resource and environmental management

Papua New Guinea Liquefied Natural Gas Project

PNG LNG

GROUNDWATER IMPACT ASSESSMENT – UPSTREAM FACILITIES

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SKM

Papua New Guinea Liquefied Natural Gas Project

GROUNDWATER IMPACT ASSESSMENT – UPSTREAM FACILITIES

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Glossary of terms and abbreviations

Terms

Alluvial
Relating to sediments that have been deposited by rivers and streams.

Aquifer
A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.

Aquitard
A saturated but poorly permeable bed, formation, or group of formations that does not yield water freely to a well or a spring. An aquitard may transmit appreciable water to or from adjacent aquifers.

Baildown recovery test
A test made by removing water from a well using a bailer for a period of time after which measurements of water level recovery in the well are recorded. The data is used to estimate the hydraulic characteristics of the aquifer.

Base flow
That portion of stream flow derived from groundwater seeping into a stream.

Colluvial
Relating to sediments that have been carried by gravity downhill slopes where they then accumulate.

Confined aquifer
An aquifer that lies below a low permeability material. The piezometric surface in confined aquifers is above the base of the confining material, eg. artesian aquifers.

Drawdown
The distance between the static water level and the surface of the cone of depression.

Ecosystem
Term used to describe species in an environment and their relationship with one another and the non-living (abiotic) community.

Electrical conductivity
The capacity of a material to conduct electricity. In a fluid, electrical conductivity increases with total dissolved solids. A measure of water salinity. (see total dissolved solids).

Groundwater
The water contained in interconnected pores, gaps or fractures located below the watertable in an unconfined aquifer or located in a confined aquifer.

Groundwater affecting activity
Any activity that has the potential to change groundwater conditions (levels and quality).

Hydraulic conductivity

A coefficient of proportionality describing the rate at which water can move through a permeable medium. Horizontal hydraulic conductivity (K_h) refers to the coefficient of proportionality in the horizontal direction, whereas vertical hydraulic conductivity (K_v) refers to the coefficient of proportionality in the vertical direction.

Hydraulic gradient

The rate of change in total head per unit distance in a given direction. The direction of gradient is that yielding the maximum rate of decrease in head.

Karst

Geologic terrain underlain by carbonate rocks having significant solution controlled groundwater.

Pigging

An operation performed on pipelines to clean and inspect them whilst allowing the continued flow of product.

Screen

Perforated well casing that allows water to enter the well from an aquifer.

Standing water level

The level at which groundwater within a well occurs. A measure of the hydraulic potential of an aquifer over the screened interval of the well.

Storativity

The volume of water released from, or taken into, storage within an aquifer per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, storativity is the same as specific yield.

Slug catcher

A slug catcher receives a mixture of production gas and liquid condensate from a production pipeline and acts to separate the two phases.

Transmissivity

The rate at which water is transmitted through a unit width of aquifer or aquitard under a unit hydraulic gradient. It is the product of aquifer thickness and hydraulic conductivity.

Total dissolved solids

The total amount of dissolved solid matter found in a sample of water. A measure of salinity.

Unconfined aquifer

A water table aquifer.

Water table

The surface between the unsaturated and saturated zones of the subsurface at which the hydrostatic pressure is equal to that of the atmosphere.

Well

A borehole that has been cased with pipe, usually steel or PVC plastic, in order to keep the borehole open in unconsolidated sediments or unstable rock. Often used interchangeably with the term bore.

Abbreviations

DEC	Papua New Guinea Department of Environment and Conservation
EC	electrical conductivity
L	litre
m	metre
m bgl	metres below ground level
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
m/day	metres per day
m^2/day	metres squared per day
m^3/day/m	cubic metres per day
MEG	mono-ethylene glycol
NEPM	(Australian) National Environmental Protection Measures
NWQMS	(Australian) National Water Quality Management Strategy
TDS	total dissolved solids
TEG	tri-ethylene glycol
μS/cm	microSiemens per centimetre

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Executive Summary

Background

Sinclair Knight Merz Pty Limited, formerly Resource & Environmental Management Pty Ltd, has been engaged by Coffey Natural Systems Pty Ltd to undertake a groundwater impact assessment for Esso Highlands Limited's Papua New Guinea Liquefied Natural Gas Project.

This report presents the groundwater impact assessment for the (onshore) upstream component of the Liquefied Natural Gas Project including pipelines, and gas conditioning and processing facilities. For the purpose of the assessment, the upstream project area extends more than 200 km from the Juha gasfields located within the Central Highlands to the pipeline landfall at the mouth of Omati River on the Gulf of Papua (Figure ES.1).

