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Soil Impact Assessment and Rehabilitation Study for the PNG LNG Project: Juha to Hides

for

Coffey Natural Systems

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Contact:	Howard Rogers, h.rogers@optusnet.com.au, 07 5543 4173 (M) 0412 013 217

Booyong Forest Science Pty Ltd
ABN: 47 117 077 808
PO Box 98 Canungra, Qld 4275

SUMMARY

This report presents the findings of the soil impact assessment and rehabilitation study for the PNG LNG Project for the proposed new areas of disturbance for route sectors between Juha and Hides in Western Province and Southern Highlands respectively. The study focuses on (A), the identification of significant landform features and potentially problematic soils, (B), assessing the potential impacts on landforms and soils associated with the project activities, (C) reviewing methods of rehabilitation of areas proposed for the PNG Gas Project and (D), providing recommendations on measures to avoid, reduce or mitigate adverse impacts on landform and soils during project construction and operation, including suitable rehabilitation techniques for the areas to be disturbed.

The proposed route from Hides to Juha traverses a diverse and rugged landscape from the lowlands to the montane zone, including a wide range of forest types that vary from species rich lowland forest through to pandanus swamp forest and *Nothofagus* dominated forest in the montane zone. This variation reflects differences in landforms, soils and changes in the climate associated with increasing altitude. The impact of construction on this varied landscape will vary depending on the type and intensity of disturbance, the terrain, the vegetation and soil type, and the erosivity of the rainfall.

Impacts will range from temporary clearance of vegetation to removal of all vegetation and topsoil with extensive sidecasting of spoil in steep terrain. Where temporary clearance occurs sites are likely to recover by natural regeneration provided soil is not exposed for a lengthy period. Where topsoil is lost active rehabilitation will be required. The level of rehabilitation needed will vary depending on the level of impact. Salvaging topsoil and salvaging cleared vegetation to spread over exposed areas will be key measures to promote effective rehabilitation. Where no topsoil remains, and subsoils are the only medium for rehabilitation a revegetation program may be required. Sidecast areas present the most difficulties for effective rehabilitation. The sidecast revegetation plan produced for the PNG Gas Project should be used as a guide to rehabilitate such sites.

A small range of forest types are likely to be heavily impacted by construction because of highly sensitive landforms and soils (deep waterlogged and unstable soils) and are unlikely to rehabilitate satisfactorily. For these areas tactical route realignments warrant consideration to avoid disturbance. This can only be determined after the final route selection has been confirmed.

A rehabilitation plan will be developed for the project prior to construction. This plan should include:

- Clearly defined objectives for rehabilitation;
- Identification of priority rehabilitation sectors;
- Targeted rehabilitation prescriptions based on the characteristics of the landform, soils and vegetation of specific route sectors; and
- A detailed rehabilitation program that has been developed in consultation with tropical rainforest rehabilitation practioners and based on the reports undertaken for the 2005 PNG Gas Project and the 2008 PNG LNG Project.

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1 INTRODUCTION

This report presents the findings of the soil impact assessment and rehabilitation study for the PNG LNG Project for the proposed new areas of disturbance for route sectors between Juha and Hides, in Western Province and the Southern Highlands respectively (Figure 2). The study supplements various impact and rehabilitation studies undertaken in 2005 for the PNG Gas Project for the route between Hides and the Omati River landfall (Rogers 2005; Rogers et al. 2005; Rogers and Tucker 2005).

1.1 PNG LNG PROJECT BACKGROUND

The Papua New Guinea Liquefied Natural Gas (PNG LNG) Project involves the development of a number of gas fields and facilities in a series of development phases to produce liquefied natural gas (LNG) for export. The development will also produce condensate. The development of the Hides, Angore, and Juha gas fields and blowdown of the gas caps at the existing Kutubu, Agogo and Gobe oil fields will supply the gas resources. An extensive onshore and offshore pipeline network will enable transportation of the gas to a new LNG Plant near Port Moresby and stabilised condensate to the existing oil processing and storage, and offloading facilities at the Kutubu Central Processing Facility and Kumul Marine Terminal respectively. Small amounts of condensate are also produced at the LNG Facilities site.

Esso Highlands Limited (Esso), a Papua New Guinea subsidiary of the Exxon Mobil Corporation (ExxonMobil), is the operator of the PNG LNG Project. The PNG LNG Project will be developed in five phases over a period of 10 years to ensure reliability and consistent quality of supply of LNG for over the 30 year life of the project.

A list of the proposed developments is provided below, and in Figure 1.

Upstream Development Components:

- Hides gas field development:

— Seven wellpads with a total of eight new wells and re-completion of two existing wells.
— Hides gathering system including gas flowlines from new and re-completed Hides wells.
— Hides spineline and mono-ethylene glycol (MEG) Pipeline in the same right of way (ROW).
— Hides Gas Conditioning Plant.
— Hides–Kutubu Condensate Pipeline in the same ROW as the LNG Project Gas Pipeline.

- Juha gas field development:

— Three new wellpads with four new wells.
— Juha gathering system including gas flowlines from new Juha wells.
— Juha spinelines and MEG Pipeline in the same ROWs.
— Juha Production Facility.
— Juha–Hides pipelines right of way (ROW) containing three pipelines including Juha–Hides Rich Gas Pipeline, Juha–Hides Liquids Pipeline and Hides–Juha MEG Pipeline.

- Angore gas field development:

— Two new wellpads with two new wells.
— Angore gathering system including gas flowlines from new Angore wells.
— Angore spineline and Angore MEG Pipeline to Hides Gas Conditioning Plant, both in the same ROW.

- Gas from existing fields:

— Gas treatment at the Agogo Production Facility and a new Agogo Gas Pipeline from the Agogo Production Facility to LNG Project Gas Pipeline.
— Gas treatment at the Gobe Production Facility and a new Gobe Gas Pipeline from the Gobe Production Facility to LNG Project Gas Pipeline.
— Gas treatment at the Kutubu Central Processing Facility and a new Kutubu Gas Pipeline from the Kutubu Central Processing Facility to the LNG Project Gas Pipeline.

- South East Hedinia gas field development: one new wellpad and two new wells; new gathering system including gas flow lines from the South East Hedinia new wells to the Kutubu Central Processing Facility in the same ROW as the Kutubu Gas Pipeline.

- Kopi scraper station.

- LNG Project Gas Pipeline:

- Onshore: from Hides Gas Conditioning Plant to Omati River Landfall.
- Offshore: Omati River Landfall to Caution Bay Landfall.

LNG Facilities Development Components:

- Onshore LNG Plant including gas processing and liquefaction trains, storage tanks, flare system and utilities.
- Marine facilities including jetty, LNG and condensate export berths, materials offloading facility and tug moorage.

Supporting Facilities and Infrastructure:

In addition to the principal gas production, processing and transport, and LNG production and export facilities, the project will involve the following permanent infrastructure and facilities:

- New roads and upgrade of existing roads.
- New bridges and upgrade of existing bridges.
- Upgrade of two existing airfields (upstream at Komo and Tari).
- New helipads (multiple).
- New wharf and an upgrade of the existing Kopi roll-on, roll-off facility.
- Water supply systems and pipelines, wastewater and waste management facilities.
- Operations Camps (at Hides, Juha and Tari).

A series of temporary works and access roads will also be required during the construction phase, including:

- Construction camps (multiple).
- Material/pipe laydown areas.

2 OBJECTIVES

Within the terms of engagement with Coffey Natural Systems the scope of this study focuses on the new areas of disturbance between Juha and Hides, which includes route sectors in the Southern Highlands and Western Province respectively (Figure 2, Plate 1, Plate 2)

The objectives of this study are to:

- Review existing information (reports, geological maps, aerial photography, databases etc.) to characterise landform and soils in the study area;

- Conduct a field survey to identify significant landform features and potentially problematic soils;

- Assess the potential impacts on landforms and soils associated with the project activities;

- Review methods of rehabilitation of areas proposed for the PNG Gas Project; and

- Provide advice on measures to avoid, reduce or mitigate adverse impacts on landform and soils during project construction and operation including suitable rehabilitation techniques for the areas to be disturbed.

3 LIMITATIONS

The findings throughout this report are based on a literature review and field survey at locations determined safe to access in remote terrain. The sample site locations reflect as far as is reasonably possible examples of the landforms, soils and vegetation traversed by the route from Juha to Hides, however the exact areas of disturbance can not be determined because of potential minor tactical route modifications that may occur. Therefore the field survey was not based on a stratified sampling regime, but was opportunistic, assessing easily accessible locations only, and may therefore not account for all landforms, vegetation and soil types traversed by the route.

Figure 1 Project Overview – New and Existing

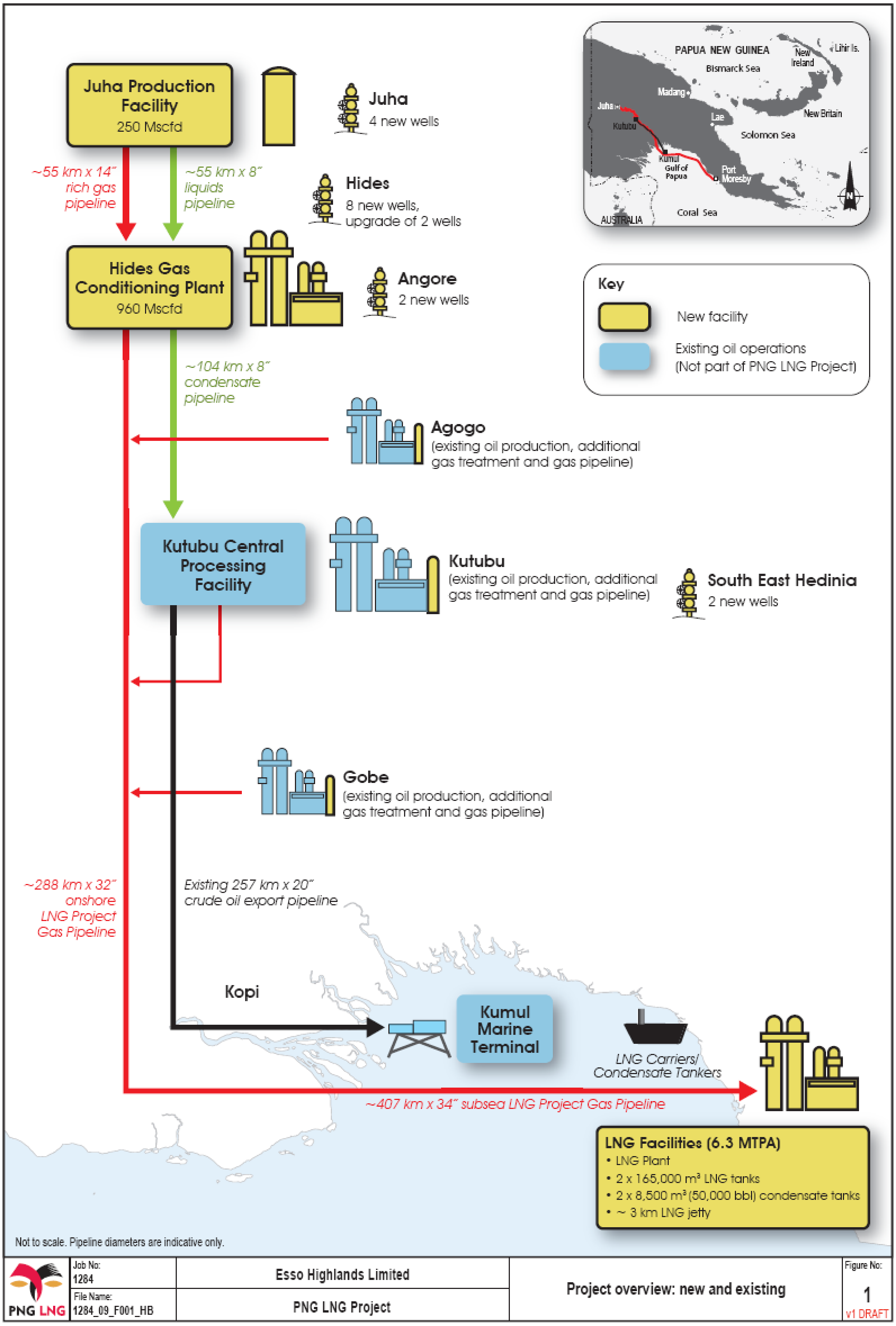
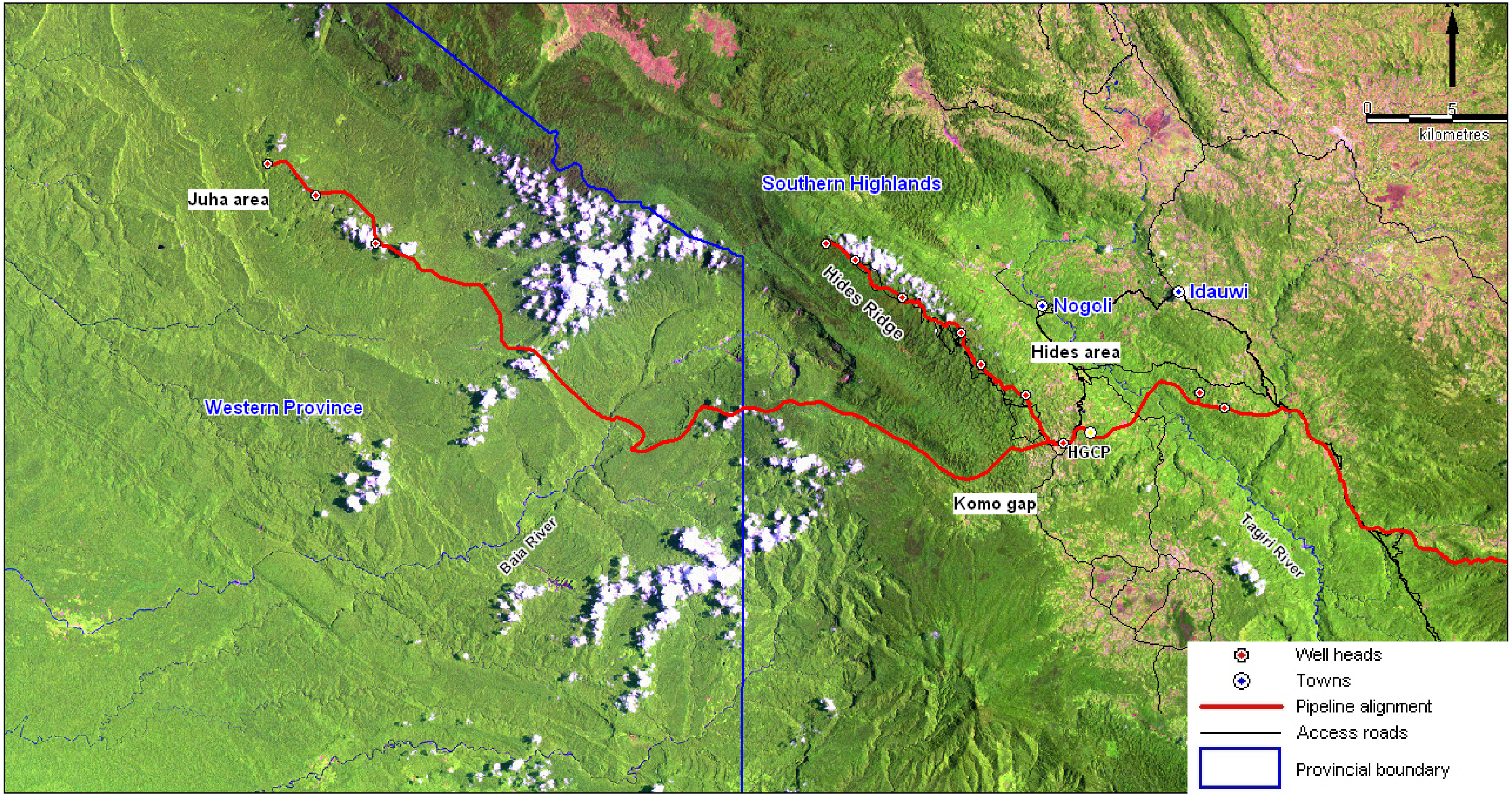


Plate 1 **Landforms and forest in the Juha area**

Plate 2 **Rugged karst terrain between the Komo Gap and Juha**

Figure 2 **Satellite image of the project route from Juha to Hides**



4 APPROACH

To characterise the soils and landforms between Juha and Hides and to determine the best strategy for rehabilitation the following tasks were undertaken:

- A review of international literature on tropical forest restoration;
- A review of methods of rehabilitation of the areas proposed for the PNG Gas Project in 2005; and
- A field survey to identify significant landform features, characteristic vegetation types and associated soils, and their response to disturbance along the route.

