport, aquaculture, ecological manipulation, control of pests, ornamentation, and improvement of subsistence welfare. Most introductions have been unsuccessful, i.e., have not become established, or were never released into the wild. Nine to eleven species are thought to be established in Papua New Guinea (Enesar, 2005). Of these, most have had a negligible impact as either food fishes or in the control of mosquitoes.

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 the mosquitofish:

- 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.
- 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.).

Allen et al., 2008 consider that the biggest threat facing the native fish of Papua New Guinea is not mining or logging, but the uncontrolled introduction and spread of introduced fish. In the early 1980s, there were no exotic species in the Fly River system but since then, they have recorded the presence of five exotic species in the Bensbach and Fly river systems:

- Walking catfish (*Clarias batrachus*), first observed in the Bensbach River in 1995.
- Climbing perch (*Anabas testudineus*), widely distributed in the Fly River system since 1985.
- Striped snakehead (*Channa striata*), recorded in the Bensbach and Fly rivers since 2000.
- Tilapia (*Oreochromis mossambicus*), introduced as food and pond fish since 1954.
- Common carp (*Cyprinus carpio*), introduced in 1959 for food and pond culture.

The walking catfish, climbing perch and striped snakehead have originated from West Papua and are now common in the lowland areas. The snakehead is a particularly harmful predator of native fishes and frogs, and data from the lower Fly River indicates a general reduction of native fish numbers and diversity where this species occurs (Allen et al., 2008). With this rate of progress eastwards, it seems likely that they will reach the rivers further east in Gulf Province.

10.4.5 Aquatic Macroinvertebrate Fauna

The aquatic macroinvertebrate fauna of rivers and streams in the highlands of the upstream project area are highly diverse, with a total of 69 species distributed among 17 families sampled or observed. The insect orders of Diptera (true flies) and Ephemeroptera (mayflies) were numerically dominant (see Appendix 2, Aquatic Fauna Impact Assessment). Aquatic macroinvertebrate abundance was found to be highest in the main-channel habitats of clear water streams and lowest in the main-channel habitats of turbid rivers.

10.4.5.1 Decapod Crustaceans

Decapod crustaceans occur in various habitats within the Omati and Kikori river systems, ranging from the small clear water streams, such as those typically found in the subcatchments of the upper Kikori catchment, to the off-channel waterbodies 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.

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*), the 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 Mount Bosavi near the village of Kafa (approximately 35 km east of the Kikori River). The latter species is white and blind and it is reported by the people from Kafa village that they are flushed out of sinkholes during the wet season.

The red-claw crayfish is one of the largest freshwater species in the world and is found in the upland rivers and streams of the Tagari-Hegigio subcatchment. For example, they were found to be abundant in streams in the vicinity of Musula and Bona/Muluma villages near Mount Bosavi. The red-claw crayfish also occurs in the Libano River near Mount Bosavi. The zebra crayfish occurs in Lake Kutubu (Enesar, 2005).

Freshwater crayfish are bottom-dwelling opportunistic scavengers, and a large part of their diet consists of decaying leaves and other plant detritus.

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.

In Tikawe Creek, a large tributary of the Baia River, a freshwater prawn species (*Macrobrachium handschini*) was recorded in low numbers. This was the only record of prawns from the upper catchment area in the 2008 aquatic fauna survey (Appendix 2, Aquatic Fauna Impact Assessment). A single species of an unidentified crab was also recorded in low numbers from a backwater swamp adjacent to the Baia River.

10.4.5.2 Aquatic Insects

The aquatic insect component of the macroinvertebrate fauna of the highlands and gulf region of the upstream project area has been poorly researched or studied, except for groups such as the Odonata, which comprises damselflies (Zygoptera) and dragonflies (Anisoptera); waterbugs (Hemiptera) and whirligig beetles (Gyrinidae).

The WWF funded a study of aquatic insects in mountainous terrain at Mount Sisa (two sites), and at a lowland floodplain site in the Sire River, a tributary of the Sirebi River, which flows into the lower Kikori River (Enesar, 2005). At these particular sites, the waterbugs (Hemiptera) 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 only 15 species recorded at the Mount Sisa sites. Dragonflies and damselflies are known to be depauperate at high altitudes in New Guinea (Enesar, 2005), so this pattern is expected. While Richards (2000) recorded 15 species of damselflies at high altitude (i.e., Mount Sisa sites), Polhemus (1995) recorded no more than 10 species at Kopi and the Kikori River delta.

10.4.6 Other Aquatic Fauna

Other aquatic fauna of the highlands and gulf region of the upstream project area include freshwater turtles, crocodiles, amphibians and aquatic mammals. Amphibians of the upstream project area are described in Section 10.3.4.5, Amphibians and Appendix 1, Biodiversity Impact Assessment.

10.4.6.1 Freshwater Turtles

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 mainstreams (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 (Enesar, 2005). This species is omnivorous and feeds on the unripe fruits of the white mangrove (*Sonneratia alba*), as well as on 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 10.25 lists freshwater turtle species known to occur or expected to be present in the Kikori catchment. Plate 10.44 shows the head of a pig-nosed turtle with its characteristic snout and nostrils.

Table 10.25 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	-
	Chelodina siebenrocki	Siebenrock's snake-necked turtle	-
	Elseya novaeguineae	New Guinea snapping turtle	-
	Emydura subglobosa	Northern short-necked turtle	-

* PNG *Fauna (Protection and Control) Act 1966.*

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 an occasional food source for local communities (see Section 10.5.2, Aquatic Resource Use).

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.* 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 legally 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 (IUCN, 2007) as 'vulnerable', while Siebenrock's snake-necked turtle is classified as 'lower risk'.

10.4.6.2 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*).

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, saltwater crocodiles were recorded about 500 km from the Gulf of Papua in the Fly River. They also swim out to sea and to coral reefs (Enesar, 2005).

The New Guinea freshwater crocodile (*Crocodylus novaeguineae*; Plate 10.45) is a moderately large crocodile, which reaches about 3.5 m in total length and occurs in lowland swamps, lakes and rivers of the Kikori and Omati river catchments. This species is able to ascend rivers and was recorded in a permanent pool of the Baia River in the 2008 survey at an altitude of 328 m. This species nests in the wet season, laying an average of about 22 eggs (Enesar, 2005). The diet is broad, encompassing a variety of terrestrial and aquatic invertebrates and vertebrates.