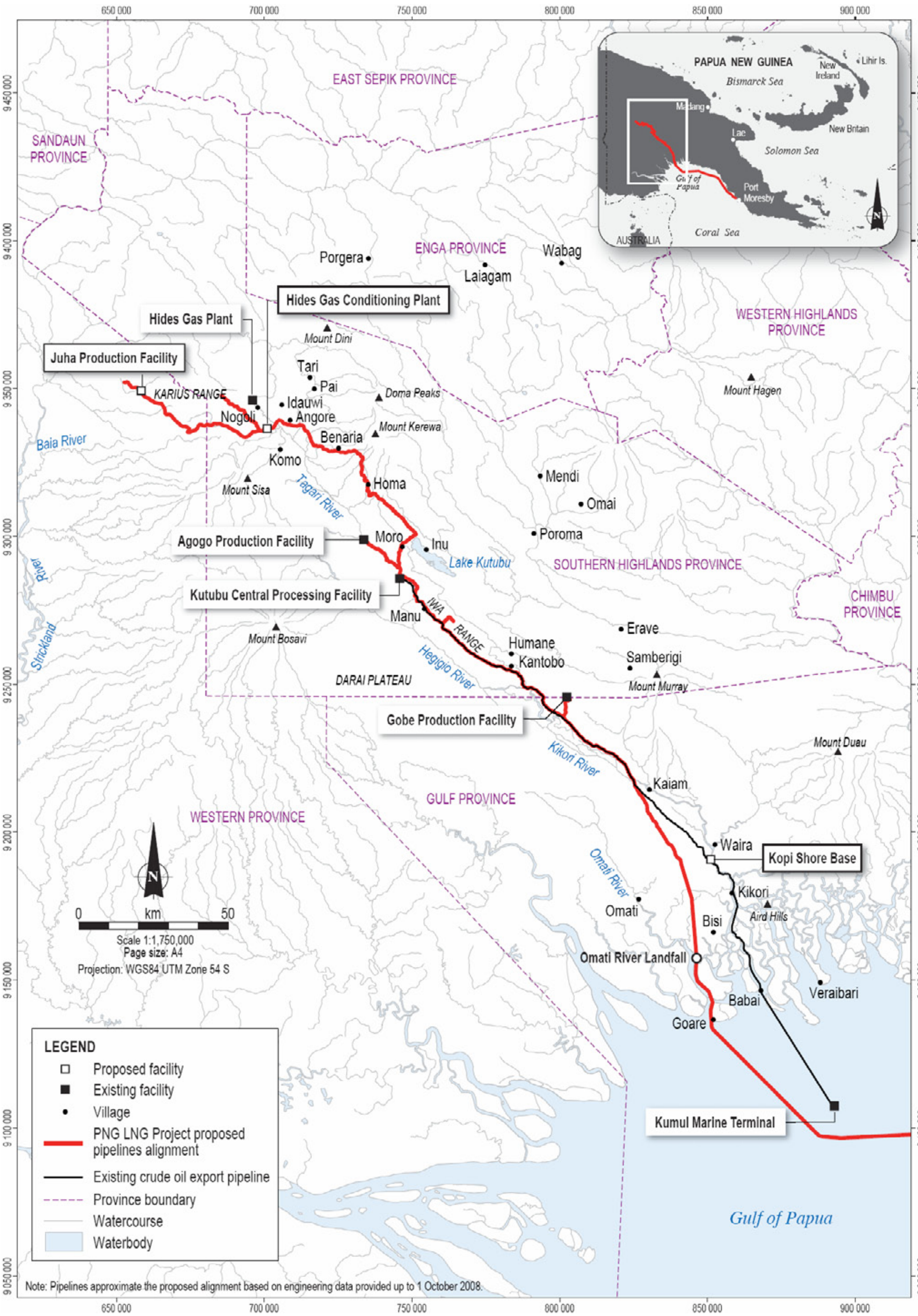
The impact assessment is required to assess the potential for contamination of groundwater resources beneath and adjacent the gas pipeline alignment and the potential for developing groundwater supplies to meet the different water needs of the upstream Project components (and address the potential for other water users to be impacted by such development).

Regulatory Framework

Water resource management and the management of potential soil and water contaminants for the Papua New Guinea Liquefied Natural Gas Project are regulated by the Environment Act (2000). The Environment Act has the primary objective of controlling activities that may give rise to adverse environmental or social impacts and addresses aspects of a proposed or existing development that may result in the release of contaminants to the environment either through accident, misuse or inappropriate storage.