4.1 FIELD SURVEY

Field survey was restricted to sampling accessible areas that could be reached safely by helicopter or road (Figure 3). For these areas sample sites were chosen that were representative of the variation along the route in both lowland (< 1000 m above sea level (ASL)) and montane (1000 m – 3000 m ASL) environments. However, some terrain/forest types such as *Araucaria* dominated forest could not be sampled because of lack of access.

The field survey procedure comprised an aerial traverse of the route and an on-ground survey. An aerial traverse was flown to verify the landforms and forest classification identified from the Papua New Guinea Resource Information System (PNGRIS) mapping (Loffler 1974; Saunders 1993). The on-ground survey involved a rapid assessment of landforms, soils and vegetation for representative areas likely to be disturbed by the project.

Soils and vegetation were sampled for undisturbed sites and where accessible sites that had been disturbed by natural processes (e.g., mass movement) or clearing (e.g., old helipads). The pre-disturbance state of the vegetation and soils provides baseline information that can be used to direct rehabilitation where appropriate. Disturbed areas provide examples of how the vegetation recovers from disturbance events, providing information on natural sequences of vegetation change (e.g. succession), and species that could be used to promote more rapid rehabilitation if revegetation is required.

4.1.1 Vegetation

For each site a brief description of the main plant species was compiled, identifying species that may have properties for inclusion in revegetation programs. Typically such species possess adaptations to disturbed environments (e.g., rapid colonisers with fast growth rates and abundant seed production).

4.1.2 Soils

The soil assessment involved soil profile descriptions, analysis of selected soils for baseline properties, and a soil stability test. At each of the vegetation (usually forest) sample sites a soil profile description was made based on extracting an auger core to 1 m depth in 20 cm increments. Soils were augured to 1 m only since previous field experience in PNG has shown that most of the soil horizonation occurs to this depth, from which the soil can be characterised and classified. In addition, many PNG soils are relatively shallow with parent material being reached before 1 m depth. The exceptions to this are volcanic soils which can be several metres deep and some Entisols (very young soils formed in recent alluvium). For each soil augured a brief profile description was made describing the main horizons, field texture, and field pH. An example of a typical soil profile is presented in Appendix A. The vegetation and soil profile description for each sample site was compiled into a representative site description and soil profile data sheet (Appendix B). Soil samples were also collected for analysis of baseline properties. An Edelman auger was used to composite samples from eight locations from a site within approximately 10 m of the soil profile description sample point. The composite samples were thoroughly mixed in a clean 20 litre bucket having removed the topsoil litter. A sub sample of approximately 0.5 kg was then collected. Soil samples were dried at 80°C for 48 hours (Plate 3) prior to dispatch for analysis. The soil samples were analysed for the following baseline properties at Southern Cross University Environmental Analysis Laboratory:

- pH water (1:5 w/v);

- Total phosphorous (P);
- Total nitrogen (N) (Kjehldahl)
- Total carbon C (Walkley-Black);
- Exchangeable bases, Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Aluminium (Al) and Cation Exchange Capacity (CEC) (NH4Oac pH 7);
- Available nutrients, Ca, Mg, K (Morgan 1 extract), available P (Bray 1, Bray 2 and Olsen); and
- Micronutrients Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu) and Boron (B).

Soil stability was also assessed using the Aggregate Stability in Water Test (ASWAT), which provides an indication of which soils may be most susceptible to erosion by assessing the stability of natural soil fragments to rapid wetting (Tongway and Hindley 2004). Small fragments (approximately 1 cm diameter) of representative soils horizons were air dried and then gently lowered into a dish of rain water (Plate 4). The stability of each fragment was then scored based on the descriptions in Table 4-1.

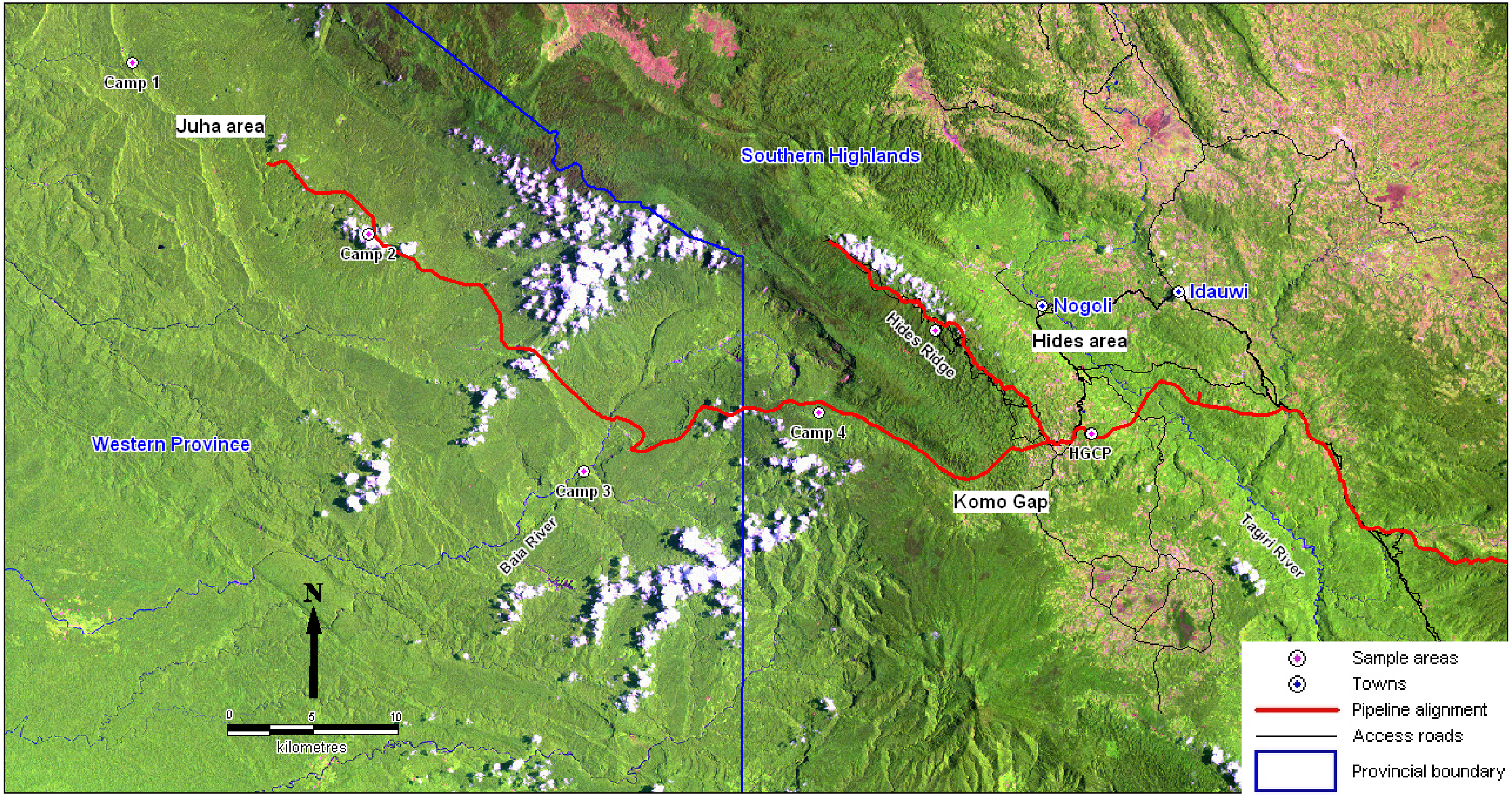
Table 4-1 Aggregate stability in water assessment guide

Observed behaviour	Class	Interpretation
	0	No coherent fragments available e.g. sand
Very unstable	1	Fragment collapses in less then 5 seconds
Unstable	2	Fragment substantially collapses 5-10 seconds; a thin surface crust remains. > 50% of the sub-crust material slumps
Moderately stable	3	Surface crust remains intact with some slumping of the sub-crust but less then 50%
Very stable	4	Whole fragment remains intact with no swelling

Plate 3 **Soil samples drying prior to analysis**

Plate 4 **Aggregate stability in water test (ASWAT)**

Figure 3 Field assessment sites



5 LITERATURE REVIEW – TROPICAL FOREST REHABILITATION

Terrestrial ecosystems across Papua New Guinea vary substantially despite occurring on the same latitudinal zone. This is highlighted by forest variation associated with the proposed route from Juha to Hides where major differences in forest type occur across an altitude gradient from lowland hill forest (lowland forest on uplands) to the montane *Nothofagus pullei* dominated forest on Hides Ridge at about 2500 m ASL. Forest variation also reflects the diversity of landforms and associated soils, which include meandering river valleys supporting pandanus swamp forest and *Nothofagus grandis* forest, to steep landslip prone limestone escarpments where skeletal soils support various stages of successional vegetation.

The different soils and vegetation associated with the different landforms and climate zone variation may be impacted in different ways by construction works, depending on the vegetation type, its natural regeneration characteristics and the associated soil properties such as stability (resistance to erosion), and fertility. Therefore, a range of approaches may be required for the mitigation of impacts and rehabilitation of disturbed areas. Although it is outside the scope of this study to review specific rehabilitation approaches to specific soil and vegetation types, general approaches to rehabilitation provide the basic principles for targeted rehabilitation effort. The following sections review tropical soils and broad approaches to tropical rainforest rehabilitation.

5.1 TROPICAL SOILS

There are five major soil-forming factors: climate, vegetation, relief, parent material, and time. Differences in the combination of these factors result in soils varying over relatively short distances such as between ridge, slope, toe slope and valley. Most soils are derived from the weathering of the underlying rock (parent material). Such weathering is at its most rapid in the humid tropics that is typical of lowland rainforest environments, and may result in very deep soils (> 10 m), particularly across stable volcanic landforms. However, in PNG shallow soils (< 2 m deep) are a more common feature, reflecting the active landscapes (Wood 1982). Erosion, instability, continuing accessions of alluvium, wind borne dust (loess) and organic matter (peat soils), and the relative youth of much of the landforms are a feature of the active soil formation environment. Thus soil parent material often originates from multiple sources (Hope and Hartemink 2006).

For example in the Hides area deep (> 10 m) weathered soil profiles of volcanic origin are found in a relatively stable landscape. These soils contrast markedly with soils in the ridge and ravine landscape that characterises much of the route towards Juha. In this landscape, mass movement, erosion and deposition are active forces resulting in relatively recent soils such as those formed from alluvium along the meanders of the Baia River, and colluvium from slips in loose siltstone overlying limestone escarpments. Consequently soils along the Juha to Hides route will vary according to their position in the landscape and associated soil formation processes. The different soils types are characterised by differences in chemical and physical properties (Bleeker 1983) which may affect their response to disturbance and their ability to act as successful rehabilitation substrate once they are disturbed.

Differences in soil type typically influence the vegetation, however in PNG, specific soil types have less influence on vegetation than altitude, topography and climate (Paijmans 1975), and relatively uniform forest types can extend across a variety of soil types in humid tropical forest regions (Burnham 1989). This has positive implications for rehabilitation, particularly in very disturbed areas where soil profiles may be severely damaged and soil profile reconstruction is required. Provided that the materials used to create a soil profile after construction are not physically and/or chemically hostile to plant growth, then the key soil factors influencing rehabilitation performance are likely to be the rate of surface erosion, available nutrients, and water infiltration and its availability over time for plant growth, rather than the specific soil type (Jasper and Tongway 2005).

Infiltration of rainfall into tropical soils is also essential for ecosystem function and natural recovery processes. If infiltration is inadequate, then accelerated runoff is likely to lead to an increased risk of erosion. Infiltration and deep drainage in tropical forest soils is considered to be dominated by two systems:

- Rapid drainage with short residence time through macropores (e.g., created by soil fauna); and
- Slow drainage and longer residence in micropores where the moisture is retained by capillarity (Nortcliff and Thornes 1989).

Infiltration in reconstructed soil profiles will depend on the method of preparation and the intrinsic properties of the soils, and less on the natural porosity typical of undisturbed soils. The predominant control of surface erosion of soils is plant cover (Schuman and Ries 1996). For example if greater than 50% vegetative cover is achieved then soil loss is reduced to less than 10% of that from equivalent bare soil (Bleeker 1983). Soils on rehabilitated areas will be at their most vulnerable to rain splash and water erosion in the first few weeks or months of growth (Jasper and Tongway 2005).

Within many tropical rain forest ecosystems the major proportion of the nutrient capital is held within plant and litter biomass (Grubb 1989; Burghouts et al. 1992). This contrasts with more temperate ecosystems, where a much larger proportion of nutrients are held in the soil. In parallel with nutrient and organic matter distribution and oxygen availability, plant roots are predominantly in the surface layers of tropical soils, their mass declining rapidly with depth (Golley 1983). The mat of fine roots and their associated mycorrhizal hyphae in surface soils and litter layers, act to capture a large proportion of nutrients mineralised and leached from these layers (Golley 1983). The number of roots in surface soils (5 – 10 cm depth) is typically around 10 times that occurring at 40 cm depth. If barriers to root exploration and extension occur within 1.8 m of the surface then these are considered to potentially influence forest rehabilitation performance (Burnham 1989).

5.2 RESTORATION OF TROPICAL FORESTS

Information regarding successful restoration of tropical forest ecosystems is relatively sparse. Most tropical forest restoration literature focuses on abandoned farmland (Holl and Cairns 2002), and on the development of forestry and agroforestry systems, aiming at maximizing productivity of a limited number of economically important species (Parrotta 2002). It has been less-common for restoration projects to focus on creating a diverse ecosystem of locally-occurring species that resembles that which previously occupied the landscape. An exception to this has been in the Wet Tropics of north eastern Australia where diverse ecosystems have been restored (Goosem and Tucker 1995), but required considerable external inputs (e.g., planting stock, weed control etc).