Plate 10.44
Pig-nosed turtle (*Carettochelys insculpta)*

Plate 10.45
New Guinea freshwater crocodile
(Crocodylus novaeguineа) at Baia River

Plate 10.46
Typical garden in the highlands

The New Guinea freshwater crocodile is endemic to New Guinea, and it is has been 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 (Enesar, 2005).

The single juvenile freshwater crocodile captured adjacent to the Baia River was located in a small swamp approximately 150 m long and 15 m wide that supported only small-bodied fish (*Mogurnda cingulata*) and thus is not considered to be a permanent crocodile habitat able to support a large number of adults. Rather, it is believed that the swamp may be used as a juvenile nursery habitat. Local labourers also reported the presence of a crocodile nest on the banks of the swamp that was found during camp construction.

Conservation Status of Crocodiles

Both the New Guinea freshwater crocodile and saltwater crocodile are classified under the IUCN Red List (IUCN, 2007) as 'vulnerable'. Under the PNG Fauna (Protection and Control) Act, both crocodile species are classified as 'restricted' because of traditional utilisation (subsistence catch) within the country.

10.4.6.3 Freshwater Aquatic Mammals

There are no freshwater aquatic mammals in Papua New Guinea. Some 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 11.3.2, Marine Fauna, describes the marine mammals that are found in the nearshore waters of the Omati–Kikori delta, as well as the offshore waters of the Gulf of Papua and northern Torres Strait.

10.4.7 Implications

In broad terms, the dynamism of the physical aquatic habitats, with high and variable fluxes of water and sediment, translates into resilience of the aquatic biota to project impacts, provided that they are similar in nature to what happens naturally, or that they are transitory and too small and localised to persist beyond the construction phase.

10.5 Terrestrial and Aquatic Resources

This section describes the subsistence and commercial resource uses in the areas surrounding the upstream project area in the highlands and the gulf region. The purpose of this section is to provide an overview of the type of natural resources that are available for use and exploitation by local landholders that might be impacted by project activities, and which would be mitigated through compensation type measures as described in Chapter 23, Project-wide Socio-economic Impacts and Mitigation Measures.

10.5.1 Terrestrial Resource Use

Sources of terrestrial resources include agriculture, gathering, hunting, forestry, and oil and gas production. Resource use varies along the alignments of the onshore pipelines, depending on local environmental conditions.

The PNG Gas Project Environmental Impact Statement (Enesar, 2005) provided information about terrestrial resource use by people living in the highlands and the gulf region. The social impact assessment for the PNG LNG Project (Appendix 26, Social Impact Assessment) updates this information and also provides information about terrestrial resource use of the geographic areas not covered by the PNG Gas Project (i.e., the Juha area). Parts of Appendix 26, Social Impact Assessment are summarised in this section. Information about forestry in the upstream area of the project is presented in the 2008 forestry impact assessment (Appendix 7, Forestry Impact Assessment), which updates the information presented in the 2005 forestry impact assessment from the PNG Gas Project (Enesar, 2005). Parts of Appendix 7, Forestry Impact Assessment are summarised in Section 10.5.1.2, Forestry.

10.5.1.1 Agriculture, Gathering and Hunting

Subsistence Agriculture, Gathering and Hunting

Agriculture has been a significant component of the PNG economy for much of the last century. In the highlands, the dominant form of agriculture is swidden horticulture, using a bush fallow technique. Gardens are maintained in fertile volcanic soils, with the main staple crop being sweet potato (*Ipomea batatas*); other crops include banana (*Musa* spp.), yam (*Dioscorea* spp.), taro (*Colocasia* spp.), pandanus (*Pandanus coniodeus*), breadfruit (*Artocarpus altilis*), okari (*Terminalia* spp.), Malay apple (*Syzygium malaccense*) and various leaf greens (*Amaranthis* spp.). Plate 10.46 shows a typical garden in the highlands.

Much of the highlands is characterised by karst terrain, which comprises sinkholes, steep ridges and limestone outcrops and is difficult to traverse. Areas around Lake Kutubu and throughout the Omati–Kikori delta are regularly inundated by water, which restricts the area of land suitable for agriculture. Thus, the Omati and Kikori catchments remain densely forested and sparsely populated. Agriculture therefore contributes less to subsistence production than does sago production, gathering, hunting and fishing. (The latter is discussed in Section 10.5.2, Aquatic Resource Use.)

Throughout the highlands and the gulf region, there are extensive sago palm (*Metroxylon* spp.) stands in waterlogged or frequently inundated areas. Although the sago palm is a naturally occurring plant in swampy areas, most sago palms are tended or planted, except for those that occur in large swamps long distances from villages. Sago palm stands are subject to group ownership but are usually harvested by individual families or individuals. Both males and females inherit rights to sago palms.

Sago palms take approximately 20 years to mature, flowering only once and then dying. The palms produce large quantities of starch as the time of flowering approaches. The most effective time to process the starch is shortly before flowering commences. Average yields from sago palm production are in the order of 100 to 150 kg per mature palm. A single palm is usually sufficient for a family of four for a month. Sago can provide approximately 75% of the food by volume for many of the villages in the Kutubu area. Sago palms are exploited mainly for sago starch (also known as sago flour), but also for the collection of sago grubs for food, for fronds used for roofing and building purposes, and for traditional clothing.

Other plants are also utilised and cultivated, including *Derris* sp. for fish poison, timber for dugout canoes, paper mulberry (*Broussonetia papyrifera*) for plaited carrying bags, tobacco plants (*Nicotiana tabacum*) for smoking, bamboo (*Bambusa* spp.) for cooking and water-storage vessels, tigasso tree (*Campnosperma brevipetiolata*) oil for self-decoration and rituals, and black palm (*Areca* spp. and *Ptychoccus* sp.) for bows. Cassowary feathers and hornbill beaks are used for trading, with end uses including personal decoration and traditional armament (e.g., shields).

In the Juha area, gardens are sparsely spread out over large areas and are left as fallow for long periods of time. Staple crops include sweet potato, taro and banana. The other major staple food is sago.

Pigs are farmed throughout the upstream project area, particularly in the highlands.

Hunting is becoming a less important component of subsistence living in much of the highlands and in the gulf region, with only 31% of people surveyed in 2005 saying that they hunted or fished as much as they had done five years earlier (Enesar, 2005). Hunting remains more significant in the Juha area, where almost half of the people surveyed said that they hunted and fished as much as they had done five years earlier.

A variety of game is targeted during hunting, including:

- Ground-dwelling fauna, such as pigs, cassowaries, wallabies, bandicoots, bush hens, megapodes, rodents and frogs.
- Low-canopy fauna, such as phalangers and snakes.
- High-canopy fauna, such as bats (including flying foxes) and birds (including hornbills and pigeons).
- Stream-bank and other riparian fauna, such as rats, lizards and crocodiles.