The regulation and management of Papua New Guinea water resources falls under the influence of the Department of Environment and Conservation, as too is the regulation of Water Resources and Wastewater Discharge into the environment (groundwater, rivers, springs, lakes & sea). The Department of Environment and Conservation issues Water Use Permits to cover these types of activities, with specific conditions to be complied with by Permit Holders.

Papua New Guinea's *Drinking Water Quality Standards* have been adopted from the World Health Organisation's *Drinking Water Quality Guidelines*. However, for receptors other than humans, environmental guidelines developed by Australia's Natural Resource Management Ministerial Council and Environment Protection and Heritage Council are considered appropriate to complement the adopted drinking water guidelines for future assessments of groundwater quality.



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PNG LNG Project
groundwater impact assessment
UPSTREAM ONSHORE COMPONENTS
LOCALITY PLAN

Figure
ES.1
Nov 2008

Project: GQ-01-1

Hydrogeological Setting

Karst aquifers are expected to dominate the Project area from the Juha gasfields in the Central Highlands down to around Kopi, which is located around 30 km north of the Omati River pipeline landfall (Figure ES.1). Groundwater systems downstream of Kopi will likely be associated with fluvial, colluvial and, possibly, aeolian sediments.

Rainfall runoff in karst parts of the Project area is expected to quickly recharge the likely highly permeable groundwater systems. A high degree of interconnectivity between karst aquifers and surface water resources is expected, and groundwater baseflow to stream and rivers is very likely to be an important component of stream flow between during dryer times of the year.

At the time of preparation of this report, there was no information available concerning aquifer hydraulic properties. However, experience from karst terrains around the world suggests that groundwater supply potential from the karst aquifers along the alignment of the gas pipeline will be highly prospective.

Groundwater quality is expected to be good, with low salinity concentrations and slightly alkaline conditions.

Groundwater Supply Potential

Groundwater resources are expected to form viable water resources to support upstream Project activities and processes. However, some form of treatment prior to use for potable camp supplies will need to be considered.

Groundwater Impact Assessment

The issues of most importance in respect to the upstream Liquefied Natural Gas Project's potential to cause adverse impact to groundwater resources are associated with seismic events (the potential to cause leaks and failure of containment systems such as pipelines, product and fuel storage tanks, and mud pits) and the predominantly karst nature of the Project area groundwater systems (potential contaminants released to groundwater will likely be highly mobile and there is likely strong interconnectivity with surface water resources).

A number of aspects of the upstream component of the Project present a moderate to serious risk of impacting adversely on groundwater resources if engineered controls are not implemented in design, including:

- Condensate pipeline and storage tank failure has the potential to release large volumes of hydrocarbons to the environment (serious risk).
- MEG and TEG system failure has the potential to release potentially toxic glycol compounds to the environment (moderate risk).
- Fuel storage and distribution system failure has the potential to also release large volumes of hydrocarbons, but engineered solutions (e.g. bunds) will mitigate against release to the environment (moderate risk).

A number of other aspects of the Project present a low risk of impacting adversely on groundwater resources, including:

- Gas production facilities (drilling, construction and development).
- Flares and vent systems
- Dehydration units.
- Demineralised water systems.
- Effluent disposal system (non-hazardous and hazardous waste containment).
- Drain systems (hydrocarbon effluent release).
- Storm water system (hydrocarbon effluent release).
- CPI oil sump (hydrocarbon effluent release).
- Groundwater supply development.

On decommissioning of the Project the risk of potential residual impacts associated with gas production, conditioning and transfer are expected to be low.

To mitigate against release of potential groundwater contaminants to the environment and impacts associated with groundwater supply development, it will be important for the Project proponent to apply international good practice engineering design and management principals in all parts of the Project (including utility and offsite components). This will need to be underpinned by an understanding of Project area conditions, adherence to appropriate codes and standards, and implementation of quality assurance procedures and protocols.