5.2.1 Natural regeneration

Many plant species from tropical forests have the potential to rapidly regenerate/re-establish without intervention, depending on the degree of disturbance. Natural regeneration has been shown to be highly successful for re-establishing native species to restore forest along the relatively flat terrain of the existing crude oil export pipeline ROW for areas where topsoil[1] remains, and/or areas where topsoil is mixed with limestone scree in karst terrain (Rogers 2005). This capacity reflects moisture and temperature conditions that are favourable for germination, a relative lack of competition from weed species, the application of salvaged topsoil with a viable soil seed bank, and or relatively abundant seed rain from the adjacent forest. Key aspects in natural regeneration that have been identified by both Parrotta (2002) and Holl and Cairns (2002) include:

- Seed and rootstock availability;
- Seed germination;
- Competition with existing vegetation;
- Microclimate, microhabitats, and fire;
- Soil nutrients and soil microbial communities;
- Herbivores and predation;
- Social factors; and

---

[1] Topsoil is the upper layer of soil which is a mineral horizon which has some accumulation of organic matter

- Time.

There is potential for limitations or constraints to occur within each of the identified aspects of the re-establishment process, which in turn may represent a limitation to the overall rate of development of a forest ecosystem. For example, absence of seed is frequently reported as limiting to vegetation establishment and diversity, with Holl et al. (2000) recording less than one eighth of seeds falling in open farmland compared to that in adjacent forest. Indirect measures such as provision of perches to encourage seed-dispersing birds, as reviewed by (Lamb 1990), are reported to increase seed numbers within the vicinity of the perches. In early phases of re-establishment, predation of seeds or grazing of seedlings is also an potential limitation (Holl et al. 2000). The particular micro-habitat for plant establishment in bare areas can be less favourable than forested areas, particularly in terms of higher soil and air temperatures, greater light, and lower humidity (Holl et al. 2000). These physical environmental factors can limit both seedling survival and germination. An additional constraint that is common in many restoration efforts is high levels of competition from groundcover species and grasses (Jasper and Tongway 2005). This competition may be in terms of reduced access of forest species to nutrient and water resources, but also physical smothering of newly-established plants by the established groundcover plants (Parrotta 2002). The soil environment is a key component influencing the likely success of any revegetation initiative (Jasper and Tongway 2005). In natural soils that have been cleared and abandoned but otherwise largely undisturbed, soil compaction and lack of both nutrients (Holl 1999) and beneficial soil microbes (Janos 1996) have been reported as constraints on successful forest restoration. These potential constraints are likely to be even more relevant in areas where topsoil may be degraded or absent. Consequently prior identification of constraining restoration factors along the different route sectors will be important in assessing the likely success of natural re-establishment of forest.

5.3 DELIBERATE RESTORATION OF TROPICAL FORESTS

Deliberate rehabilitation of tropical forests, as distinct from natural processes, is increasingly being practiced to restore forest ecosystems on previously-cleared lands (ITTO 2002) and in mine environments. Typical strategies are built on an understanding of the establishment ecology of tropical forest species and may include:

- Defining any potential soil constraints to plant establishment and growth;
- Introducing topsoil where appropriate and when available;
- Planting seedlings of appropriate early colonising tree species; and
- Controlling grasses and groundcovers to prevent smothering and competition for resources.

As an appropriate microclimate develops, enrichment planting including the use of shade-tolerant species may occur, or establishment of these species may be encouraged indirectly by attracting seed-dispersing fauna, such as through fruit bearing trees (Goosem and Tucker 1995, Jasper and Tongway 2005).

6 JUHA - HIDES AREA CHARACTERISTICS

The area of new disturbance between Juha and Hides will traverse a range of terrestrial environments from about 2600 ASL on Hides Ridge to the lowland forests in the Juha area of Western Province. The dominant topographic feature of the region is the Karius Range and Mt. Sisa which is located to the southeast of the route. The geomorphology of the new route sector is dominated by denudational and volcanic land forms. The Hides area is predominantly classified as polygonal karst (Loffler 1974) which changes to volcanic foot slopes and volcano-alluvial fans, partly dissected or undissected as the route passes westward from the Komo Gap. The remainder of the route is predominantly ridge and ravine landforms comprising a spectacular limestone dominated landscape. These landforms are formed from fluvial erosion and mass movement.

The dominant vegetation varies from low altitude forest on uplands (lowland hill forest) to lower montane forest up to 2600 m ASL on Hides Ridge (Figure 4). Anthropogenic grasslands also occur in the Hides area. Forest types are broadly mapped at a scale of 1:1000000 as medium crowned lowland forest on uplands (below 1000 m), small crowned lower montane forest (1000 – 3000 m ASL) and small crowned lowland forest with *Nothofagus* (1000 – 3000 m ASL) (Saunders 1993). Lowland forest on uplands is found across a wide range of landforms, slope, rock type, soil, and climate and may occur beyond its typical altitude limit of 1000 m to 1400 m ASL. Consequently the structure and floristic composition can vary widely from site to site. The small crowned lower montane forest is typically confined to the mountain ranges (Saunders 1993). This forest type classification is constrained by the scale of mapping resulting in several distinctly different forest types being grouped together. Specific forest types for these broad classes identified during field survey are summarised in Table 6-1.

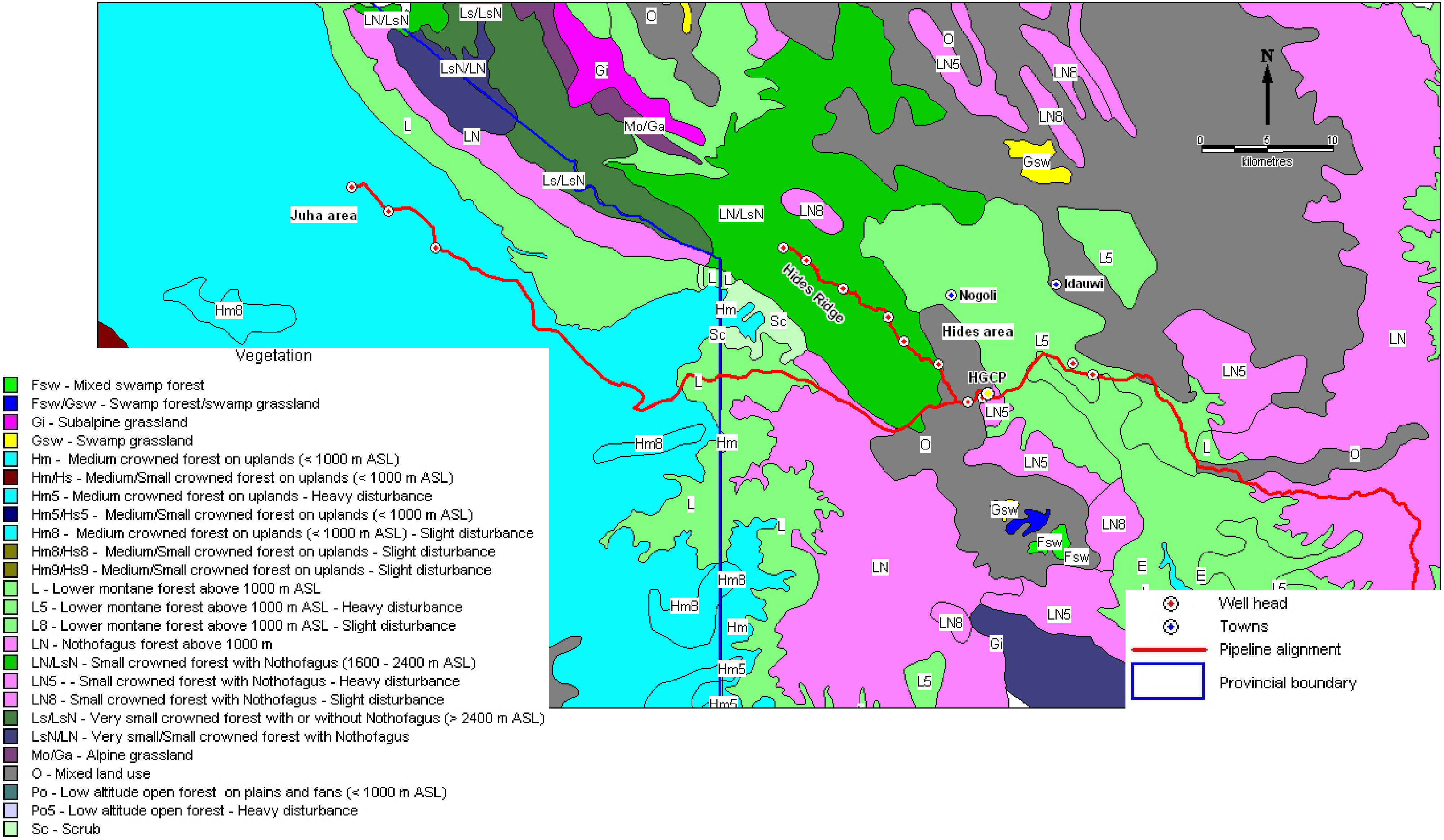
Vegetation associated with the proposed route is largely unmodified apart from in the Hides area where much of the accessible forest has been cleared for gardens, leaving a mosaic of cultivated land, grassland and remnant patches of native forest. Away from Hides the vegetation is predominantly unmodified and is dominated by extensive tracts of primary rainforest, apart from in the Komo Gap area where occasional gardens occur. The main disturbances to the forests from the Komo Gap westwards to Juha are natural disturbance events, such as large landslides which are a characteristic of PNG's forested lands (Johns 1986).

Table 6-1 Vegetation types predicted to occur/observed between Juha and Hides

Broad Altitude zone (m) from PNGRIS	Altitude zone (m) from (Johns 1977)	PNGRIS vegetation type (Hammermaster and Saunders 1995)	Vegetation type from Johns (1977) and field observations	Landform from Loffler (1974) and field observations	Known location
Lowlands:< 1000	0 – 300 (lowlands)	Medium crowned forest on uplands	Mixed lowland rainforest	Homoclinal ridge and ravine. Limestone	Juha area
Lowlands:< 1000	300 – 1000 (lower montane)	Small/medium crowned forest with *Araucaria* common	*Araucaria* forest	-	West of Camp 4
Lowlands & Lower montane: 1000 - 3000	600 – 1500 (lower montane – mid montane)	Small crowned forest with *Castanopsis*	*Castanopsis acuminatissima* dominated forest	Polygonal karst overlain by volcanic deposits	HGCP
Lower montane: 1000-3000	-	Medium crowned forest	Pandanus dominated swamp forest	Alluvial plain/volcanic alluvial fan	Camp 4
Lower montane: 1000-3000	1500 – 2000 (mid montane)	Medium crowned forest	*Nothofagus grandis* dominated forest	Alluvial plain	Camp 4
Lower montane: 1000-3000	1500 – 2000 (mid montane)	Small/very small crowned forest with *Nothofagus*	*Nothofagus flaviramea* dominated	Polygonal karst	Hides Ridge
Lower montane: 1000-3000	1500 – 2000 (mid montane)	Very small crowned forest with *Nothofagus*	*Nothofagus pullei* dominated forest	Polygonal karst	Hides Ridge
Lowlands - montane	-	Riverine successions dominated by grass	Stream bed sere	Composite meander plain	Camp 1 to Camp 4
Lowlands - montane	Lowlands - montane	Grassland	Anthropogenic grasslands	Polygonal karst overlain by volcanic deposits	HGCP

- = not known

Figure 4 Major vegetation classes traversed by the route



7 FIELD SURVEY FINDINGS

The field survey was undertaken to characterise the soils and associated vegetation for representative sites along the route. The main sites assessed were located to the south of the Karius Range in Western Province, along Hides Ridge, and at the location of the proposed HGCP facility in the Hides area. The sites available for assessment in the Western Province sectors of the route were located at Camp 1 and Camp 2 in the Juha area, Camp 3 adjacent to the Baia River, and Camp 4 near the South Karius River (Figure 3). The landform, soil and vegetation characteristics of the field sample sites are summarised in Table 7-1, with site and soil profile descriptions provided in Appendix B.

7.1 SOILS

The majority of soils sampled were from three main soil orders, Inceptisols, Alfisols and Entisols. Inceptisols are moderately weathered soils, with slightly developed horizons. Alfisols are moderately weathered soils that have an argillic horizon (a layer within the soil profile with higher clay content due to movement of clay from the top to lower layers). Entisols are very young soils, with little or no profile (horizon development) except for a thin humic[2] surface horizon, and occur mainly on recent alluvium or on steep slopes where soil erosion takes place. These three soil orders are groupings of several different soil types (great groups). Hope and Hartemink (2006) should be consulted for a summary of PNG soils and refer to Bleeker (1983) for a detailed explanation of the soil properties.

The different soils were characterised in the field by their depth to parent material, topsoil depth, field pH, and texture (proportion of sand silt and clay). Soil depth varied from > 10 m in the volcanic landforms of the HGCP site to < 1 cm on degraded limestone sidecast sites. Most unmodified soils were > 1 m deep apart from one soil of 40 cm depth in the Camp 2 area. Topsoil depth also varied amongst the soils varying from an absence of any substantial topsoil on sidecast slopes in karst terrain on Hides Ridge, to a maximum depth of about 20 cm in stable forested sites in the lowlands and lower montane zone. Topsoil depth is an important soil feature because it is the most fertile soil horizon with the highest level of exchangeable cations (Bleeker 1983), and contains a large soil seed bank. In conjunction with seed rain, soil seed banks are critical for the success of rehabilitation programs that rely on natural regeneration.

Most of the soils had a silty clay loam field texture, with more sandy soils occurring adjacent to Baia River and South Karius River reflecting colluvial and alluvial deposits. Soil texture partly determines the response of soils to disturbance and their ability to be rehabilitated. For example peat soils can be irreversibly damaged by draining and become susceptible to fires, while some clay soils are highly dispersive, particularly if they are kaolin clays which are prone to erosion. A test was not conducted for dispersiveness, but soil stability was assessed. The silty clay loam soils were generally stable, with unstable silty loams and sandy soils present in river valleys and on river terraces.

Soil field pH mainly varied from strongly acid (pH 4 – 5) to weakly acid (pH 5.5 – 6) with only soil formed in the alluvial sands adjacent to the Baia River having an alkaline pH (pH 8). This may reflect the presence of limestone fragments in the soil profile. This range is consistent for soil pH values reported for other sites across PNG (Bleeker 1983; Rogers 2006). Soil pH affects the availability of nutrients for plant uptake and the activity of important soil micro-organisms, both of which peak in slightly alkaline soils and are low in strongly acidic or strongly alkaline soils (Mckenzie et al. 2004). This may have implications for the direction of natural regeneration and suggests that a nitrogen fixer such as Mung Bean (*Munga vigna*) may be warranted as a soil conditioner at some locations where strongly acid soils are present.

The results from the soil fertility analysis (Table 7-2) showed marked variation amongst the soils which varied from strongly acid to slightly alkaline, and fertile to infertile. These results are discussed below. Guidelines to the interpretation of nutrient concentrations are presented in Table 7-3 and Table 7-4.