Terrestrial fauna supply the major portion of hunted game, with pig (Plate 10.47) and cassowary (Plate 10.48) being the most commonly hunted (Rhoads, 1980). (Aquatic fauna resources are described in Section 10.5.2, Aquatic Resource Use.)

The forests of the coastal plains of the lower Omati–Kikori delta contain a large variety of fauna that are hunted for their meat, feathers, skin or eggs; many are a primary source of protein to local villagers. The main limitation on hunting in the coastal plains is accessibility due to seasonal flooding.

A high level of consensus exists among local people throughout the highlands and the gulf region that there has been some decline in the presence of targeted fauna, either through a reduction in fauna populations or migration by fauna away from hunting areas. The following percentages of local people surveyed in 2005 believed there had been declines in the presence of the following animals targeted for hunting: bird of paradise (50%), cassowary (80%), possum (44%), snake (47%), lizard (21%) and frog (17%) (Enesar, 2005).

Plate 10.47
Juvenile pigs

Plate 10.48
Juvenile cassowary

Plate 10.49
Disused logging roads in Gulf Province

Commercial Agriculture

The Department of Agriculture and Livestock is responsible for agricultural policy and coordination in Papua New Guinea. The department's five-year strategic plan provides generalised policy statements about increased delivery, increased community participation and increased landowner capacity for self-employment.

People have generally focused their agricultural activities on subsistence production. Various attempts to commercialise agriculture on a large-scale basis have proved unsustainable, and a high proportion of commercial enterprises are failing or have failed. This is generally attributed to a lack of sustained interest (i.e., if there are no immediate returns, this can led to a lack of interest in repeat farming), lack of transport support and road problems, income not being reinvested and flooding. Agricultural and livestock opportunities remain largely undeveloped, partially due to lack of communications and transport infrastructure.

Projects to grow coffee, vanilla, chilli, mandarins and rice have been undertaken on a fairly small scale. None has yet taken off in a manner likely to have a material positive impact on local cash economies. These agricultural projects have generally been developed with assistance from the local business development sections of resource development companies operating in the area, such as Oil Search Limited, and through non-government organisations, such as the Community Development Initiatives (CDI) Foundation. Seedlings for coffee and vegetables are grown in nurseries located at Hides, Habono, Kobalu, Hedemali, Waralo, Pari, Andawali, Hambuali, Komo and Nogoli. Vanilla cuttings have also been widely distributed.

Diversified food and animal crops for commercial production, including African yams, Chinese cabbage, nutmeg, wongbok, salabeer, capsicum, pak choi, new varieties of taro, and muscovy ducks, are gradually being introduced through distribution from the Moro Agriculture Resource Centre. In Kikori, a market for local hunters to sell crocodile skins has also been developed through the CDI Foundation with sales to the Bush Development Company in Port Moresby. In Moran and Kutubu, the CDI Foundation has assisted farmers to sell fruit and vegetable produce. Similarly, in the Omati area, the foundation has assisted the community to establish its agriculture resource centre and nursery. A successful harvest was sold to Turama Forest Industries logging camp.

Agricultural products, including vegetables, fruit, meat and livestock, are sold and traded at local markets throughout the highlands and the gulf region. Most other products traded at markets, such as biscuits, tinned food, rice, cooking oil, canned drinks, tobacco and soap, are imported.

Few local markets are present in the Juha area, and survey results indicate that agricultural officers from national or provincial government agencies have not visited the area and that visits by forestry department officers and other government officers are infrequent or do not occur.

As mentioned in Section 10.3, Terrestrial Biological Environment, the Kikori River Programme (KRP) has been established and is currently managed by the World Wide Fund for Nature (WWF). The KRP aims to provide sustainable conservation of globally significant ecosystems and biodiversity by assisting communities with conservation, rural development, income-generating activities, resource management and sustainable development. It is through this program that wildlife management areas have been established and formally gazetted by DEC. Section 10.3.5, Conservation Areas, describes these wildlife management areas. The management regimes for the wildlife management areas include provisions for subsistence gardening and small-scale cash cropping.

10.5.1.2 Forestry

Vegetation in the Upstream Area of the Project

The broad vegetation groups in the highlands are predominately lower montane forest, with some relatively small areas of grasslands. Large areas of low-altitude forest, particularly low-altitude medium-crowned forest, are present near Juha, Mount Bosavi, Moro and Lake Kutubu. Areas of swamp forest and swamp woodland are also present near Lake Kutubu. The broad vegetation groups in the gulf region include medium-crowned to small-crowned forest, low-altitude medium-crowned forest and multiple lowland forest groups. Swamp forest, swamp woodland and mangroves are present throughout the Omati–Kikori delta (see Figure 10.12). Broad vegetation groups are described in more detail in Section 10.3.3, Vegetation and Flora.