1. Project overview

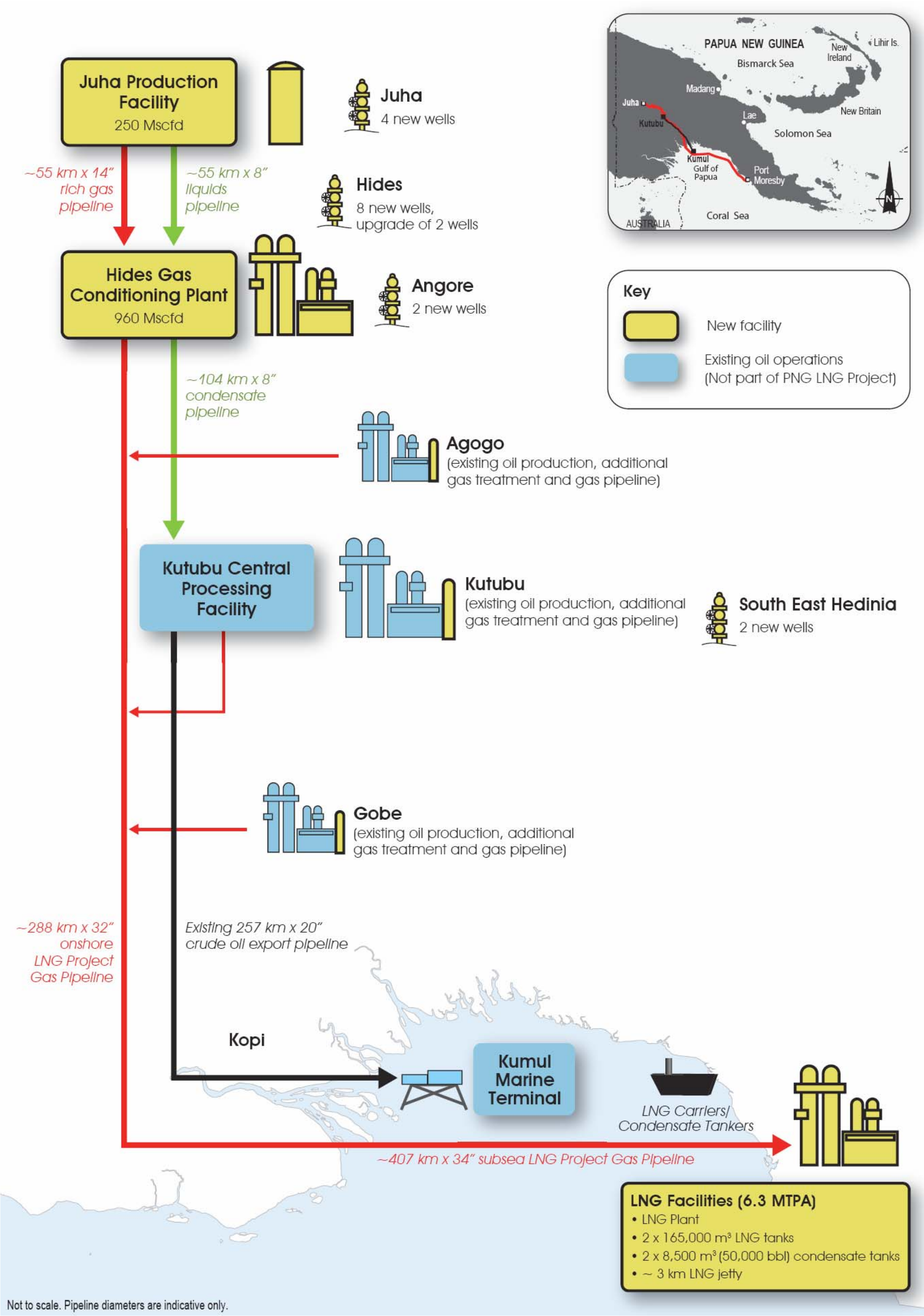
The Papua New Guinea Liquefied Natural Gas (PNG LNG) Project involves the development of a number of gas fields and facilities in a series of development phases to produce liquefied natural gas (PNG LNG) for export. The development will also produce condensate. The development of the Hides, Angore, and 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 PNG 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 PNG 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 PNG LNG for over the 30 year life of the Project.

A list of the proposed developments is provided below, and Figure 1.1 shows a schematic of facilities and pipelines:

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 PNG 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.



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PNG LNG Project
groundwater impact assessment
PROJECT LOCALITY PLAN

Figure
1.1
Mar 2008

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 PNG LNG Project Gas Pipeline.
  - Gas treatment at the Gobe Production Facility and a new Gobe Gas Pipeline from the Gobe Production Facility to PNG 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 PNG 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.
- PNG LNG Project Gas Pipeline:
  - Onshore: from Hides Gas Conditioning Plant to Omati River Landfall.
  - Offshore: Omati River Landfall to Caution Bay Landfall.