Soils from Camp 2 (S8) and from the HGCP site (S3 and S4) (deep volcanic soils) were the least fertile of all the soils having a low CEC of 4.6, 6.1 and 7.9 $cmol^+/Kg$ respectively. A Cation Exchange Capacity (CEC) between 5 and 15 $cmol^+/Kg$ is rated as low, 15 – 25 as medium, 25 – 40 high and > 40 very high (Landom 1991). The CEC value provides a guide to the nutrient levels in the soil. A soil

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[2] Humic substances are the material that results from the decay of organic material and gives the soil its brown colour.

with a high CEC (> 25 cmol^+/Kg) suggests the soil retains high levels of nutrients which are available for plant uptake. For the HGCP site, sample S3 had been taken from an area dominated by anthropogenic grasslands (*Imperate cylindrica*), and S4 had been taken from a remnant forest area. The modified soils of the grasslands were only slightly less fertile than the soil from the forest remnant, with slightly lower CEC, total Nitrogen (N), total Phosphorous (P), and available P. More fertile soils occurred in a range of locations including Camp 2 (S7), which was a shallow soil on a narrow limestone ridge and had the highest CEC of 43.3 cmol^+/Kg, and at Camp 3 for the soils on the river terraces (S9, S10 & S11) which all had high CECs (> 25 cmol^+/Kg). Soils of intermediate fertility occurred on Hides Ridge (S5) and at Camp 4 for the *Nothofagus grandis* dominated forest (S12) and the pandanus swamp forest (S15).

Many of the soils had low values of micronutrients. All the soils had low values of Boron and would be rated as deficient since they all had < 1 ppm, which is the indicator level for deficiency (Landom 1991). Several soils also had low values of Zinc, Manganese and Copper based on the typical ranges stated in Table 7-4. Soil samples S3, S5, S6, S8 and S12 have zinc concentrations of between 0.5 and 1 ppm which is regarded as deficient for the analytical method used (Landom 1991). The most fertile soils from Camp 2 (S7) and Camp 3 (S9 and S10) all had concentrations of micronutrients within normal ranges apart from Boron. The least fertile soil S8 from Camp 2 had low values of all the trace elements apart from Iron. Therefore the Camp 2 area contained the most fertile and least fertile soils sampled.

Most of the soils had adequate levels of Total Nitrogen (N), with sample S7 (limestone ridge from Camp 2) having the highest Total N (1.48 %). All the samples from the Baia River area (Camp 3) were low, particularly on the more recent soils on the young river terraces S9 and S11 which had total N values of 0.13 and 0.11 respectively. Values between 0.1 and 0.2 are rated as low (Landom 1991).

Total carbon (C) showed a similar trend to total N. Total C was highest in S7 in Camp 2 and lowest in Baia River area of Camp 3 (S9, S10 and S11) and in S8 in Camp 2 which all had Total C < 4 % which is rated as low. High values of total C were also found in the soils of the Camp 4 area (S12 and S15). These soils were very wet compared to the other sites, which is often associated with higher total C (Mckenzie et al. 2004). The carbon in the soil is directly related to the amount of organic matter in the soil. Organic matter is important in soils since it improves soil structure and soil chemical properties. Soil organic matter is often responsible for up to half the CEC and acts as a stabilising agent for soil aggregates (Mckenzie et al. 2004).

To determine available phosphorous different methods were used since the preferred method depends on the soil pH. For soils of pH > 7 the Olsen method is preferred, and for acid soils the Bray methods are preferred (Landom 1991). The Bray 1 test is strongly correlated with response to fertilizer application and the Bray 2 test is similar to Bray 1 but uses higher levels of acid to extract soil phosphorous. The requirement to use different methods makes interpretation difficult, however there was some consistency in the trends amongst the methods. The low fertility sample S8 in the Camp 2 area had low values for available P across all the tests used. Samples S3, S4, S6 and S15 also had values of P rated as low for the Olsen method. The fertile soil, S7 in Camp 2 had the highest level for available P for the Olsen test only, however this is not the preferred method for such an acid soil. Soils from the Baia River area S9, S10 and S11 also had elevated available P.

For Camp 4 (South Karius area) soils from the *Nothofagus* forest (S12) and the pandanus swamp forest (S15) had very similar properties, which suggest that variation in the forest type primarily reflects the different drainage conditions rather than soil chemistry. This highlights the potential sensitivity of these forest types to an altered drainage, which could potentially cause major shifts in species composition and a loss of forest type.

Drawing firm conclusions about the soil properties over such a large and diverse landscape based on a small number of samples is problematic. However some general trends can be inferred as follows:

- Soil properties vary considerably across the route, with large variations possible across any one site;
- A site may contain fertile and infertile soils associated with small changes in the landscape/topography;

- The majority of the soils are acidic with some soils being strongly acid (pH 4 – 5);
- Soils in similar landscape positions have similar properties, e.g. soils of the alluvial plains along the Baia River;
- For a specific altitude zone soil drainage and landform may play greater role in determining forest type than soil fertility properties; and
- Despite potential nutrient deficiencies in some soils (e.g. micronutirents and available P) most sites support productive primary rainforest.

Table 7-1 Summary of the field assessment of landform, soils and vegetation[3]

Site No.	Location[4]	Geology	Landform	Topography	Soil order	Texture	Field pH	Vegetation	HASL (m)	Soil depth (m)	Topsoil depth (cm)	Stability
S3	HGCP1	Volcanic	Rolling hills	Flat - slope	Inceptisol	Silty clay loam	6.0	Grassland	1700	> 10	12	Stable
S3b	HGCP1	Volcanic	Rolling hills	Slope	Inceptisol	Silty clay loam	6.0	Grassland	1700	> 10	22	Stable
S4	HGCP1	Volcanic	Rolling hills	Slope	Inceptisol	Silty clay loam	5.5	*Castanopsis* forest	1700	> 10	10	Stable
S5	Hides Ridge	Karst	Mountain range	Flat - slope	-	Silty clay loam	4.5 – 6.0	*Nothofagus pullei* forest	2500	> 1	25	Stable/Moderately stable
S5 1a	Hides Ridge	Karst	Mountain range	Side cast slope	-	Rock	-	Sparse regeneration	2400	< 0.01	< 1	(no soil to test)
S5 1b	Hides Ridge	Karst	Mountain range	Terrace	-	Rock/Gravel	-	Sparse regeneration	2400	< 0.01	1	(no soil to test)
S6	Camp 1	Karst	Steep hills	Flat - slope	Alfisol	Silty clay loam	4.5 - 5.0	Lowland forest on uplands	350	> 1 m	15	Stable
S7	Camp 2	Karst	Steep hills	Flat - slope	Alfisol	Silty clay loam	5.5	Lowland forest on uplands	950	0.4 m	10	Stable
S8	Camp 2	Karst	Steep hills	Ridge	Alfisol	Silty clay loam	4.0	Lowland forest on uplands	950	> 1 m	8	Stable
S9	Camp 3	Colluvium	Raised river terrace	Flat	Entisol	Sandy clay	5.0 – 6.0	Regrowth - Lowland forest on uplands	350	> 1 m	7.5-8	Moderately stable
S10	Camp 3	Karst	Steep hills	Undulating	-	Silty clay – silty/clay loam	5.0	Lowland forest on uplands	350	> 1 m	20	Moderately stable
S11	Camp 3	Alluvial sands	River terrace	Flat	Entisol	Sandy loam	8.0	Lowland forest on uplands	350	> 1 m	5	Unstable
S12	Camp 4	Valley deposits	Valley floor, incised	Flat	-	Silty loam	4.5	Montane *Nothofagus grandis* forest	1370	> 1 m	20	Unstable
S13	Camp 4	Alluvial sands and gravel	River terrace	Flat	Entisol	Sand	-	Stream bed sere	1370	-	-	Unstable
S15	Camp 4	Valley deposits	Valley floor, swamp	Flat	-	Silty clay loam	5.5	Pandanus swamp forest	1370	> 1 m	20	-

(- = not known)

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[3] Site and soil profile descriptions and photos are presented in Appendix B

[4] Field sampling coordinates are presented in Appendix B

Table 7-2 Baseline soil fertility properties

Test	Nutrient		Units*	Soil sample location and number										
				HGCP	HGCP	H Ridge	Camp 1	Camp 2	Camp 2	Camp 3	Camp 3	Camp 3	Camp 4	Camp 4
				S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S15
Soluble Tests & Morgan 1 Extract	Calcium	Ca	ppm	277	250	429	286	1636	29	3689	2078	4060	340	261
	Magnesium	Mg	ppm	54	68	129	78	90	12	220	209	60	50	71
	Potassium	K	ppm	64	43	71	33	127	20	115	42	47	62	68
	Phosphorus (Bray 1)	P	ppm	1	1	1	1	2	1	2	8	2	1	1
	Phosphorous (Olsen)	P	ppm	2	4	7	4	12	3	8	13	5	8	3
	Phosphorus (Bray 2)	P	ppm	1	2	8	3	11	1	60	48	39	14	12
	pH (1:5 water)		units	5.36	5.06	4.58	4.35	5.43	4.31	7.34	6.19	7.74	4.54	4.55
	Conductivity (1:5 water)		S/cm	141	178	229	164	408	66	251	187	185	229	256
	Organic Matter		%	12.81	17.42	17.13	8.59	48.41	4.96	3.38	5.70	4.08	22.24	22.24
Ammonium Acetate Equiv. Extract	Calcium	Ca	cmol$^+$/Kg	4.15	4.66	7.67	4.74	37.85	0.24	29.05	25.21	27.50	6.33	5.20
	Magnesium	Mg	cmol$^+$/Kg	0.85	0.99	2.12	1.59	1.63	0.17	2.92	3.16	0.69	0.87	1.18
	Potassium	K	cmol$^+$/Kg	0.29	0.20	0.42	0.35	0.54	0.10	0.70	0.27	0.28	0.37	0.44
	Sodium	Na	cmol$^+$/Kg	0.05	0.10	0.11	0.06	0.12	0.03	0.05	0.07	0.07	0.11	0.14
	Aluminium	Al	cmol$^+$/Kg	0.16	0.95	3.55	7.17	0.15	2.45	0.01	0.01	0.02	4.84	4.71
Acidity Titration	Hydrogen	H^+	cmol$^+$/Kg	0.64	1.00	2.84	5.63	3.02	1.64	0.00	0.48	0.00	3.78	4.02
	Cation Exchange Capacity		cmol$^+$/Kg	6.13	7.91	16.71	19.54	43.31	4.63	32.73	29.20	28.55	16.31	15.69
Micronutrients-DTPA +Hot $CaCl_2$ Extracts	Zinc	Zn	ppm	0.7	1.4	0.2	0.3	8.7	0.3	1.8	1.5	1.7	0.3	1.8
	Manganese	Mn	ppm	7.1	8.0	28.2	30.6	116.0	1.0	27.0	34.9	15.5	8.7	32.1
	Iron	Fe	ppm	180.7	253.5	358.4	66.8	419.7	179.6	91.1	113.3	70.1	281.3	685.3
	Copper	Cu	ppm	3.4	4.8	0.5	0.2	5.2	0.4	2.6	3.0	1.7	0.5	5.7
	Boron	B	ppm	0.10	0.10	0.10	0.10	0.26	0.10	0.10	0.05	0.07	0.10	0.10
Total Nutrients	Total Carbon	C	%	7.32	9.96	9.79	4.91	27.66	2.83	1.93	3.26	2.33	13.50	12.71
	Total Nitrogen	N	%	0.45	0.56	0.59	0.44	1.48	0.15	0.13	0.24	0.11	0.89	0.83
Acid Digest	Total Phosphorus	P	ppm	337	454	723	721	1473	931	543	509	633	1072	923
	Colour	c		Orange	Orange	Orange	Orange Brown	Brown	Orange	Light Brown	Light Brown	Grey	Brown	Brown

*Units: ppm = parts per million, S/cm = micro Siemen per centimetre, cm, cmol$^+$/Kg = centimole per kilogram, % = percentage

Table 7-3 Guidelines to the interpretation of major nutrient concentrations

Nutrient	Units	Very Low	Low	Medium	High	Very High
Phosphorous (Olsen)	ppm	NS	< 5	5 - 15	>15	NS
Cation exchange capacity	cmol$^+$/Kg	< 5	5 - 15	15 - 25	25 – 40	> 40
Exchangeable Calcium	cmol$^+$/Kg	NS	NS	NS	NS	NS
Exchangeable Magnesium	cmol$^+$/Kg	NS	< 0.2	0.2 – 0.5	> 0.5	NS
Exchangeable Potassium	cmol$^+$/Kg	NS	0.2 – 0.3	0.2 – 0.4	0.4 – 0.8	NS
Exchangeable Sodium	cmol$^+$/Kg	NS	NS	NS	NS	NS
Exchangeable Aluminium	cmol$^+$/Kg	NS	NS	NS	NS	NS
Total Carbon	%	< 2	2 - 4	4 - 10	10 - 20	> 20
Total Nitrogen	%	< 0.1	0.1 – 0.2	0.2 – 0.5	0.5 – 1.0	> 1.0

NS = Not Stated (source: Landom 1991)

Table 7-4 Guidelines to the interpretation of micronutrient concentrations

Micronutrient	Units	Mean	Usual Range
Zinc	ppm	90	1 – 900
Manganese	ppm	1000	20 – 10,000
Iron	ppm	NS	NS
Copper	ppm	30	2 - 250
Boron	ppm	20	2 – 270

NS = Not Stated (source: Landom 1991)

8 POTENTIAL IMPACTS

The potential impacts of project construction will depend on a range of factors including the type, frequency, and intensity of disturbance, the properties of the soils impacted (e.g. stability and susceptibility to mass movement), the vegetation type and its ability to naturally regenerate once disturbed, landscape position, and the rainfall pattern. For example steep slopes will be prone to gulley erosion and mass movement if disturbed, particularly if located in an area of volcanic soils that receives runoff from upper slopes. In contrast karst plains may be less affected by impacts, and are unlikely to be subject to high rates of sheet or gulley erosion. Erosion results in the loss of the fertile topsoil and removes the soil seed bank, leaving the lower productivity subsoil exposed.

The potential impacts of the project are summarised in Table 11-2. The degree of impact and mechanism of impact will partly depend on the type and intensity of the disturbance. The disturbance may be direct, e.g., a construction activity or indirect, e.g., the introduction of weeds and fungal pathogens. Potential impacts may include the following:

- Temporary clearance of woody vegetation leaving a relatively intact ground cover;
- Clearance of all vegetation cover exposing topsoil;

- Complete removal of vegetation and topsoil exposing bedrock;
- Complete removal of vegetation and topsoil in steep terrain with extensive sidecasting of excess spoil;
- Excessive compaction of the soil surface;
- Erosion;
- Weed invasion;
- Increases susceptibility to catastrophic fire;
- Edge effects; and
- Introduction of the fungal pathogen *Phytophthora cinnamomi*

These different types of impacts are discussed below.

8.1 TEMPORARY CLEARANCE OF WOODY VEGETATION

Where woody vegetation has been temporarily cleared and soils remain relatively intact, vegetation is expected to rapidly regenerate, particularly in the lowlands. Examples of good recovery from this type of disturbance occur throughout the existing crude oil export pipeline ROW on flat or gently sloping terrain (Rogers 2005). The rate of recovery from this type of disturbance will be highest in the lowland zone and lowest in the montane zone where growth rates are reduced because of the cooler climate. Rates of recovery appeared slowest along Hides Ridge at about 2500 m ASL This observation was based on field visits to Hides Ridge in 2005 and 2008 and is consistent with the results from growth modelling undertaken across a range of forest types across PNG, which show growth rates to be slowest in montane *Nothofagus* forests compared to lowland forest environments (Alder 1998).