Forestry in Papua New Guinea

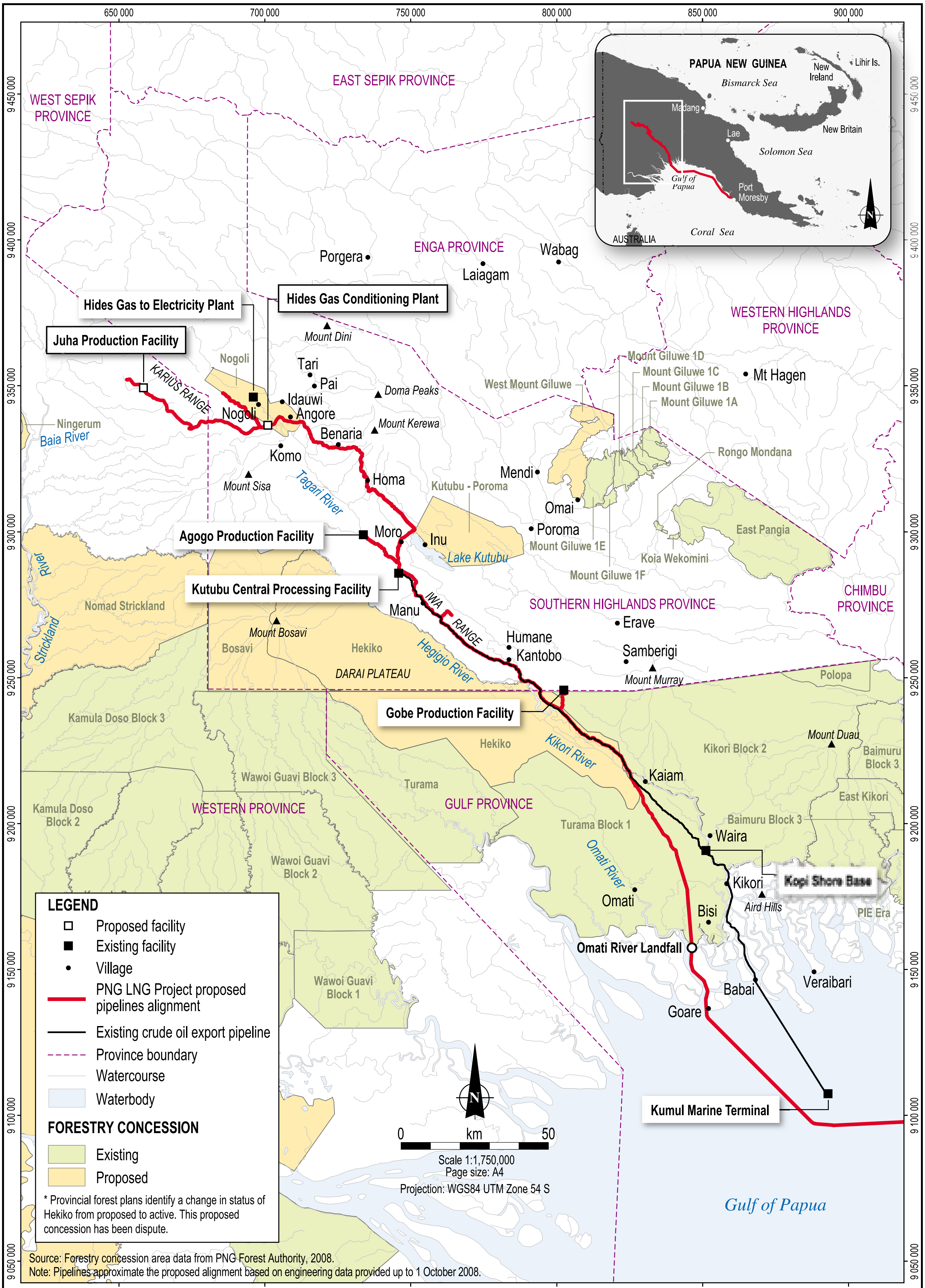
PNG's logging industry focuses on the harvesting of large-scale certified forestry concessions (called forest management areas (FMA)) for round log exports. Logging practice is subject to the PNG Logging Code of Practice (1996) and there are approximately 30 concessions currently in production over an area of 3.5 Mha across the country. The forestry concessions in the upstream area of the project are shown in Figure 10.13. These concessions are run by the large privately owned international companies. Most timber production is exported as round log, with the balance as processed and semi-finished products.

National Forest Policy and Government intend to provide a favourable environment for continued industrial-scale logging of lowland primary forests throughout Papua New Guinea. However, the industry has been under criticism for many years, on the basis that logging exceeds sustainable yield (ITTO, 2007; ODI, 2006; Shearman & Cannon, 2002; Shearman et al., 2008) estimated an annual rate of forest loss and degradation of 1.71% in the period 2005 to 2006 and found 'the major drivers (to be) logging in lowland forests and subsistence agriculture in the Highlands, with minor contributions from forest fires, plantation establishment and mining'.[7]

The government of Papua New Guinea receives over US$30 million in revenue annually. This money partly pays for the National Forest Service, the Department of Environment and Conservation and the independent log export monitoring program undertaken by Société Générale de Surveillance. However, the government's provision of infrastructure and social services to the communities whose forest has been logged is limited (Appendix 7, Forestry Impact Assessment).

Large-scale timber harvesting requires road networks to access coupes and transport logs for export, which raises the issue of whether improved access could facilitate logging in areas where it would not otherwise have been feasible. It has, for example, been reported that oil exploration roads intersecting the Turama Block 1 FMA had subsequently been used for logging activities (Shearman, pers. com., as cited in Booyong Forest Science, 2005). The potential for the PNG

[7] The deforestation rate assumes that all logged forest is 'deforested', whereas in many cases it will have been selectively logged and not subjected to wholesale clearing: see for example Plate 10.49 in Box 10.1.



PNG LNG	Date: 21.10.2008 MXD: PNG_LNG_Project_GIS.mxd File Name: 1284_09_F10.13_GIS_HB	Esso Highlands Limited PNG LNG Project	Forestry concessions in the highlands and the gulf region	Figure No: 10.13

LNG Project infrastructure to assist commercial logging in this way is discussed in 'Improved Access' in Section 18.7.4.2, Indirect Impacts on Habitats, Flora and Fauna During Construction and Operations and Section 24.3.1, Forestry.

Forestry in the Highlands

In the highlands generally, the majority of deforestation and forest degradation is related to the cultivation of land for agriculture (Appendix 7, Forestry Impact Assessment). There are no active forestry projects in the highlands part of the upstream project area other than small-scale ('walkabout') sawmill operations. This largely reflects distance from the sea and the relatively low timber volumes. The nearest active concession is the large-scale East Pangia FMA some 50 km east of Mendi. The undeveloped Ningerum concession west of the Juha Production Facility may be logged in the future.

Medium-scale logging previously occurred in the early 1980s, primarily to harvest klinki pine in the Tagari River valley. The northeastern slopes of Hides, including the Tagari River valley, have been in part gazetted as the proposed Nogoli FMA. To the west of Juha, the Department of Environment and Conservation is assessing a proposal to develop the Trans-Papua Logging Road to provide access to the Strickland River. Furthermore, the Papua New Guinea Forest Authority is currently updating the National Forest Plan and the Provincial Forest Plans, which may result in future changes to forestry in the vicinity of the project.

Notes on specific concessions are given in Box 10.1.

Forestry in the Gulf Region

The Hekiko FMA has recently been gazetted. Turama Forest Industries (which operates the Turama Block 1 concession south of the Hekiko concession) or another company are expected to start operations there in due course.

Considerable logging has taken place in the forests inland from the coast in Gulf Province, including, more recently, in the Omati area. Turama Forest Industries currently operates at two sites (Omati and Sirebi) and plan to build a landing site near Veiru Creek for shipping logs to Paia Inlet for export. Logging is selective rather than clear felling (see Plate 10.49).

Box 10.1 Notes on existing and proposed forest management areas on the PNG LNG Project area

Kikori Block 2 FMA

This FMA has overlapped the existing road between Kopi and Gobe since large-scale logging began in the Lower Kikori region in 1996. Logs are exported by river (Plate 10.50).