PNG LNG Facilities Development Components:

- Onshore PNG LNG Plant including gas processing and liquefaction trains, storage tanks, flare system and utilities.
- Marine facilities including jetty, PNG 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 PNG 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. Groundwater impact assessment

2.1 Introduction

Sinclair Knight Merz Pty Limited (SKM), formerly Resource & Environmental Management Pty Ltd, has been engaged by Coffey Natural Systems Pty Ltd (Coffey) to undertake a groundwater impact assessment for the Papua New Guinea Liquefied Natural Gas (PNG LNG) Project.

Documentation for the Project is to be completed in two stages:

(i) Down-stream aspects of the development (the PNG LNG plant and associated infrastructure).

(ii) Upstream aspects of the development (such as gas production, processing and conditioning, and product transfer pipelines).

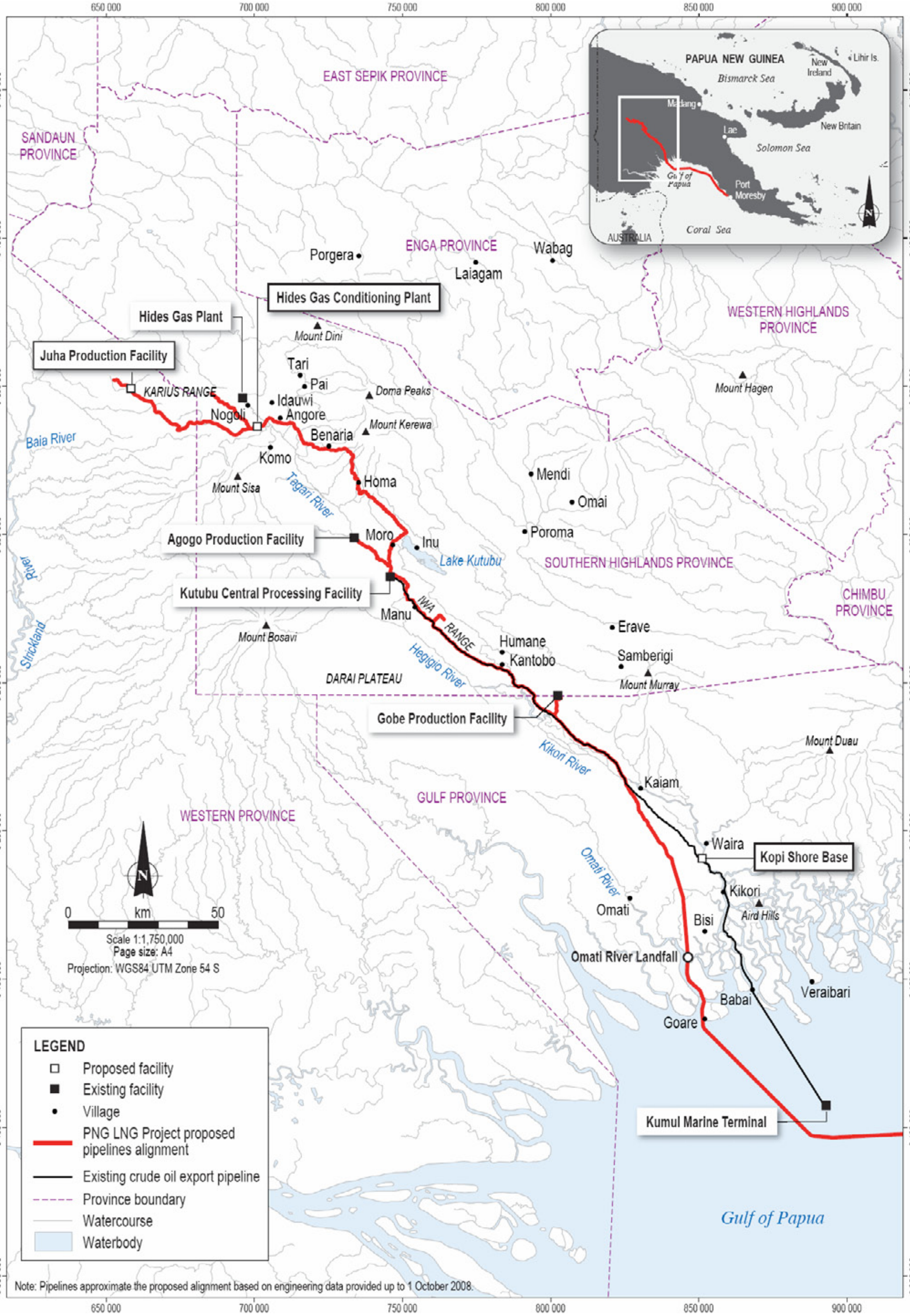
This report presents the groundwater impact assessment for the upstream infrastructure and activities (Figure 2.1), and addresses:

- Potential groundwater contaminant issues in relation to operation of the various facilities and activities involved in producing gas and transferring the product to the PNG LNG Plant located on Portion 152.
- Groundwater supply development for hydrotesting of the gas flowline, drilling operations and construction activities (including potable camp supplies).