8.2 COMPLETE REMOVAL OF VEGETATION AND TOPSOIL EXPOSING BEDROCK

Where all vegetation is cleared sites will potentially be exposed to erosive rainfall, particularly on cleared sloping sites, and in the lowlands where rainfall erosivity is highest (Plate 5). Observation in the Hides area on volcanic landforms suggest that on sloping sites exposed topsoil is rapidly eroded leaving the clay rich, and lower fertility subsoil. On steeper sites erosion gullies are likely to develop, with slips possible. Observations along the Samberigi Road which cuts through mountainous volcanic and karst landforms indicated that the stability of road cuttings in volcanics is variable, with slumping and slips possible (Plate 6), providing an unstable surface for rehabilitation, in places.

Moreover, the subsoil remaining provides a poor medium for natural regeneration, particularly for native forest species. Typically grasses such as *Imperata cylindrica* colonise and dominate these sites which may then become permanent grasslands, which will not revert to forest without planting.

8.3 REMOVAL OF VEGETATION AND SOIL

Much of the construction work is likely to result in the complete removal of vegetation and topsoil, exposing subsoil and bedrock, particularly in karst areas. Soils in karst terrain are shallow compared to volcanic terrain, therefore construction is likely to frequently expose bedrock more frequently across karst landscapes. Despite such an intense disturbance, in the lowland zone disturbed karst areas have been shown to regenerate effectively on flat or gently sloping sites provided limestone scree (small fragments) is mixed with topsoil and spread over the bedrock. Regeneration appears enhanced where accumulation and decomposition of leaf litter from the adjacent forest occurs. However, where limestone pavement is exposed the relatively smooth surface appears to prevent plants establishing and these areas will remain largely vegetation free for decades without active rehabilitation (Plate 7). Convex limestone pavements sites are especially prone to rehabilitation failure (Rogers 2005), and this was especially evident in the Hides area.

8.4 COMPLETE REMOVAL OF VEGETATION AND TOPSOIL IN STEEP TERRAIN WITH EXTENSIVE SIDECASTING

In steep terrain sidecasting excess spoil will be required. Good examples of comparable sidecast impacts in lowland karst terrain are associated with the construction of the Samberigi Road, shown in

Plate 8, and the gas flow line along Hides Ridge for the montane zone (Plate 9). The impacts of sidecastng were reviewed for the 2005 PNG Gas Project by Rogers et al. (2005), who suggested that for karst terrain in the montane zone sidecast will not rehabilitate at an acceptable rate without active rehabilitation measures, particularly where little or no topsoil remains. Observations made along the Samberigi Road suggest this conclusion is also applicable to the lowland zone. Sidecast in the area has shown poor revegetation by natural processes. Four years since sidecasting vegetation is completely absent on some of the sidecast slopes, particularly where the sidecast aggregate is relatively small. Where the sidecast aggregate comprises larger boulders sparse regeneration has occurred (Plate 8). Although rehabilitation is unsatisfactory the slopes appear relatively stable and are not prone to slips.

The impact of sidecasting in volcanic terrain was not fully assessed in the field because of lack of comparable sites. However, small volcanic sidecast areas on gentle slopes were present along the Samberigi Road. These have been subject to erosion and had flowed into adjacent forest resulting in dieback (Plate 10). Cuttings from road construction along the Samberigi Road (volcanic soil sections) also demonstrated poor stability and slumping was evident.

8.5 EXCESSIVE COMPACTION OF THE SOIL SURFACE

Compaction reduces the permeability of the soil reducing both the infiltration of rain, and the ability of roots to spread through the soil. If rain infiltration is reduced runoff and associated erosion will increase. A compacted rooting environment will inhibit natural regeneration and growth, slowing the rate of rehabilitation and the time taken for a forest canopy to form. An increase in time to canopy closure also increases the time the soil is exposed to erosive rainfall events.

Plate 5 Example of topsoil erosion where vegetation has been cleared

Plate 6 A slip in a volcanic soil cutting

Plate 7 Poor regeneration on limestone pavement on Hides Ridge after 15 years

Plate 8 **Sidecast slope along the Samberigi Road - four years old**

Plate 9 **Sporadic regeneration on limestone sidecast > 15 years after Hides Ridge construction**

Plate 10 Erosion of volcanic sidecast material on the Samberigi Road causing mud flows and dieback

8.6 EROSION

The different types of potential impacts will expose the construction landscape to modified levels of erosion forces from rain, flowing water, and gravity (mass movement) which will vary according to the terrain and position in the landscape (e.g. ridge, slope or valley) resulting in different erosion hazards throughout the route.

The variable terrain includes gently sloping alluvial and karst plains, dissected volcanic plateau and steep montane karst environments. Within each of these environments rainfall energy/erosivity (the potential ability of rain to cause soil erosion) is dissipated, modified or concentrated. Resistance to rainfall erosivity is provided by vegetation, other forms of surface cover (e.g., salvaged vegetation debris), and soil/regolith properties. In relation to soil properties this resistance is referred to as erodibility, and varies with soil type (Bellamy 1995) with unstable soils being most susceptible. Construction practices can modify the impact of erosive rainfall by dissipating its energy by measures such as contour banks, and increasing soil or vegetation resistance by mulching or brush-matting.

The Hides to Juha route, particularly in the lowland sections occurs in areas which have a moderate to high index of erosivity (Bellamy 1995), which means that the rainfall occurs at an intensity that will readily detach soil particles which are then transported by rain splash and runoff causing erosion. The erosivity of the rainfall will be increased by a reduction and loss of vegetation cover from clearance for the pipeline construction, sloping sites and unstable soils. Steep slopes are a common feature of the terrain, which combined with the high erosivity of the rainfall suggests that high rates of erosion are likely where soil is exposed. Unstable soils which will be particularly susceptible to erosion also occur along the route but are mainly confined to river terraces. Potentially high rates of erosion on exposed river terraces may partly be naturally mitigated by the high porosity of the sandy loams.

Soil loss by erosion in the humid tropics after removal of vegetation can range from 10 – 62 tha^{-1} for slopes of 10 and 42 degrees respectively. By comparison, soil loss from forested slopes in negligible. A forested slope of 22 degrees has a soil loss of < 1 tha^{-1}. Soil loss above 50 tha^{-1} is rated as a high level of soil degradation (Bleeker 1983). Therefore large volumes of soil could potentially be eroded during construction without prompt mitigation and rehabilitation procedures.

8.7 WEEDS

The construction of the ROW potentially provides a pathway for the migration of weeds into previously weed free areas. Introducing exotic plant species into new environments can have many unanticipated ecological effects. In particular invasive species can have serious effects on ecosystem quality and functioning through out-competing indigenous species (Van Groenendael et al. 1998). Moreover severe weed infestations could potentially reduce the success of rehabilitation measures. Common weeds that may typically invade the ROW were identified in 2005 for the PNG Gas Project (Rogers 2005).

8.8 INCREASES SUSCEPTIBILITY TO CATASTROPHIC FIRE

The impacts of fire on PNG's forests were reviewed for the PNG Gas Project (Rogers 2005b). Frequent fire is recognised as a threat to the survival of PNG's forests, which if severe causes permanent loss of forest and conversion to grasslands (Shearman et al. 2008). The climatic conditions for severe fire occur about once each decade and depend on the presence of an ignition source which commonly originates from landholders. Montane forests in particular are susceptible to catastrophic fires. The forests in the Juha to Hides area will potentially be subjected to an increased fires risk associated with the increased population caused by construction, new camps and possible migration by landholders to the project area.

8.9 EDGE EFFECTS

The construction of the ROW will cause edge effects. Edge effects have been reviewed in detail by Rogers (2005) for the PNG Gas Project. Typical effects include increased tree mortality, turnover and damage within 100 m of forest edges, with detectable effects up to 300 m from edges (Laurance et al. 2000). Other effects include increased growth and recruitment of pioneer (secondary) species due to changes in the microclimate, which could ultimately lead to a loss in old growth rainforest characteristics (Sizer and Tanner 1999). The magnitude of edge effects (the distance to which edge effects can be detected) vary with season, aspect, climate and edge vegetation structure (Didham and Lawton 1999).

8.10 INTRODUCTION OF FUNGAL PATHOGENS

Construction of the ROW could introduce the fungal pathogen *Phytophthora cinnamomi* which has the potential to cause extensive dieback of mature *Nothofagus* forests (Paijmans 1976; Ash 1982; Arentz 1984; Rogers 1999). Death of trees is preceded by defoliation of the crown and the development of epicormic shoots on the bole and lower crown. There have been two explanations of dieback in *Nothofagus*. One is that it reflects natural senescence of a stand that has established relatively synchronously, the other being that the dieback is a result of attack by the root pathogen *Phytophthora cinnamomi* newly introduced into an area. However (Arentz 1984) found that *P. cinnamomi* was more common in soils collected from under healthy stands than dieback stands, suggesting that *P. cinnamomi* does not play a primary role in causing patch dieback in *Nothofagus*. Another pathogen may be responsible since the pattern of dieback has similarities to dieback caused by *Chalara australis* for *Nothofagus* in Australia (Read and Hope 1996). Drought may also play an important role in disease related dieback in PNG, by causing stress predisposing trees to other dieback agents (Arentz 1988). The impact of *Phytophthora* on *Nothofagus* forests was reviewed for the PNG Gas Project by Rogers (2005b).

9 SIGNIFICANT FEATURES – IMPACTS

The section considers significant landforms, vegetation and soil features identified from field survey along the route. These features may warrant special attention to mitigate impacts.

9.1 KARST TERRAIN

Steep karst landforms occur between Hides and Juha. These range from steep ridge and ravine landforms in the lowlands to more rolling hill terrain in the montane zone up to about 2600 m ASL along Hides Ridge. The steep karst landforms include imposing escarpments (Plate 2) which appear prone to massive landslips. Depending on the final route selection and topography, sidecasting of excess spoil may be required, presenting a difficult environment to effectively rehabilitate, as reviewed in section 10..

9.2 VOLCANICS

Volcanic landforms are a feature of the route, particularly in the Hides area, the HGCP location and beyond Komo. These hilly landforms may present constraints to rehabilitation because they are susceptible to rapid loss of topsoil when the vegetation cover is removed. The infertile subsoil becomes permanently dominated by a range of grasses and ferns, including the grass *Imperata cylindrica* and the fern *Sphaerostephanos* sp. Where deeper topsoil has redeveloped, typically on gentle concave slopes the woody shrub *Dodonea viscosa* also establishes. Occasional patches of the tall native grasses *Saccharum spontaneum* and *Pennisetum macrostachyum* may also be present. Once grasses have established they are susceptible to fire, which has the potential to encroach into the surrounding forest, particularly in severe drought caused by an El Nino event. Fire can have a devastating impact on PNG's rainforests and this has the potential to be a major collateral impact associated with the project.

9.3 PANDANUS DOMINATED SWAMP FOREST

Pandanus swamp forest is a feature of some of the montane alluvial plains at about 1300 m ASL (Plate 11). The landform is characterised by a water table which is close to the surface. The waterlogged nature of much of the soil profile in these swamp plains would be very susceptible to construction damage, particularly from heavy machinery. This forest/landform is considered unsuitable for a pipeline alignment because of potentially high impacts that would extend beyond the ROW and therefore it should not be disturbed where possible. If impacts are unavoidable careful consideration should be given to allowing for adequate surface and subsurface water flows.

9.4 NOTHOFAGUS FOREST ON DEEPLY INCISED VALLEY FLOORS

Montane river valleys also support *Nothofagus grandis* (beech) dominated forest which occurs on deep alluvial soils, incised several metres by numerous narrow creeks (Plate 12). The soils are unstable (based on the ASWAT soil stability test) and would be prone to rapid erosion if disturbed. Any disturbance would also impact the hydrology of the complex creek system that is a feature of this forest type. This forest/landform is considered unsuitable for a pipeline alignment because of the potentially high impacts that would extend beyond the ROW and therefore it should not be disturbed if possible. If impacts are unavoidable careful consideration should be given to allowing for adequate surface and subsurface water flows.

9.5 RIVER BED SUCCESSIONAL VEGETATION

The route traverses numerous meandering rivers that range from deep fast flowing rivers such as the Baia River to more moderately paced and shallow rivers such as the South Karius. These river environments are dynamic and cause both erosion, and deposition resulting in river terraces. In the South Karius River area the depositional landforms comprise river gravels and cobbles overlain by sand (Plate 13). This landform provides a suitable substrate for rapid colonisation by a variety of early successional plant species (Plate 14). Where impacted, landforms are likely to re-establish from sedimentation which should be readily naturally colonised.

9.6 *NOTHOFAGUS PULLEI* FOREST ON KARST TERRAIN AT HIGH ALTITUDES

The rehabilitation constraints associated with montane *Nothofagus pullei* forests (Plate 15) have been reviewed above and primarily relate to potential sidecasting and the creation of limestone pavement areas, which will not rehabilitate at a satisfactory rate. Potential measures to rehabilitate this environment have been reviewed for the PNG Gas Project (Rogers and Tucker 2005). *Nothofagus* forests may also be subject to extensive dieback by the introduction of the root pathogen *Phytophthora cinnamomi*, which could be readily brought into the area by contaminated construction machinery. The potential impact of fungal pathogens is reviewed in section 8.10. Mechanisms of forest dieback were reviewed for the PNG Gas Project by Rogers (2005b). This forest type and other *Nothofagus* forests should also be protected by the implementation of a fire management plan since they are susceptible to catastrophic fire in drought year Rogers (2005b).

9.7 *ARAUCARIA* FOREST

Araucaria forests comprise tall emergent klinkii pine (*Araucaria hunsteinii*) (Plate 16) and or hoop pine (*Araucaria cunninghamii*) over an angiosperm dominated lower canopy. These forests are prone to anthropogenic catastrophic fires that can permanently destroy large stands, particularly in the dry season of an El Nino year (Johns 1986; Johns 1989). This forest type is considered unsuitable for a pipeline alignment and should not be disturbed where possible. A fire management plan should be implemented to protect this forest type from catastrophic fire.

Plate 11 Pandanus swamp forest in the Camp 4 area, South Karius

Plate 12 *Nothofagus* forest adjacent to recently colonised river banks

Plate 13 River terrace profile along the South Karius River near Camp 4

Plate 14 Succesional vegetation along the South Karius River

Plate 15 ***Nothofagus pullei*** **dominated forest on Hides Ridge**

Plate 16 **Klinkii pine (*Araucaria hunsteinii*) in the Nogoil area**

10 MITIGATION AND REHABILITATION RECOMMENDATIONS

This section discusses rehabilitation objectives and mitigation and rehabilitation measures, incorporating information from studies from the 2005 PNG Gas Project. For the 2005 PNG Gas Project the following related studies were undertaken:

- Assessment of regeneration, rehabilitation and degradation along the existing crude oil export pipeline ROW and implications for the PNG Gas Project (Rogers 2005);
- Sidecast revegetation plan for the PNG Gas Project EIA (Rogers and Tucker 2005); and
- Rehabilitation and revegetation of side cast associated with the proposed Papua New Guinea Gas Project (Rogers et al. 2005).