East Kikori FMA

This FMA has been logged since 1996 (Plates 10.51 and 10.49). Part of this FMA already overlaps the existing road from Kopi to Gobe, but logs from this block are exported by barge down the Omati River (Plate 10.52).

Hekiko FMA

The PNG Forest Authority has granted the Hekiko FMA, but its status within Gulf Province is subject to a dispute over land ownership. At present, it is uncertain whether or not it will become an active concession or, as seems more likely, the portion in Gulf Province will be logged as an extension to Turama Block 1.

Much of the gross area of some 430,000 ha seems unlikely to be commercial: the PNGRIS terrain and soils data suggest that between a quarter and a third of the area of this FMA might support accessible timber of commercial quality.[8]

Juha–Hides (no FMA **proposed)**

These forests are likely to contain some commercial timber but steep slopes will make logging access difficult in places (Plates 10.53, 10.54 and 10.55).

The klinkii pine (*Araucaria hunsteinii*) logged in the 1980s is now a prohibited export (Plate 10.56).

Nogoli (proposed FMA)

This proposed FMA is probably too far inland to supply export markets in the foreseeable future but could possibly support small-scale logging to supply domestic sawn timber 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.

Bosavi (proposed FMA)

The forests on the gentle, western foot slopes of the Mt Bosavi volcano 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 (Crome, pers. com., 1997). Haulage distances to the coast are considerable and the block seems too distant to use existing petroleum infrastructure to expand or accelerate timber harvesting.

Kutubu–Poroma (proposed FMA**)**

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 nominally precluded for environmental protection reasons (Plate 10.57).

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 is not required for normal operations at Kutubu and has been untrafficable for much of the time since it was built.

Small-scale Logging

Small-scale logging routinely accompanies construction works in rural Papua New Guinea.

Kikori Pacific, an eco-forestry umbrella company established by WWF, acted as a marketing agent and provided training for community-based eco-forestry groups in the lower Kikori River area until its closure in 2000. Kikori Pacific had been buying, milling and exporting timber to international customers. Kikori Pacific promoted walkabout sawmills that were owned by or hired to landowners and were part of the sustainable harvest awareness activities of the former KICDP. Small-scale landowner sawmills (including walkabout sawmills) continue to operate at Sirebi and Ero villages in Gulf Province.

[8] The footnote to Table 24.1 in Section 24.3.8, Cumulative Impacts Upstream Summary labelled ‘f’ explains the basis for this estimate.

Plate 10.50
Log barge, Kikori River

Plate 10.51
Sirebi logging camp, Kikori River

Plate 10.52
Loading logs at Paia Inlet, Gulf Province

Plate 10.53
Forest traversed by the Juha–Hides route

Plate 10.54
Lowland forests in the Juha area

Plate 10.55
Rugged terrain in the vicinity of the Juha–Hides route

Plate 10.56
Emergent klinkii Pine in the Hides area

Plate 10.57
Steep polygonal karst terrain of the Kutubu–Poroma proposed concession

Plate 10.58
Lake Mabuli

Walkabout sawmills owned by local landowner companies and individuals in the Moran, Kutubu and Gobe areas meet petroleum industry requirements and sometimes continue in intermittent use thereafter to service local demand for housing materials.

The evidence from Moro and Moran is that small-scale operators will log commercial trees within perhaps 1 to 2 km of a road to provide sawn timber for landholder companies (Plate 10.58).

A small team of individuals will carry a portable sawmill into the forest and assemble it next to the felled tree. The impact of such operations depends on the proportion of the trees taken from any given area, and can occur at unsustainable intensities over a localised area. The PNGFA requirement for small scale-loggers is to work under an approved Timber Authority (TA) if the timber is for commercial sale, but unpermitted (that is, illegal) operations are known to occur in the Moro area.

Localised but permanent loss of forest occurs when logged over areas are converted into food gardens and or settlements.

10.5.1.3 Oil and Gas Production

Oil and gas resources that have been developed in the highlands and the gulf region include oil at Kutubu, Agogo, Gobe and Moran fields (to be developed as associated gas reserves for the project), and gas at the Hides gas field, which feeds the gas-fired power station that supplies electricity to Porgera gold mine. Local landowners receive royalties for these oil and gas resources and also receive compensation for the land disturbance required to develop the resources. Direct use of oil by local people is limited to fuel for public motor vehicles, private vehicles and generators (e.g., at medical centres). Gas resources are not currently used directly by local people in the highlands and the gulf region.

10.5.1.4 Implications

The petroleum industry continues to co-exist with subsistence economic life in the upstream project area. The implications for the PNG LNG Project are that subsistence resources will continue to play a major role in the village economies of the upstream project area, and that the relatively small loss of resources due to the project will not change this situation.

10.5.2 Aquatic Resource Use

Aquatic resource use includes water use, fisheries, and crocodile and freshwater turtle hunting.

A number of fishery studies were conducted in the KRP area by WWF, as presented in the following documents:

- Subsistence fish catch monitoring of Lake Kutubu report (Leary, 1997).
- Libano fish survey report (Vui, 2003).
- Technical report for Kikori Integrated Conservation and Development Project (WWF, 1998).
- Review of the aquatic fauna and flora of Kikori basin, report for Kikori Integrated Conservation and Development Project (Namo, 2003).

Other relevant studies include:

- Production of fish at Gwaimasi village, Western Province, Papua New Guinea (Minnegal & Dwyer, 1995).
- Kutubu Petroleum Development Project Environmental Plan (NSR, 1990).
- Social and Economic Impact Study (Volumes 1 to 3), PNG Gas Project Environmental Plan (Simpson et al., 1998).
- Census of crocodile populations and their exploitation in the Purari area. Report for the Purari River (Wabo) Hydroelectric Scheme (Pernetta & Burgin, 1980).
- The management of crocodiles in Papua New Guinea. Report in *Wildlife management: crocodiles and alligators* (Hollands, 1987).
- Freshwater turtles of the Kikori (with special reference to the pig-nosed turtle) (Georges et al., 2007).
- Conservation biology of the pig-nosed turtle, *Carettochelys insculpta* (Georges & Rose, 1993).

The social impact assessment for the PNG LNG Project (Appendix 26, Social Impact Assessment) updates the assessment made for the PNG Gas Project and provides additional information on studies of aquatic resource use by people living in the highlands and the gulf region. The 2008 Resource Use Survey of the Omati and Kikori Delta (Appendix 3, Resource Use Survey of the Omati-Kikori Delta) also provides recent information. Information from both of these appendices is summarised in this section.