2.2 Scope of work

The project brief identifies the following scope of work for the groundwater impact assessment:

- Impact related issues
  - identification of activities and facilities that could impact on groundwater resource condition during Project construction and operation;
  - identification of legislation, guidelines and policies that apply to potential groundwater affecting activities associated with Project construction and operation;
  - identification of management strategies that can be employed to avoid, reduce or mitigate adverse impacts to groundwater resources, consistent with obligations under relevant legislation, guidelines and policies; and
  - assess ongoing liabilities relating to groundwater resources (residual impacts) associated with the Project.



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PNG LNG Project
groundwater impact assessment
UPSTREAM ONSHORE COMPONENTS
LOCALITY PLAN

Figure
1.2
Nov 2008

- Groundwater resource related issues in the study area
  - resource characterisation and current uses; and
  - identification of beneficial uses of groundwater.

2.3 Report structure

This report is structured as follows:

- Section 1; General Project overview
- Section 2; Introduction (background information and scope of work).
- Section 3; Regulatory framework (in relation to environmental approvals and management).
- Section 4; Physical setting (background information regarding climate, topography, geology and hydrogeology).
- Section 5; Groundwater impact assessment (assessment of risk posed to groundwater resource condition by upstream gas production facilities and associated activities).
- Section 6; Discussion and conclusions (wrap-up of the potential for upstream facilities and activities to impact adversely on groundwater and receiving environment conditions).
- Section 7; References.
- Appendices: Supporting information and calculations.

With the exception of Sections 3, 7 and 8, and unless otherwise indicated, the information presented in this report has been sourced from either the 1998 *PNG Gas Project Environmental Plan* (NSR, 1998) or the 2007 *Papua New Guinea PNG LNG Project Early Project Development Basis* report (Esso Highlands, 2007).

3. Regulatory framework

3.1 Legislation

The Project has been determined by the PNG Department of Environment and Conservation (DEC) as a Level 3 activity (DEC, 2004). Level 3 activities are described in Schedule 2 of the *Environment (Prescribed Activities) Regulation (2002)*, and defined within the Environment Act as being of national importance and/or having the potential to result in significant environmental impact.

Water resource management and the management of potential soil and water contaminants for PNG's mining industry (including the oil and gas industry) is regulated by the *Environment Act (2000)* (Lyday, 2001). The Environment Act replaces the *Environmental Contaminants Act (1978)*, *Water Resources Act (1982)* and *Environmental Planning Act (1978)*.

The Environment Act has the primary objective of controlling activities that may give rise to adverse environmental or social impacts (ESCAP, 2003). The Environment Act addresses aspects of a proposed or existing development that may result in the release of prohibited chemicals (contaminants) to the environment (including soil and water resources), either through accident, misuse or inappropriate storage. In the case of the Project, activities such as landfilling (with putrescible or hazardous materials), operation of burn (or flare) pits, mud pits and water disposal pits, release of treated waste water to the environment, and the use and storage of hazardous goods and chemicals would be covered by the Environment Act.

The Environment Act offers specific guidance with regard to the use of water resources (both surface and underground). Specifically, landholders or occupiers can freely access adjoining surface water resources for stock and domestic purposes (including for employees). In addition, the PNG Government has the ability to issue permits allowing access to water resources by users other than those who hold land adjoining those water resources. These permits will normally specify a rate of water take and the use to which the water is put. In addition, permits can be obtained to allow the release of water and contaminants to the environment, and will usually stipulate conditions and standards by which to control this release.

The Environment Act also requires permits be issued by the relevant government agency for the purpose of conducting water investigations. Whilst the Act doesn't specifically define what is meant by 'investigation', it is assumed to relate to intrusive investigations and not to the act of sampling water for assessment of water quality parameters.