Although these studies are applicable to the additional impact area from Hides to Juha, the new route sectors traverse more rugged terrain and will potentially impact a wider variety of landforms, soils and vegetation types than have previously been assessed.

10.1 REHABILITATION OBJECTIVES

Prior to developing a rehabilitation program it is important to have a clear statement of the rehabilitation objective. The objectives will determine the technical requirements of the rehabilitation and its feasibility for the various landform soil and vegetation complexes along the route. The primary objective of rehabilitation programs is typically to return a site to a floristic diversity similar or comparable to the undisturbed site and where the different ecosystem components are functioning in a manner that will maintain the system (e.g. nutrient cycling, seed dispersal, regeneration etc.).

In most instances the immediate objective will be to return sites to a closed canopy of fast growing native species (where practicable), which will provide the appropriate environment for the later development of mature forest by natural processes. This is dependant on the presence of appropriate soil conditions in which rehabilitation can take place. However, it is recognised that the return of mature forest will take many decades to achieve, although rehabilitation can ensure that an appropriate successional trajectory is achieved. There will be some situations particularly in steep sidecast areas where this may not be practical for safety reasons and the objective will require modification. It is recommended that the project proponent consider adopting the following objectives depending on the area of disturbance:

1. Creation of a final landform that is conducive to both site stability and active rehabilitation, e.g., along the ROW;
2. Development of a stable and self-sustaining ecosystem that has characteristics of the original ecosystem (i.e., closed canopy forest) but may not have an identical species composition; and
3. Where practicable and required re-creation of the original biota and biological processes, i.e. a return to the original vegetation structure and species composition, e.g. for a temporary camp area.

10.2 REHABILITATION BY NATURAL REGENERATION

Natural regeneration of disturbed sites can be a highly successful method of rehabilitation across a range of naturally occurring soil and vegetation types, particularly where topsoil, or part topsoil remains. The ability of disturbed sites to rehabilitate by natural regeneration was assessed by Rogers (2005) for the existing crude oil export pipeline ROW. Assessment was made for the following substrates which will also be created by construction of the additional route sectors:

- Disturbed forest floor;
- Soil sidecast (on flat terrain);
- Limestone scree mixed with soil;
- Bare rock (limestone pavement);
- Cuttings; and
- Mounded trench fill.

Except for bare rock, good regeneration occurs on all these substrates in the lowlands (< 1000 m) and lower montane zone (Plate 17) provided sites are flat or on gentle slopes. This reflects the abundant sources of seed from both the topsoil and seed rain, and limited erosion (Rogers 2005). An important factor contributing to the successful and quick regeneration was the retention of topsoil. However, poor regeneration can occur in the lowlands in karst terrain, particularly on convex slopes where the topsoil will erode exposing limestone pavement (Rogers 2005). For lowland forests that regenerate successfully it may take up to 40 years to develop a structure and composition comparable to that of the adjacent primary forest (Aide et al. 2000).

To improve the effectiveness of rehabilitation by natural regeneration the following measures are recommended:

10.2.1 Soil dominated surfaces

All disturbed sites are at risk from high rates of erosion because of the erosivity of the rainfall. To prevent loss of topsoil and the associated soil seed bank, cleared vegetation should be reapplied as mulch. In some instances the use of hydro mulching warrants consideration, particularly on erosion prone surfaces where establishment of a rapid plant cover is required. Hydromulching techniques were reviewed for the PNG Gas Project by Rogers and Tucker (2005).

Regeneration performance on soil dominated surfaces can be inhibited by the creation of raised soil banks during construction, which can impede drainage, causing regeneration failure and forest dieback in adjacent undisturbed areas (Rogers 2005). Therefore the final construction landforms should consider minimising impacts on drainage adjacent to rehabilitation areas and intact forest. Where soils are most prone to slumping/slippage, consideration should be given to benching the cut in preference to more vertical (1:1) cuts. Benched surfaces are more likely to promote natural recovery. Field trials have shown that laying back slopes and leaving space for a berm or bench allows a level surface which promotes faster regeneration and better slope stability. In areas where soils are more erosion prone (volcanic substrates) laying back cuts should result in faster recovery times and more stable slopes.

10.2.2 Limestone dominated surfaces

Limestone dominated surfaces are a poor rehabilitation medium when exposed, particularly for natural regeneration. The following measures are recommended for consideration to improve rehabilitation success:

- Minimise the creation of limestone pavement (bare rock) by avoiding exposing soil on convex slopes;
- Consider scarifying/ripping the surface of limestone pavement areas followed by the application of topsoil/subsoil followed by mulching;
- Minimise the creation of limestone rubble dominated surfaces, particularly in *Nothofagus* dominated forest; and
- Consider crushing limestone rubble to reduce aggregate size and mix with topsoil on flat/gently sloping surfaces to facilitate natural regeneration.

10.3 SOIL MANAGEMENT FOR REHABILITATION

Where practical, temporary salvage, stockpiling and reuse of topsoil (at least the top 20 cm) cleared from the ROW warrants consideration as the main rehabilitation medium for all surfaces that have topsoil removed and can be protected from high rates of erosion. The use of topsoil retention and dispersal was recommended for the PNG Gas project by Rogers and Tucker (2005), and is equally applicable to the new route sectors. Topsoil handling procedures will need to be considered to test the effectiveness of this measure since topsoil can degrade with handling in wet conditions.

10.4 REPLANTING

For sites where topsoil has been lost but subsoil has been retained, rehabilitation by natural regeneration is unlikely to be effective, and planting may be required. Approaches to manual planting were developed for consideration by the PNG Gas Project (Rogers and Tucker 2005). Suggestions included directing and accelerating native woody succession by establishing a selected range of local plants which have the following characteristics:

- Occurrence on both volcanic and limestone derived substrates;
- Distribution across the altitude range of the priority sites;
- Species with known germination mechanisms and nursery performance;
- Rapid and/or persistent growth;
- Ability to attract frugivorous birds which are the major dispersal vectors in PNG forest; and
- An ability to cope with open and degraded conditions.

10.5 SIDECAST REHABILITATION

Sidecast sites require a combination of engineering works and revegetation to achieve site rehabilitation. To mitigate the impacts of sidecasting Rogers and Tucker (2005) suggest the following measures for consideration:

- Establish an immediate organic/plant cover to reduce erosion and run off potential; and
- Establish longer lived, native woody vegetation to ensure that succession (vegetation colonisation and development) is accelerated and directed toward a desired "end point" – in this case a complex, multi-layered forest structure.

A combination of approaches will be required involving topsoil retention and dispersal where practicable, salvage and reuse of vegetation debris, hydromulching, manual planting and trialling the use of a lattice framework or brush-mats to trap organic matter (e.g. leaf litter) at intervals along the sidecast slope.

10.6 WEEDS

For all the rehabilitation sites weeds are a potential limiting factor to successful rehabilitation measures. Invasive weeds have the potential to out-compete native species and inhibit natural regeneration. Prior to the start of construction it is recommended that a weed management plan be developed to control the spread of significant invasive weeds (e.g., *Piper aduncum*), incorporating the objectives, (a), prevention and exclusion, (b), early detection and rapid assessment, and, (c), control/containment and eradication (Rogers and Tucker 2005). The construction of vehicle was-down facilities and a ban on the import of exotic seeds and plants into the project area also warrant consideration.

Plate 17 Good regeneration on a soil dominated surface near Hides Ridge

11 IMPACT SIGNIFICANCE

Assessment of the significance of the impacts is based on an adaptation of the approach used for the PNG Gas Project. The assessment presumes the implementation of the recommended mitigation and rehabilitation measures. The final assessment of significance focuses on the impact on soils and vegetation and their potential to be rehabilitated rather than the regional values of the site. Biodiversity issues are not considered as part of this study. Impact significance for the range of potential impacts are summarised in Table 11-2. Criteria for the assessment of the significance of impacts are described in the following sections.

11.1 SENSITIVITY OF THE RESOURCE/RECEPTOR

Low:

- Vegetation: Vegetation can recover relatively rapidly from disturbance by natural processes (e.g., regeneration) or by limited rehabilitation measures; and
- Soils: Soils are not erosion prone if exposed and have no major adverse properties.

Medium:

- Vegetation: Vegetation has some capacity to regenerate if severely disturbed, e.g. from established seedlings or seed rain. Vegetation type is not restricted in its distribution. Recovery may take decades due to slow growth rates (e.g. montane forest along Hides Ridge); and
- Soils: Thin soils that may be unstable and relatively easily disturbed. Or sensitive soils such as very wet, waterlogged or peaty soils that are easily damaged.

High:

- Vegetation: Vegetation is sensitive to disturbance and has a limited capacity to regenerate from a soil seed bank and may be confined to a narrow niche (restricted habitat). Recovery may take decades. Sensitive to other disturbances such as fire and weeds; and
- Soils: Soils have adverse properties if disturbed e.g. unstable and or dispersive

11.2 TEMPORAL SCALE OF RESIDUAL IMPACT:

- Very short : Residual impacts lasting < 3 years;
- Short term: Residual impacts lasting between 3 and 7 years;
- Medium term: Residual impacts lasting between 7 years and 25 years; and
- Long term: Residual impacts lasting more than 25 years.

11.3 SPATIAL SCALE OF RESIDUAL IMPACT:

- Very limited: Immediate environs of an impact footprint and extending to a radius of less than 200 m;
- Limited: Immediate environs of an impact location and extending to a radius of between 200 m and 2 km;
- Local: Generally occurring within a radius of between 2 and 10 km from an impact footprint; and
- Regional: Generally occurring over a large area that extends to a radius of more than 10 km from the footprint location.

11.4 MAGNITUDE OF RESIDUAL IMPACT

The criteria for the magnitude of the residual impact primarily reflect the likelihood that a disturbed site can be rehabilitated to its pre-disturbance condition, or something very similar, even if the site is relatively small. The potential biodiversity significance is not part of the criteria.

- Very High (V) – Major change in the environment. Highly likely to result in the permanent loss of the forest type for the impacted site and possible conversion to grasslands. High levels of erosion possible;
- High (H) – Major change in the environment. Likely to have a significant negative impact on a site. Full recovery of the pre existing vegetation type is unlikely. Partial recovery likely but structure and species composition will differ markedly. Major interference with site hydrology likely;
- Medium (M) – Significant change in site caused compared to the pre-disturbance environment, but full recovery expected over a long time period (decades). No significant erosion likely;
- Low (L) – Small change in the existing environment. Detectable but small impact and unlikely to have any significance; and
- Negligible (I) – Unlikely to cause detectable change in the environment.

11.5 ASSESSMENT OF SIGNIFICANCE OF RESIDUAL IMPACT

Assessment of significance was made using the matrix of significance in Table 11-1

Table 11-1 Assessment of significance of residual impact matrix

	Sensitivity of Resource/Receptor				
Magnitude of impact	**Very High**	**High**	**Medium**	**Low**	**Negligible**
Very High	Major	Major	Major	Minor	Negligible
High	Major	Moderate	Moderate	Minor	Negligible
Medium	Moderate	Moderate	Minor	Minor	Negligible
Low	Moderate	Minor	Minor	Minor	Negligible
Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
Positive	Positive	Positive	Positive	Positive	Positive

Table 11-2 Assessment of significance of impact summary

Type and level of impact	Response	Possible long term impact	Mitigation/Rehabilitation Measures	Spatial/Temporal Scale of Residual Impact	Sensitivity of the Receptor/Magnitude of Residual Impact	Significance of Residual Impact
Temporary clearance of vegetation for ROW construction	Vegetation recovers by natural processes	Forest vegetation will take several decades to return to its pre-clearing condition	ROWs and roadways to be located within or adjacent to existing disturbed areas where practicable.	Very Limited/Long Term	Medium/Medium	Minor
	Invasion by ephemeral weed species	Permanent presence of weeds in a previously weed free area	Vehicle wash down facilities Ban on the import of exotic species, including seed into the project area	Widespread/Long Term	Medium/Low	Minor
Clearance of vegetation and topsoil	Response is site dependant depending on the topography, soil type and vegetation. Rapid natural regeneration is likely on relatively flat terrain in the lowlands. Revegetation may be very slow in the montane environment. Sloping sites will be subjected to high rates of soil erosion	Temporary to permanent loss of original vegetation type. Low to high rates of erosion. Sidecasting of excess spoil will potentially result in a high level of impact	Where practicable, utilise land clearing techniques that preserve the rootstock of removed vegetation in the ground. Spread cleared vegetation back on to the ROW as mulch, where practicable. The extent of clearing and earthworks along the ROW should be limited and the time for which surfaces are exposed prior to natural revegetation will be reduced to the extent practicable Develop a revegetation management plan that will be detailed in the EMP and which will include measures to assist revegetation in areas found to be slow to revegetate naturally – On Hides Ridge – In areas between Idauwi and Homa, in particular unstable volcanic terrains. – Along sections of the existing Moro to Homa public road In karst areas fine particle size organic matting or a lattice framework or similar will be used to trap organic matter across sidecast where safe and practicable Where practicable, soil, mulch and discarded vegetation debris (including natural seed stock) should be spread on reclaimed or rehabilitated disturbed land surfaces to facilitate natural revegetation Where practicable, topsoil will be stripped and stockpiled separately in designated topsoil stockpile areas at facility construction sites for later reuse Salvage topsoil for rehabilitation of slopes, where practicable	Limited/Long Term	**Flat terrain in the lowlands:** Low/Medium **Sidecast sites in steep karst and volcanic terrain:** Medium/Very High **Hides Ridge:** Medium/Very High	 Minor Major Major

Type and level of impact	Response	Possible long term impact	Mitigation/Rehabilitation Measures	Spatial/Temporal Scale of Residual Impact	Sensitivity of the Receptor/Magnitude of Residual Impact	Significance of Residual Impact
Edge effects from permanent linear infrastructure (i.e. ROW)	Drying out of the forest microclimate adjacent to the Row and up to 100 m either side of the ROW.	Increased treefall up to 100 m from the edge	ROWs and roadways will be located within or adjacent to existing disturbed areas where practicable. Re-establish forest edge to minimise microclimate changes. The standard ROW width for the project is 30 m and following construction the ROW should be allowed to naturally regenerate except for 15 m, to allow for a gap in the canopy for aerial surveillance of the pipeline. If there is a requirement to exceed the ROW design width, the contractor shall seek approval through a formal procedure from the Operator	Very Limited/Long Term	Medium/Medium	Minor
Modification of natural drainage pattern in pandanus swamp forest	Raising of the water table causing tree depth, or lowering of the water table from drains causing invasion by non pandanus swamp species and drying out of the swamp	Long term degradation of forest and possible canopy collapse Introduction of fungal pathogens (e.g. *Phytophthora*) that are readily transported by water and can cause major dieback	Conduct fine-scale routing of the ROW/access ways to reduce traversing this forest type, where practicable Develop a management plan to reduce impacts to pandanus swamp forest. Design ROW and roadways to allow adequate surface and subsurface flows and avoid redirection of stream flows where practicable.	Local/Long Term	Medium/High	Moderate
Modification of drainage pattern and associated soil disturbance in *Nothofagus* forest on valley floor	Waterlogging and erosion of unstable soil, possibly causing increased susceptibility to windthrow Introduction of fungal pathogens that are readily transported by water and can cause major dieback	Long term dieback and loss of forest type. Replacement by grassland Introduction of fungal pathogens (e.g. *Phytophthora*) that are readily transported by water and can cause major dieback	Conduct fine-scale routing of the ROW/access ways to reduce traversing this forest type, where practicable Develop a management plan to reduce impacts on *Nothofagus* forest and the spread of dieback. Design to allow adequate surface and subsurface flows and avoid redirection of stream flows where practicable	Local/Long Term	Medium/High	Moderate
Migration of weed species along the ROW	Rapid colonisation of disturbed areas inhibiting rehabilitation	Introduction of potentially invasive weeds into a previously weed free environment. Dispersion of weeds into the wider environment, particularly along watercourses etc	Implement a weed control management plan that identifies foreign and invasive weed threats and appropriate control measures.	Widespread/Long Term	Medium/High	Moderate