10.5.2.1 Water Uses

Throughout the Omati and Kikori catchments and the upper Strickland catchment (Juha area), local people use the main channels of the rivers extensively. River water uses include the processing of sago palm pith to produce sago flour, cooking, washing garden produce and kitchen utensils, swimming, bathing, and washing clothes. The rivers are also used to transport heavy materials, such as timber and bamboo for building, by floating such materials downstream.

Water is also used for drinking and for cultural or spiritual activities, and these are discussed further below.

Drinking Water

In the highlands, clear-water tributary streams of the major tributaries of the Kikori River (i.e., the Tagari, Hegigio and Mubi rivers) and groundwater are the main sources of drinking water for many local people. In addition, the main channels of the major rivers are sometimes used as a source of drinking water; however, the suitability of this water for drinking is often limited by naturally high turbidity. Where there are no perennial clear-water tributary streams, communities use main-channel river water for all their domestic uses, including as a source of drinking water. In such areas, turbid water is often collected and left to settle to improve water clarity.

Springs or freshwater streams are available to many riverine villages in the highlands as an alternative source of water. These springs range in reliability from perennial springs that can be used on a daily basis to intermittent springs that flow only during the wet season. During periods of drought characteristic of El Niño-Southern Oscillation events, the perennial springs continue to provide sources of adequate drinking water throughout both the wet and dry seasons.

Given the high annual rainfall throughout the highlands and the gulf region, it is common for rainwater to be collected for drinking and washing purposes in drums or buckets from gutters and galvanised iron roof sheeting. Increasingly, people, who build metal-roofed houses, construct a gutter system to capture rainfall and divert it to a small outside tank. Oil Search Limited has installed communal water-tank systems in a number of villages that provide a ready source of clean drinking water. Water collected in these tanks is mainly used for drinking, with water for other domestic uses (e.g., washing garden produce, utensils and clothes) still being sourced from the main channels of the rivers.

While water tanks are used in some villages, they still represent a relatively small proportion of the drinking water sources available to local people. In the gulf region, in places such as Bisi, Kikori, Kopi and villages along the Omati River as far down river as Goare village, access to clean fresh water has been a longstanding problem. Traditional water sources include local streams and rivers, and clean groundwater that flows out of subterranean karst cavities.

Cultural or Spiritual Water Uses

Sacred sites may be located on riparian land and in watercourses. Therefore, both landscapes and waterscapes have been considered when recording cultural and spiritual places and water uses. Some of the sacred sites associated with water link the places of the living (such as villages) with the places of the dead through the journeys travelled by the spirits of dead family and clan members.

In the Hides area for instance, Lake Mabuli (Plate 10.58) is a sacred spirit lake located a short distance from the road to the Hides Wellpad A. Lake Mabuli was traditionally a site where pigs were sacrificed to the spirits.

There are few sacred sites associated with the rivers and streams of the upper Kikori catchment and most are associated with the lower Kikori and Omati rivers and the delta. However, Lake Kutubu is also the locale for a number of traditional myths. Sisibuitono, a myth site of major significance to the Lake Kutubu region, is a tiny grassy island at the northern end of Lake Kutubu that marks the location of the original mythical tree from which the waters of Lake Kutubu flowed.

In general the number of sacred sites associated with the rivers and streams is higher in the lower Kikori and Omati catchments compared to the upper Strickland and upper Kikori catchments. Further details about cultural and spiritual uses of river, stream, lake and subterranean waters are provided in Chapter 14, Cultural Heritage Environment: Upstream Facilities and Pipelines.

10.5.2.2 Fisheries

The National Fisheries Authority is responsible for research, administration and local fisheries management plans in Papua New Guinea. There are no commercial fisheries operating in the upstream project area of the highlands or the gulf region. However, artisanal and subsistence fishing by local people 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. Interviews with local people indicate that there is a general perception that fish are becoming less abundant (Goldman, 2005).

Subsistence Fisheries in the Juha area

Febi people in the Juha area fish using nets, spears and arrows in the larger rivers of the area. Spear guns made from slim plastic tubing and rubber tubing are used by some people. Fishing is also done with fishing line and hooks of bone, hardwood or steel. Fishing areas along rivers are accessed by canoe and occasionally hand-lining is conducted directly out of canoes. Catfish (Plotosidae and Ariidae) and barramundi (*Lates calcarifer*) are known to have been caught in the larger rivers near the Strickland River. Freshwater crayfish (*Cherax* spp.) are caught by hand. In addition to their use as a food source, freshwater crayfish shells are used to make ritual rattles (Minnegal & Dwyer, 1995).

Subsistence Fisheries of the Upper Kikori River System

Subsistence fishing takes place in many of the upland rivers and their tributaries in the vicinity of villages or outlying village gardens. However, the local people are primarily gardeners, and subsistence fishing is of secondary concern. In general, fishing is undertaken when there are feasts and other important social occasions. Fishing methods include gill nets, hand lining, trapping, hand-spearing and chemical stupefaction (i.e., derris root poisoning).

Many of the fish caught are small species, such as gobies (Gobiidae) and rainbowfish (Melanotaeniidae). Larger fish that are caught include mullets (Mugilidae), grunters (Teraponidae), gudgeons (Eleotridae) and catfish. Grazing shoals of greenback mullet (*Liza subviridis*) are commonly observed (and potentially utilised) in the tributary streams of the upper catchments, such as the Libano River (Vui, 2003) in the Tagari-Hegigio subcatchment.

The major crustacean resource comprises red-claw crayfish (*Cherax quadricarinatus*), zebra crayfish (*Cherax papuanus*) and giant freshwater prawns (*Macrobrachium spp.*). In the upper catchment rivers (e.g., Libano River), zebra crayfish and giant freshwater prawns are abundant under logs and in mud holes, where local people catch them.

Lake Kutubu Fishery

Fish are the main source of protein for people living around Lake Kutubu. The lake contains at least 14 fish species and is regarded as having an exceptionally high research and conservation value, as most species are endemic to the lake. Plate 10.59 shows a subsistence catch of Kutubu tandans (*Oloplotosus torobo*) and fimbriate gudgeons (*Oxyeleotris fimbriata*) from Lake Kutubu. Crustaceans also provide a source of protein for the people living around Lake Kutubu, which contains at least seven species of crayfish and prawns.