In short, the regulation and management of PNG water resources falls under the influence of the DEC. The regulation of Water Resources and Wastewater Discharge into the environment (groundwater, rivers, springs, lakes & sea) is also the function of the DEC. The Environment Act provides comprehensive standards for protection of environment and water. The DEC issues Water Use Permits with conditions to be complied with by the permit holders. The Permits can be for groundwater exploration, extraction of groundwater and surface water or discharge of wastewater into a water body.

The extraction, treatment and distribution of water and the collection, treatment and discharge of wastewater are the functions of two State-owned water utilities. PNG Waterboard established under the National Water Supply and Sewerage Act, manages water supplies and sewerage services in eleven major centres throughout the country. On the other hand, Eda Ranu registered under the Companies Act and solely owned by the PNG Government, operates the Port Moresby City Water Supply and Sewerage systems. The water supply and sanitation services not operated by the two utilities are operated and managed by Provincial Governments or Local Level Governments.

3.2 Environmental guidelines

PNG's *Drinking Water Quality Standards* have been adopted from the World Health Organisation's *Drinking Water Quality Guidelines* (WHO, 2000). Any groundwater (or surface water) supplies developed for potable purposes should conform to these guidelines. Ongoing environmental assessments in relation to potential Project impacts on water resources will also need to consider the *Drinking Water Quality Standards* as well as other guidelines designed to address water quality issues associated with marine and aquatic ecosystems (SKM, 2008), such as the Australian:

- National Water Quality Management Strategy (NWQMS).
- National Environmental Protection Measures (NEPM).

4. Physical Setting

4.1 Project area

The Project (Figure 1.1) involves:

- Development of the Juha, Hides and Angore gasfields.
- Construction and operation of a gas production facility at Juha, including spinelines between the facility and gas production wellpads.
- Construction and operation of a gas processing and conditioning facility at Hides (termed the Hides Gas Conditioning Plant), including spinelines between the facility and gas production wellpads.
- Construction of a gas transfer pipeline from the Hides Gas Conditioning Plant to the PNG LNG Plant located at Portion 152 (the PNG LNG Project Gas Pipeline).
- Construction of a condensate pipeline termed the Hides-Kutubu Condensate Pipeline from the Hides Gas Conditioning Plant Production and conditioning facilities to the Kutubu Central Processing Facility.
- An offshore pipeline from the Omati River Landfall to the PNG LNG facility located on the coast of the Gulf of Papua at Portion 152, approximately 20 km northwest of Port Moresby.
- Construction of the PNG LNG facility, marine terminal and materials offloading facility on the Gulf of Papua near Port Moresby.

The upstream Project area (i.e. the onshore components of the Project that do not include the PNG LNG facility) extends from the coastal lowland around Kopi to the highlands around Kobalu (Figure 2.1). The gas pipeline alignment traverses more than 200 km from the Juha Production Facility to the Omati River Landfall around 30 km south of Kopi. Most of the pipeline alignment lies within the Kikori River basin and has much the same alignment as the existing Kutubu crude oil export pipeline (Figures 1.1 and 2.1).

4.2 Climate

The upland regions where the gas production facilities are located experience annual rainfalls of around 4,000 to 4,500 mm, and humidity levels typically ranging above 70%. Near the Kutubu Central Processing Facility mean monthly temperatures range between 22 and 24^{o}C.

In the lowlands around Kopi and Omati (Figure 2.1) the average annual rainfall is around 5,700 mm and is more seasonal than that experienced in the uplands. Humidity levels are also consistently high.

4.3 Topography and Geology

The Project area rises from near sea level at the Omati River Landfall to more than 1,000 m elevation at Juha (Figures 2.1 and 4.1). Figures 4.1 and 4.2 show that limestone dominates the landform and strongly influences topography within the Project area:

- Undulating karst limestone plains occupy the central part of the Kikori valley at around 40 to 100 m above sea level (ASL), which is likely the base level of chemical weathering within the limestone formations.
- Flat-topped limestone plateaus with often ill defined and discontinuous incised karst corridors dominate the southeastern part of the Darai Plateau.
- Polygonal karst, a landscape that is pitted by closed depressions the origins of which are in an uplifted surface that is subsequently fissured by shear and tension joint systems, comprises the larger part of the Project area landscape. On the Darai Plateau cone karst is common, whilst elsewhere along the Kikori, Hegigio and Mubi valleys (Figure 4.2) a variety of landforms occur (cones, pinnacles, dolines, caves and underground rivers).