Type and level of impact	Response	Possible long term impact	Mitigation/Rehabilitation Measures	Spatial/Temporal Scale of Residual Impact	Sensitivity of the Receptor/Magnitude of Residual Impact	Significance of Residual Impact
Introduction of fungal pathogens into *Nothofagus* forest along the ROW	Extensive forest dieback	Widespread modification of the forest structure, canopy species composition and dependant biota	A weed, exotic pest and pathogen management plan should be established to protect the *Nothofagus* forests of the Hides Ridge and Juha areas. This will include establishment of chemical washdown points at or near the Hides Gas Conditioning Plant to prevent weeds and pathogens being transported to and within Hides Ridge and Juha for the life of the project. The plan will be detailed in the Environmental Management Plan.	Widespread/Long Term	Medium/High	Moderate
Sidecasting excess spoil	Total loss of forest on major sidecast slopes in steep terrain Significant erosion gullies and landslips in volcanic landforms	Slow to nil recovery of forest. Potential invasion by fire prone grasses	In karst areas fine particle size organic matting or a lattice framework or similar will be used to trap organic matter across sidecast where safe and practicable	Limited/Long Term	**Lowlands:** Medium/High **Hides Ridge:** Medium/Very High	Moderate Major
	Increased erosion of river banks and vegetation from sediment loaded streams	Increased frequency of significant slips, particularly in volcanic landforms	Prohibit side-casting material directly into waterways where practicable. Install sediment control structures to intercept sediment-laden surface runoff to reduce sediment delivery to watercourses	Local/Long Term	Medium/High	Moderate
Increased susceptibility to fire	The presence of people in a previously remote area with no road access increases the chance of anthropogenic fires	Significantly increased susceptibility to fire. Permanent loss of forest (several 1000s of ha) and subsequent conversion to grassland	Implement a fire management plan for the construction and operations phases of the PNG LNG Project aimed at reducing the likelihood of the project starting any wildfires to very low. The plan should consider measures like prohibiting the burning of cleared vegetation and other fires in the montane environment in drought years, if these occur during construction works. Pushed vegetation should be left to rot at forest edge rather than burnt	Widespread/Long Term	Very High/Very High	Major

12 CONCLUSIONS

The proposed route from Juha to Hides traverses a diverse landscape and a wide range of forest types from lowland forest on uplands through to pandanus swamp forest and *Nothofagus* dominated forest in the montane zone. This variation reflects differences in landforms, soils and changes in the climate associated with increasing altitude. The impact of construction on this varied landscape will vary depending on the type and intensity of disturbance, the terrain, the vegetation and soil type, and the erosivity of the rainfall.

Impacts will range from temporary clearance of vegetation to removal of all vegetation and topsoil, and extensive sidecasting of excess spoil in steep terrain. Where temporary clearance occurs sites are likely to recover by natural regeneration provided soil is not exposed for a lengthy period. Where topsoil is exposed, particularly on sloping sites, erosion will occur exposing the lower productivity subsoil which may become permanently dominated by grasslands, thus not reverting to forest without rehabilitation. Where extensive sidecasting of excess spoil occurs high rates of erosion are expected, particularly in volcanic terrain. In karst terrain, the limestone aggregate will protect sidecast sites from extensive erosion.

The level of rehabilitation required will vary depending on the intensity of the impact. Salvaging topsoil and salvaging cleared vegetation to spread over exposed areas will be key measures to promote effective rehabilitation. Where no topsoil remains, and subsoils are the only medium for rehabilitation an active revegetation program will aid successful rehabilitation. Areas of sidecast spoil present the most difficulties for effective rehabilitation. The sidecast revegetation plan produced for the PNG Gas Project (Rogers and Tucker 2005) should be implemented to rehabilitate such sites. The main recommendations from the sidecast revegetation plan are:

- Steep, exposed, and loose sidecast surfaces in the high rainfall environment are conducive to high rates of erosion requiring a combination of engineering works and revegetation to achieve site rehabilitation;
- A combination of approaches is suggested for sidecast rehabilitation, involving top soil retention and dispersal, salvaging cleared vegetation, hydromulching, manual planting and use of a lattice framework;
- Hydromulching will provide a rapid soil cover that will quickly reduce sediment erosion in addition to improving substrate suitability for subsequent planting. The proposed species to be planted are pioneer species that naturally colonise cleared sites and exposed surfaces such as landslips;
- Suitable sites to propagate nursery seedling stock exist at Moro, Nogoli and Kobalu (near Iduawi), where existing community coffee nurseries are located which can be developed for seedling production by contractors; and
- Trials should be undertaken to refine and test the efficacy of some of the proposed measures.

The success of rehabilitation (whether active or passive) depends to a large extent on the final construction surface. Steep (1:1) cuts will be prone to slumps and slips. Whilst steep cuts minimise the area of forest cleared, field trials have shown that laying back slopes and leaving space for a berm or bench allows a level surface which promotes faster regeneration and better slope stability. In areas where soils are more erosion prone (volcanic substrates) laying back cuts should result in faster recovery times and more stable slopes.

A small range of forest types are likely to be impacted severely by construction in project footprint areas because of sensitive landforms and soils (deep waterlogged and unstable soils), and are unlikely to readily rehabilitate. For these areas tactical route realignments warrant consideration to avoid disturbance.

13 RECOMMENDATIONS

It is recommended that a rehabilitation plan is developed for the project prior to construction. This plan should include:

- Clearly defined objectives for rehabilitation;
- Identification of priority rehabilitation sectors;
- Targeted rehabilitation prescriptions based on the characteristics of the landform, soils and vegetation of specific route sectors; and
- A detailed rehabilitation program that has been developed in consultation with tropical rainforest rehabilitation practioners and based on the reports undertaken for the 2005 PNG Gas Project and the 2008 PNG LNG Project.

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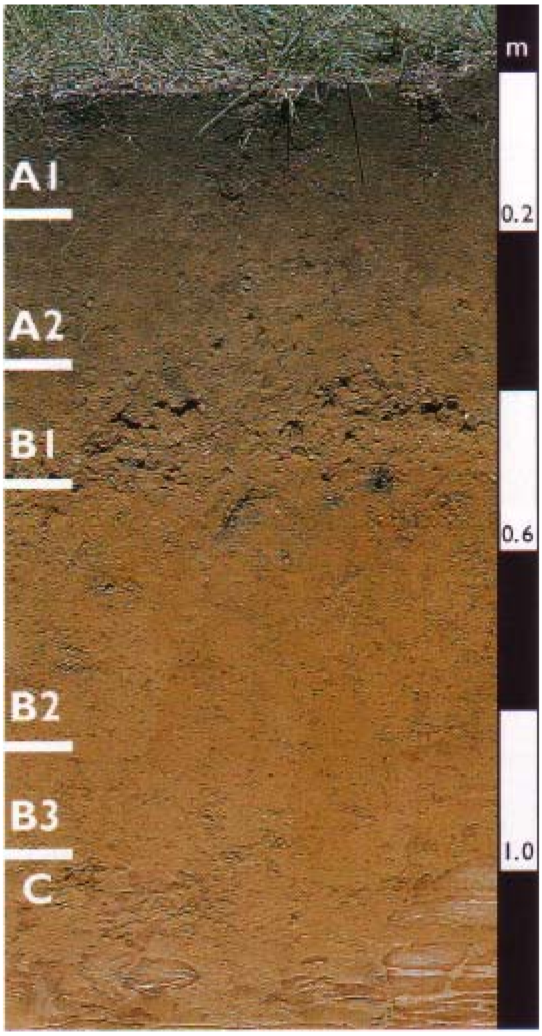
APPENDIX A

EXAMPLE OF A TYPICAL SOIL PROFILE

A soil profile showing typical horizon types commonly found



A horizons

These are mineral horizons at or near the surface (topsoils) that have some accumulation of organic matter. Typically they are darker than underlying horizons.

A1 horizon

This is a mineral horizon at or near the soil surface that has some accumulation of organic matter. It is usually darker than the underlying horizons and it is in the zone of maximum biological activity. It typically contains a large soil seed bank that will rapidly germinate if disturbed and exposed.

A2 horizon

This is a mineral horizon that has less organic matter, oxides or clay than the horizon above or below. It is a pale horizon resulting from bleaching. Bleaching is caused by the removal of organic matter, clay, iron, aluminium and nutrient elements. This is caused by leaching from rainfall which leaves an accumulation of silica giving the horizon its pale colour. This horizon is not always present in PNG soils.

A3 horizon

This is a transitional horizon between A and B horizons.

B horizons

These are subsoil horizons which have one or more of the following properties:

- Concentration of clay, iron, aluminium or organic material;

- A structure or consistence unlike the overlying A horizon and different from the horizons below; and
- Stronger colours than the horizons above or below.

B1 horizon

This is a transitional horizon between the A and B horizon.

B2 horizon

This horizon exhibits the strongest development of the features listed above.

B3 horizon

This is a transitional horizon to the underlying parent material

C horizons

These are layers below the A and B horizons composed of consolidated or unconsolidated materials. These materials are usually partially weathered and geological features (e.g. consolidated rock and stones) are evident

(Horizon description adapted from Mckenzie et al. (2004))

For this study horizons were grouped as A, B or C only because of some horizon mixing caused by the hand auguring process which obscured identification of transitional horizons such as A3 and B1 etc.

APPENDIX B

REPRESENTATIVE SITE DESCRIPTION SHEETS

Representative Site Description and Soil Profile

Soil Type	Site No: S3 – HGCP Site 1	**Date:** 3/4/2008

Concept
Silty clay loam formed from weathered volcanic deposits over limestone.

Soils may be several metres in depth.

Species: *Imperata cylindrica, Ageratum conyzoides, Cyperus dichotoma, Digitaria setigera, Iresesine sp, Paspalum conjugatum, Sphaerostephanos sp., Bidens pilosa**

* = weeds

Position (WGS): S6 00.112 E142 48.876

Height ASL: 1700 m

Soil Classification: Soil Order: Inceptisol

Landform Element	Flat
Landform Pattern	Rolling hills
Slope	< 5 - 20 ^{0} on slopes
Microrelief	None
Surface condition	No surface features. No surface rocks evident. Some disturbance by domestic pigs.
Land Condition	Degraded.
Land Use	Old garden site, previously used for traditional subsistence agriculture
ASWAT	Stable
Vegetation and Type	Dominated by kunai grass (*Imperata cylindrica*).
PNGRIS Type	Grassland with some forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Relatively shallow topsoil. The presence of kunai suggests reduced fertility. Soil seed bank will be dominated by non-forest species.

0.0 m
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m

0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1m

Horizon	**Depth (cm)**	**Description**
A	10	Silty clay loam Field pH 6
B	12 - > 100	Silty clay loam Field pH 6 Reduction in colour intensity with depth
Recommended Topsoil Strip Depth		12 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S3B – Hides GCP Site 1	**Date:** 5/4/2008

Concept
Silty clay loam formed from weathered volcanic deposits over limestone. Soils may be several metres in depth

The site was previously used for subsistence agriculture which has since been colonised by some woody species.

Species: *Dodonea viscose*, *Macaranga* sp., *Macaranga montana*, *Imperata cylindrica*, *Calcluvia* sp., *Cyperus dichotoma*, Iresesine sp, *Mapania* sp., *Mimosa* sp., *Pennisetum macrostachyum, Phragmites* sp., *Polygonum* sp. , *Physalis minima, Pteredium* sp., *Rubus* sp., *Sphaerostephanos* sp., *Sonchus* sp., *Spermacocce* sp.

Position (WGS): S6 00.060 E142 48.856

Height ASL: 1700 m

Soil Classification: Soil Order: Inceptisol

Landform Element	Slope
Landform Pattern	Rolling hills
Slope	15 ^{0}
Microrelief	None
Surface condition	No surface features. No surface rocks evident. Some disturbance by domestic pigs.
Land Condition	Degraded.
Land Use	Old garden site, previously used for traditional subsistence agriculture
ASWAT	Stable
Vegetation and Type	Dominated by tall kunai grass (*Imperata cylindrica*), the fern *Pteridium* sp and the small tree *Dodonea viscosa*.
PNGRIS Type	Grassland with some forest
Samples for analysis	No

Rehabilitation Suitability Summary :
Sloping sites, particularly on concave faces appear to have deeper top soils than on the drier spurs. A better topsoil for rehabilitation but the soil seed bank will be dominated by non forest species, particularly grasses and forbs.

0.0 m	0.6 m	**Horizon**	**Depth cm**	**Description**
0.1 m	0.7 m	A	22	Silty clay loam Field pH 6
0.2 m	0.8 m	B	22 - > 100	Silty clay loam Field pH 6
0.3 m	0.9 m	**Recommended Topsoil Strip Depth**		22 cm
0.4 m	1.0 m			
0.5 m	1.1m			

Representative Site Description and Soil Profile

Soil Type	Site No: S4 – HGCP Site 1	**Date:** 5/4/2008

Concept
Silty clay loam formed from weathered volcanic deposits over limestone. Soils may be several metres in depth

The site comprises remnant primary forest dominated by *Castonopsis acuminatissima*.

Position (WGS): S6 00.110 E142 48.903 (within 150 m of this point)

Height ASL: 1700 m

Soil Classification: Soil Order: Inceptisol

Landform Element	Slope
Landform Pattern	Rolling hills
Slope	$10 - 15^{0}$
Microrelief	Undulating
Surface condition	Abundant dead wood and decomposed leaf litter. Occasional small streams.
Land Condition	Minor anthropogenic disturbance
Land Use	Primary forest
ASWAT	Stable
Vegetation and Type	*Castonopsis acuminatissima* dominated forest
PNGRIS Type	Lower montane forest (above 1000 m). Small crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 20 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

Horizon	Depth (cm)	Description
A	22	Clay loam Field pH 5.5
B	22 - > 100	Silty clay loam Field pH 5.0

Recommended Topsoil Strip Depth 22 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S5 – Hides Ridge	**Date:** 7/4/2008

Concept
Silty clay loam formed over limestone karst terrain.

The site comprises remnant primary forest dominated by *Nothofagus pullei*.