Leary (1997) estimates that a total of 1.2 million fish and crustaceans were caught per year during the period from September 1995 to February 1997. The annual catches of fish for four Lake Kutubu villages were estimated by Leary (1997) as follows: Gesege (5,960 kg), Tugiri (5,860 kg), Wasemi (4,860 kg) and Yo'obo (7,260 kg). Although the species caught varied between villages, the pooled catch revealed that three species accounted for 80% of the catch, namely, freshwater crayfish (35%), Adamson's grunters (*Hephaestus adamsoni*; 23%) and fimbriate gudgeons (22%). As much as 70,000 kg of fish are removed from Lake Kutubu annually, with an estimated value of

K400,000. However, reports indicate that the fish resources are in decline, due to increases in human population and fish catch efficiency (i.e., use of gill nets) (WWF, 1998).

Fish are caught by a variety of methods, including traditional methods, such as poisoning with plant extracts. Pooled data for five Lake Kutubu villages (Leary, 1997) showed that the principal fishing methods were hand lining for fish (30%), hand-lining for crayfish (24%), spearing (17%) and gill-netting/mixed gill-netting (17%). Hand lining for fish and crayfish are the two most important fishing activities as they contributed 54% of the total catch (by weight) for the five villages.

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 local people. The amount of time spent fishing for the five villages combined was estimated to be 370 person-hours per 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. Fishing generally took place during daylight, starting after 6.00 a.m. and finishing at 8.00 p.m.

Until the 1990s, Lake Kutubu was one of the most inaccessible areas in Papua New Guinea, with access only by light aircraft or on foot. The development of oil and gas industries in the region has increased access through the development of roads, and the development of airstrips and regular flights. Following the increase in access to the area, local people have expressed concern about 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 were established in a closed area of the lake near Gesege in December 1996 and 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 people have been aware of how such management actions can be beneficial to the recovery of fish stocks within the lake. Lake Kutubu communities continue to manage their fisheries and open and close selected areas to fishing, as required.

In addition to overfishing, a potential threat to the Lake Kutubu fishery is the recent introduction of European carp (*Cyprinus carpio*), which competes with native and endemic species, as well as causing water turbidity by its disturbance of lake bed sediments caused by its benthic mode of foraging and feeding.

Plate 10.59
Subsistence catch of Kutubu tandans and fimbriate gudgeons from Lake Kutubu

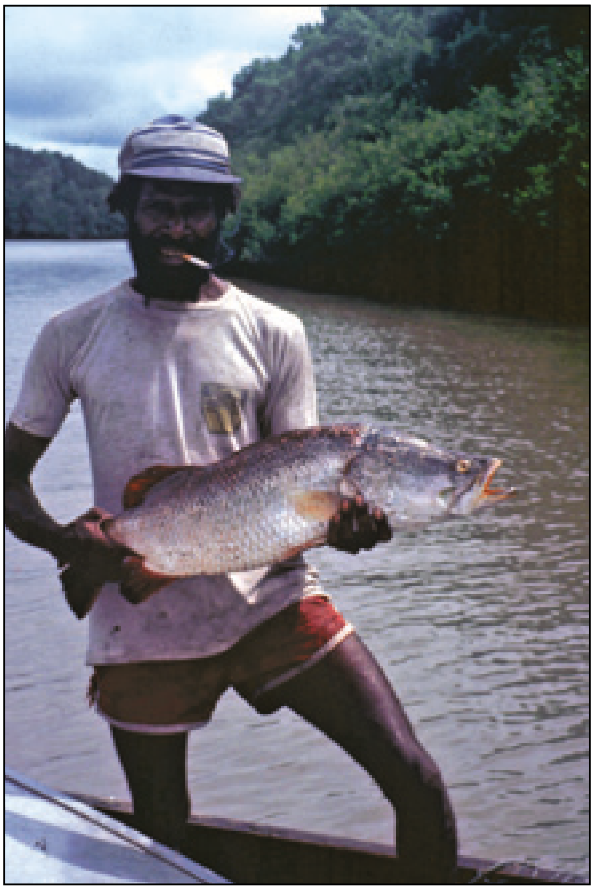


Plate 10.60
Fisherman holding a barramundi caught in the Omati-Kikori delta

Artisanal and Subsistence Fisheries of the Omati–Kikori Delta

The saline and brackish-water swamps of the Omati–Kikori delta are among the largest in the South Pacific. Fish, turtles, crabs and shellfish have traditionally been an important source of food for local people in the delta, and they provide an important source of cash income. While there are currently no commercial fisheries, both artisanal and subsistence fisheries are prevalent in the Omati–Kikori delta.

The riverine resources in the Omati–Kikori delta comprise at least 22 species of freshwater and saltwater fish, eels, turtles, crayfish and prawns, which are exploited by local people. Key subsistence and artisanal fishing includes all the fish groups and species listed in Section 10.4.4.2, Riverine Fish Fauna of the Gulf Region. Other species caught include black bass (*Micropterus* spp.), bream, nurseryfish (Kurtidae), ponyfish (Leiognathidae), prawns (including *Macrobrachium* spp.), mud crabs and crocodiles (*Crocodylus* spp.).

Most of the larger fish, such as barramundi, threadfin catfish (*Arius stirlingi*) and threadfin salmon (such as king threadfin (*Polydactylus sheridani*) and fourfinger threadfin (*Eleutheronema tetradactylum*)), are caught with gill nets, especially six-inch mesh monofilament or multifilament barramundi nets. Smaller mesh sizes down to three-inch mesh are also used. These nylon nets have largely replaced the bamboo and bark cord nets that were used historically. Gill nets are typically set overnight, and the catch is retrieved the next morning, although daytime net setting with regular inspections is also practised, which allows fish to be consumed immediately. Nets are set in doline ponds and in both large and small tidal creeks in the Omati–Kikori delta. Plate 10.60 shows a fisherman holding a barramundi that was caught in the Omati–Kikori delta.

Fishing along the barging route used to bring supplies to Kopi was surveyed in 2008 and was found to be limited, likely due to the presence of the barges. However, there are many other delta channels and tidal creeks nearby that are used for fishing activities. 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.

Fishing is mainly a subsistence activity, and fish is an important daily source of dietary protein. While surplus catch is sold to local village markets and logging camps, such sales tend to be opportunistic and fishing as an artisanal-scale activity has declined, with fisher women and men seeking other sources of income.