Position (WGS): S5 56.511 E142 43.845

Height ASL: 2450 m

Soil Classification: Soil Order: Inceptisol

Landform Element	Ridge
Landform Pattern	Mountain (Karius Range)
Slope	< 5 ^{0}
Microrelief	Undulating
Surface condition	Abundant dead wood and decomposed leaf litter.
Land Condition	Primary forest
Land Use	Adjacent to gas pipeline
ASWAT	Stable
Vegetation and Type	*Nothofagus pullei* dominated forest
PNGRIS Type	Lower montane forest (above 1000 m). Small crowned forest with *Nothofagus*
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 20 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

0.0 m		0.6 m	**Horizon**	**Depth (cm)**	**Description**
0.1 m		0.7 m	A	22	Silty clay loam with limestone fragments Field pH 6
0.2 m		0.8 m	B	22 - > 100	Silty clay loam with limestone fragments at 80 cm. Field pH 4.5
0.3 m		0.9 m	**Recommended Topsoil Strip Depth**		22 cm
0.4 m		1.0 m			
0.5 m		1.1m			

Representative Site Description and Soil Profile

Soil Type	Site No: S5 – Hides Ridge 1a	**Date:** 7/4/2008

Concept
Developing thin soils on sidecast slope at 2365 m asl. Minimial soil under moss cover, particularly on areas of fine gravel sidecast

Pre clearing the site would have been dominated by montane forest with *Nothofagus pullei* dominant in places

Species: *Calanthe* sp., *Cyathea* sp., *Imperata cylindrica, Fimbristlis* sp., *Hamsiopanax* sp., *Pennisetum* sp., *Pteridium* sp., *Scrophularia* sp., *Saurauia altitera; Surauia trugur, Sauraia bifida*, *Spermacoccae* sp., *Vaccinium* sp.

Position: S5 56.825 E142 43.932

Height ASL: 2400 m

Soil Classification: **NO SOIL**

Landform Element	Ridge slope
Landform Pattern	Mountain (Karius Range)
Slope	40 ^{0}
Microrelief	Undulating and slightly gullied
Surface condition	Limestone sidecast Fine gravel to aggregate size up to 75 cm. Fine gravel bound by moss
Land Condition	Sidecast and scattered regrowth and grasses
Land Use	Old sidecast area adjacent to gas pipeline and well head
ASWAT	Not applicable
Vegetation and Type	Regeneration on sidecast slope. Dominated by scattered *Saurauia* spp. and *Fimbtistylis* sp.
PNGRIS Type	Lower montane forest (above 1000 m). Small crowned forest with *Nothofagus*
Samples for analysis	No

Rehabilitation Suitability Summary :
No original top soil remains. Regeneration is sparse and appears slow to colonise and grow. Regeneration is better on mixed aggregate size which can trap leaf litter and nutrient flows, possibly providing an improved regeneration niche.

0.0 m	**NO SOIL**	0.6 m	**Horizon**	**Depth (cm)**	**Description**
0.1 m		0.7 m	A		
0.2 m		0.8 m	B		
0.3 m		0.9 m	**Recommended Topsoil Strip Depth**		
0.4 m		1.0 m			
0.5 m		1.1m			

Representative Site Description and Soil Profile

Soil Type	Site No: S5 – Hides Ridge 1b	**Date:** 7/4/2008

Concept
Developing thin soil on limestone terrace (Hides 2 wellhead), at 2365 m asl. Minimial soil under moss cover.

Pre clearing the site would have been dominated by montane forest with *Nothofagus pullei* dominant in places.

Species: *Imperata cylindrica,Fimbristlis* sp., *Hamsiopanax* sp.,*Scrophularia* sp., *Saurauia altitera; Surauia trugur, Sauraia bifida*, *Spermacoccae* sp., *Vaccinium* sp.

Position (WGS): S5 56.825 E142 43.932

Height ASL: 2400 m

Soil Classification: **NO SOIL**

Landform Element	Ridge
Landform Pattern	Mountain (Karius Range)
Slope	Flat
Microrelief	Flat
Surface condition	Flat limestone surface with scattered small depressions causing poor drainage
Land Condition	Well head
Land Use	Past well head construction area
Erosion/ASWAT	Not applicable
Vegetation and Type	Poor woody regrowth, with occasional *Sauruia* spp and the grasses *Imperata cylindrica* and *Fimbristylis* sp
PNGRIS Type	Lower montane forest (above 1000 m). Small crowned forest with *Nothofagus*
Samples for analysis	No

Rehabilitation Suitability Summary :
No original top soil remains. Regeneration is sparse and appears slow to colonise and grow. Regeneration may partly be impeded by poor drainage in places. Surface is stabilised by moss development. No significant soil development.

			Horizon	**Depth (cm)**	**Description**
0.0 m	**NO SOIL**	0.6 m			
0.1 m		0.7 m	A		
0.2 m		0.8 m	B		
0.3 m		0.9 m	**Recommended Topsoil Strip Depth**		
0.4 m		1.0 m			
0.5 m		1.1m			

Representative Site Description and Soil Profile

Soil Type	Site No: S6 – Camp 1	**Date:** 8/4/2008

Concept
Silty clay loam formed from weathered volcanic deposits over limestone.

GPS (WGS):	S5 48.420 E142 18.529 (approximately 1 km east of this point)
Height ASL:	350 m
Soil Classification:	Soil Order: Inceptisol
Landform Element	Ridge
Landform Pattern	Steep hills and valleys
Slope	5^0
Microrelief	Undulating
Surface condition	Abundant dead wood and decomposing leaf litter.
Land Condition	Primary forest
Land Use	None
ASWAT	Stable
Vegetation and Type	Lowland primary forest
PNGRIS Type	Low altitude forest on uplands (below 1000 m). Medium crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 15 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

0.0 m
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m

0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1m

Horizon	**Depth (cm)**	**Description**
A	10-15	Silty clay loam with limestone fragments Field pH 4.5 - 5
B	15 - > 100	Silty clay loam with limestone fragments at 80 cm. Field pH 4.5 - 5
Recommended Topsoil Strip Depth		15 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S7 – Camp 2	**Date:** 10/4/2008

Concept
Silty clay loam formed over limestone.

Species: *Cryptocarya* sp., *Garcinia* sp., *Litsea* sp., *Lophopetalum* sp., *Syzygium* sp., *Terminalia* sp., *Teijsmanniodendron* sp., Weinmannia sp.,

GPS (WGS): S5 53.836 E142 25.983 (approximately 500 m west of this point)

Height ASL: 980

Soil Classification: Soil Order: Inceptisol

Landform Element	Ridge
Landform Pattern	Steep hills and valleys
Slope	Flat
Microrelief	Hummock and hollow
Surface condition	Abundant dead wood and decomposing leaf litter.
Land Condition	Primary forest
Land Use	None
ASWAT	Stable
Vegetation and Type	Lowland primary forest
PNGRIS Type	Low altitude forest on uplands (below 1000 m). Medium crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 15 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

0.0 m
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m

Horizon	**Depth (cm)**	**Description**
A	10 - 15	Silty clay loam Field pH 5.5
B	10 - 40	Silty clay loam with limestone gravel below 30 cm Field pH 7

Recommended Topsoil Strip Depth 15 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S8 – Camp 2	**Date:** 10/4/2008

Concept
Silty clay loam formed over limestone.

Position (WGS): S5 53.836 E142 25.983 (approximately 150 m west of this point)

Height ASL: 965 m

Soil Classification: Soil Order: Inceptisol

Landform Element	Ridge
Landform Pattern	Steep hills and valleys
Slope	Flat
Microrelief	Undulating
Surface condition	Abundant dead wood and decomposing leaf litter.
Land Condition	Primary forest
Land Use	None
ASWAT	Stable
Vegetation and Type	Lowland primary forest
PNGRIS Type	Low altitude forest on uplands (below 1000 m). Medium crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 8 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

Horizon	**Depth (cm)**	**Description**
A	8	Silty clay loam Field pH 4.0
B	30 - > 100	Silty clay loam Field pH 4.0 – 6.0 Increasing intensity of colour with depth Small stones at 90 cm
Recommended Topsoil Strip Depth		10 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S9 – Camp 3	**Date:** 10/4/2008

Concept

Sandy clay loam on river terrace adjacent to the Baia River. Regrowth vegetation post landslide disturbance from siltstone deposits overlaying limestone cliffs above.

Species: *Aglaia* sp.,*Anthocephalus chinensis, Dendrocnide*, *Duabanga, Casuarina* sp., *Elaeocarpus sphaericus,Drynaria* sp., *Ficus dammaropsis, Ficus pungens Macaranga triloba, Paraserianthes falcataria*, *Pipturus, Pometia pinnata,*

Position (WGS): S6 01.350 E142 32.799

Height ASL: 350 m

Soil Classification: Soil Order: Not known; Great Group: Not known; Great Group: Not known

Landform Element	Raised terrace 8 m above Baia River. Limestone cliffs above.
Landform Pattern	River valley
Slope	Flat – gently undulating
Microrelief	Undulating
Surface condition	Decomposing leaf litter.
Land Condition	Regrowth dominated by *Duabanga moluccana* and *Ficus.*
Land Use	None
ASWAT	Moderately stable - unstable
Vegetation and Type	Regrowth
PNGRIS Type	Low altitude forest on uplands (below 1000 m). Medium crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :

Top soil is about 20 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

0.0 m

0.1 m

0.2 m

0.3 m

0.4 m

0.5 m

0.6 m

0.7 m

0.8 m

0.9 m

1.0 m

1.1 m

Horizon	**Depth (cm)**	**Description**
A	20	Sandy clay loam with siltstone fragments Field pH 7.5 - 8
B	20 - 100	Sandy clay loam Brown mottles Field pH 7.5 - 8
Recommended Topsoil Strip Depth		20 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S10 – Camp 3	**Date:** 10/4/2008

Concept
Silty clay to silty clay loam over weathered sandstone, beneath limestone cliffs.

Position (WGS): S6 01.350 E142 32.799 (approximately 1 km NE of this point, along and above Baia River)

Height ASL: 220 m

Soil Classification: Soil Order: Not known; Great Group: Not known; Great Group: Not known

Landform Element	Baia River valley
Landform Pattern	Toe slope beneath limestone cliffs, above the Baia River
Slope	< 5°
Microrelief	Undulating
Surface condition	Decomposing leaf litter.
Land Condition	Regrowth
Land Use	None
Erosion/ASWAT	Moderately stable
Vegetation and Type	Lowland primary forest
PNGRIS Type	Low altitude forest on uplands (below 1000 m). Medium crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 20 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

Horizon	Depth (cm)	Description
A	20	Silty clay – silty clay loam Field pH 5.0
B	45- > 70	Silty clay loam, Orange mottles. Field pH 6.0 Grey weathered sandstone from 70 cm depth of pH 8.5
Recommended Topsoil Strip Depth		8 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S11 – Camp 3	**Date:** 10/4/2008

Concept
Sandy loam on a recent river terrace adjacent to the Baia River. River banks lined with basalt boulders.

Position (WGS): S6 01.104 E142 32.998

Height ASL: 220 m

Soil Classification: Soil Order: Entisol; Great Group: Fluvents; Great Group: Tropofluvents

Landform Element	Raised terrace 2-3 m above Baia River.
Landform Pattern	River valley
Slope	Flat
Microrelief	Flat
Surface condition	Decomposing leaf litter.
Land Condition	Uniform (even sized) young primary forest
Land Use	None
ASWAT	Unstable
Vegetation and Type	Young Primary forest
PNGRIS Type	Low altitude forest on uplands (below 1000 m). Medium crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 5 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

0.0 m
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m

0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m

Horizon	Depth (cm)	Description
A	5	Sandy loam Field pH 8.0
B	5 > 90	Sandy loam Field pH 8.5. Basalt rock at 90 cm
Recommended Topsoil Strip Depth		5 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S12 – Camp 4	**Date:** 12/4/2008
Concept Very wet silty loam supporting *Nothofagus grandis* dominated forest. Numerous small creeks draining in to the South Karius River.		

GPS (WGS): S5 59.473 E142 40.278

Height ASL: 1350 m

Soil Classification: Soil Order: Inceptisol; Great Group: Not known; Great Group: Not known

Landform Element	Valley floor with deeply incised (3 m deep) narrow streams draining into South Karius
Landform Pattern	Wide river valley
Slope	Flat
Microrelief	Undulating
Surface condition	Decomposing leaf litter and dead wood
Land Condition	Undisturbed forest
Land Use	None
ASWAT	Unstable
Vegetation and Type	Primary forest dominated by large *Nothofagus grandis*
PNGRIS Type	Lower montane forest (above 1000 m). Small crowned forest with *Nothofagus*
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 5 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.

Horizon	Depth (cm)	Description
A	15 - 20	Silty clay Field pH 4.5
B	5 > 90	Silty clay (20 – 80 cm) to sandy loam at 80cm. Field pH 6. Orange mottles.
Recommended Topsoil Strip Depth		20 cm

Representative Site Description and Soil Profile

Soil Type	Site No: S15 – Camp 4	**Date:** 12/4/2008

Concept
Very wet silty loam supporting Pandanus and Syzygium dominated forest. Water table at 20 – 40 cm depth. Numerous small creeks close to the level of the forest floor.

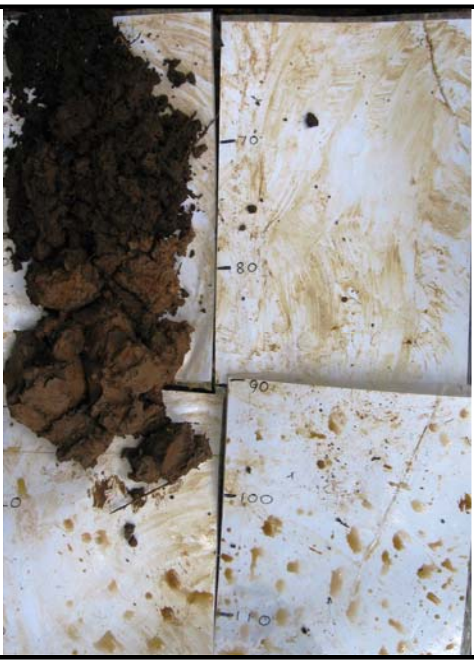
GPS (WGS): S5 59.470 E142 40.281

Height ASL: 1350

Soil Classification: Soil Order: Inceptisol; Great Group: Not known; Great Group: Not known

Landform Element	Valley floor
Landform Pattern	Valley
Slope	Flat
Microrelief	Flat
Surface condition	Decomposing leaf litter and dead wood
Land Condition	Primary forest dominated by *Nothofagus grandis*
Land Use	None
ASWAT	No sample
Vegetation and Type	Primary forest
PNGRIS Type	Lower montane forest (above 1000 m). Small crowned forest
Samples for analysis	Yes

Rehabilitation Suitability Summary :
Top soil is about 20 cm depth. The top 10 cm will typically contain a seedbank dominated by fast growing pioneer (woody) species. This soil provides the best potential for quick rehabilitation if it can be stripped and set aside during construction.



Horizon	Depth (cm)	Description
A	20	Silty clay loam Field pH 5.5
B	20 +	Silty clay loam. Too wet to extract below 40 cm. Field pH 4.5 - 5. Orange mottles.
Recommended Topsoil Strip Depth		20 cm