Approximately 60% of households surveyed in the Kikori area from 1998 to 2005 reported having received cash income from fish during the past year, compared with the Lake Kutubu area where an average of 13% of households reported such income. Surveys in 1998 indicated that Kikori people collectively earned cash income of approximately K90,000 per annum from fishing (Simpson et al., 1998). Some of this income would have come from local fishermen selling their catch to the Delta Fish Plant at the Kikori township, which filleted, froze and on-sold fish to markets in Port Moresby. The Delta Fish Plant closed in early 2008 (following 52 years of operation) due to inconsistency of supply, leading to an inability to fulfil market obligations. Many of the people who had supplied the fish plant had alternative sources of income and therefore were not consistently involved in fishing.

10.5.2.3 Crocodile Hunting

The saltwater crocodile (*Crocodylus porosus*) and the New Guinea freshwater crocodile (*Crocodylus novaeguineae*) are traditionally hunted by local people. There is a long history of crocodile harvesting by indigenous Papua New Guineans, but subsistence hunting probably has had limited impact on crocodile populations (Pernetta & 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). The *Crocodile Trade (Protection) Act 1974* 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 PNG rivers may be reducing crocodile populations in some areas.

Both saltwater and freshwater 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. Local people generally hunt crocodiles from canoes or outboard-driven dinghies using torchlight and spears, bows and arrows, or nets. However, the greatest threat to crocodiles is from the harvesting of their eggs and, to a lesser extent, the selling of juveniles to crocodile farms (Namo, 2003).

10.5.2.4 Freshwater Turtle Hunting and Egg Collection

All six species of freshwater turtle occurring in the Kikori River system are hunted for their meat (adults) and/or for their eggs. Pig-nosed turtles (*Carettochelys insculpta*) and their eggs are a significant food source for local people along the river system and around Lake Kutubu. The remaining species are also a food source for local people.

Local people mostly capture adult pig-nosed turtles by hook and line. Subsistence and artisanal use of this species by local people has a long history but apparently used to occur only at moderate levels. In recent decades, harvest pressures have escalated to levels that are widely perceived to be unsustainable and threaten the species over much of its range (Georges et al., 2007; Georges & Rose, 1993). Plate 10.61 shows pig-nosed turtle eggs collected by local people in the Omati–Kikori delta and Plate 10.62 shows captured pig-nosed turtles that are likely to be sold.

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 a food source for local people dwelling around the fringes of the rivers.

10.5.2.5 Implications

The petroleum industry continues to co-exist with subsistence economic life in the upstream project area. The implications for the PNG LNG Project are that subsistence aquatic resources will continue to play a major role in the village economies of the upstream project area, and that loss of resources should be small enough to allow this situation to continue.

Photo: M. Pauza, WWF

Plate 10.61
Pig-nosed turtle eggs collected in the Omati-Kikori delta

Photo: M. Pauza, WWF

Plate 10.62
Captured pig-nosed turtles

There is in the short term of construction the imperative to protect or substitute village water supplies from the degradation by runoff from construction works areas.

10.6 Implications for Upstream Facilities Planning, Design and Management

10.6.1 Natural Environment

The biodiversity of the project area is of almost uniformly high quality and value. Moreover, in many areas it remains little disturbed by human activity, an increasingly rare phenomenon globally. Project siting and route planning, design and management, and reducing potential impacts on biodiversity have therefore been a project priority.

The project area's size, remoteness and low human population density are major contributors to its condition and value, but they mean too that any given part of this area will probably be little or not at all disturbed. This, in turn, means that there are few areas totally free of some sort of biodiversity constraint (see Section 6.1.1, Routing Constraints and Criteria), while the size of the area limits the opportunities to preferentially site and route project facilities and infrastructure components on already disturbed land.

Within this overall high value project area are places that are either of particular conservation note or particularly susceptible to impact. Places which are both (such as Hides Ridge and bat caves) or which are not susceptible but have formal conservation status (such as Lake Kutubu) have been made priorities for mitigation through both engineering design and specific measures identified by the studies conducted for this EIS.

In particular, managing earthworks has been a major focus of environmental mitigation. This chapter has noted that rainfall is heavy, streams and rivers are numerous and flows high and consistent. The high-relief environments are typically dynamic and are dominated by erosional processes. Earthworks in these areas inevitably create fugitive sediment that for practical purposes cannot be contained. The vegetation is adapted to this environment and will generally recolonise disturbed areas. Mitigation has therefore focused on the few situations where this might not happen readily.

By contrast, low-relief environments are typically stable and dominated by sedimentary processes. Earthworks in these areas are typically more straightforward except where impeded drainage creates poor ground conditions for construction. Fugitive sediment potential is low, by virtue of both the small volumes of material disturbed and the flat or subdued terrain.

Managing stream water quality and ecology is closely linked to earthworks design and management. The lower-order rivers can be reasonably clear during low flows but tend to be turbid and carry a high bed load under most flow conditions. The high-order streams, on the other hand, are generally of low turbidity, except during floods and (infrequently) if there is a landslide in the catchment. Thus protection from fugitive sediment is focused on these higher-order, smaller streams, often neglected in such projects. The implications of this is as follows:

- Direct impacts of construction – mainly clearing and fugitive sediment – should be broadly similar to natural environmental perturbations and are typically of short duration.

- The terrestrial and aquatic flora and fauna are adapted to natural perturbations of the environment and would therefore be expected to survive the direct impacts of project induced impacts, provided these impacts do not exceed – in nature, intensity or duration – what occurs naturally. (The co-existence of the biodiversity around Lake Kutubu with more than 25 years of petroleum exploration and production is a case in point.)
- At the same time, all environments will be vulnerable to any impact that persists. For the PNG LNG Project, this means any impacting process that the project might introduce but which survives beyond the period of direct disturbance. These are the 'indirect impacts': susceptibility to fire, weeds and plant pathogens and feral pests.
- Within these broad observations are quite specific exceptions. Caves are common, but not so caves able to be colonised by bats. Such caves are therefore regionally important, and their dependent populations are vulnerable to the loss of what could be the roosting or breeding habitat of an entire colony. Lekking areas for birds-of-paradise are similarly important. Tactical routing and siting of project facilities and infrastructure will be informed by biodiversity preconstruction ground surveys. This is a main mitigation measure to protect these local-scale features.
- Mitigation focus is twofold: to protect particularly susceptible features from direct impacts; and to pay due attention to preventing indirect impact processes that could survive the period of direct impacts.

10.6.2 Noise and Air Quality

The noise and air quality environments of the upstream project area reflect the low level of development. The project's ability to meet ambient standards should not be a superimposition on pre-existing industrial impacts and so the issue of cumulative impacts does not arise except from any additional emissions at existing petroleum production operations (see Section 24.2.1, Existing Developments).