North and east of the Kikori valley, mountain systems comprising of karst and other features formed by fractured limestone beds, that have been folded and faulted, overlie clastic sediments. Within some reaches of the river valleys fluvial floodplains have formed and, closer to the coast, relict alluvial plains, mangrove and beach dune complexes are formed with the river deltas.

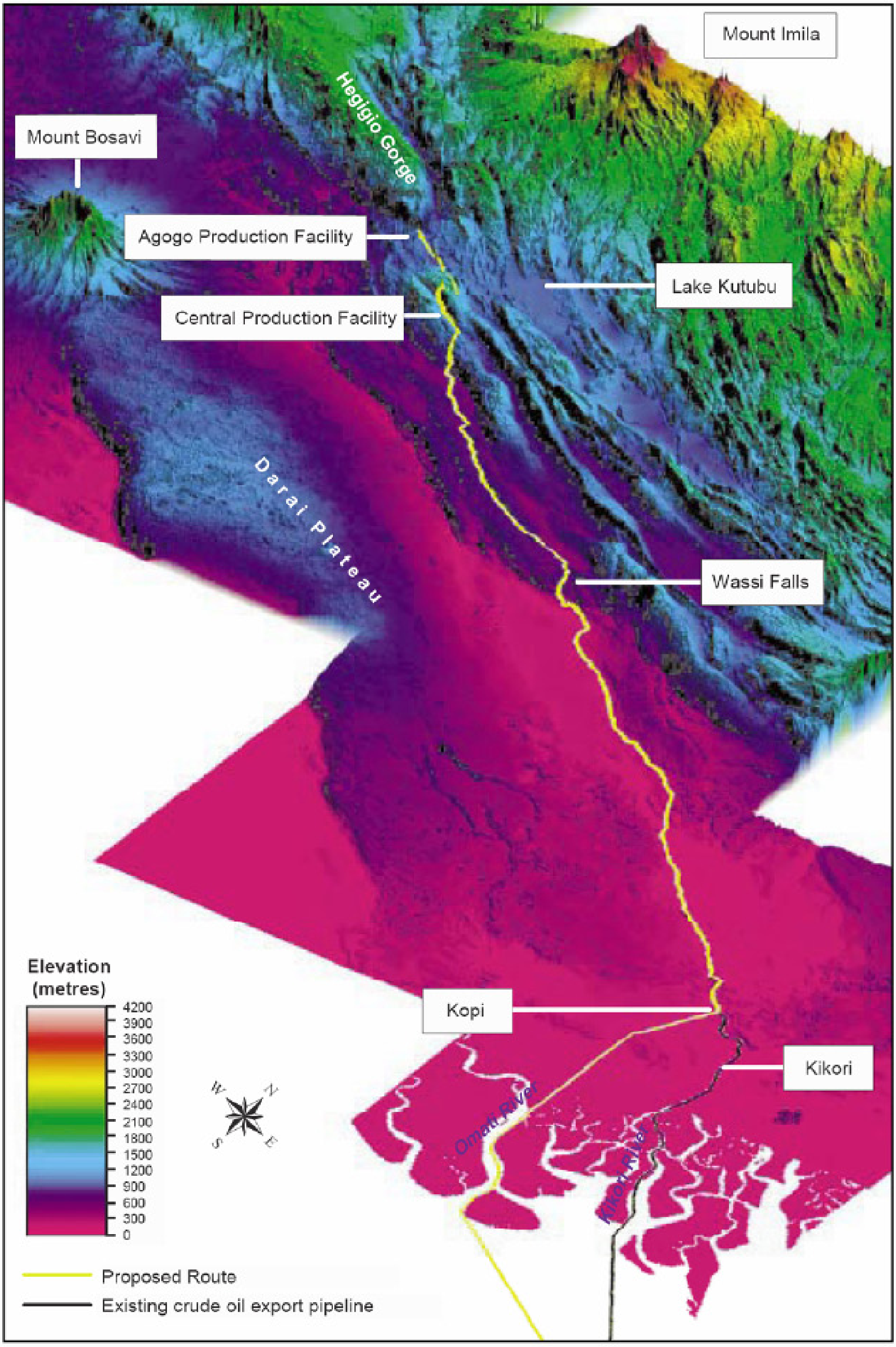
PNG is an area of complex tectonics with active subduction zones with shallow and deep earthquakes, and is one of the World's most active seismic and volcanic regions (McCue, undated). Figure 4.3 presents a plan showing PNG seismic events, indicating that the upstream Project area is located within an active seismic region.

4.4 Hydrology

The upstream Project area is drained by the Hegigio, Mubi and Kikori River systems (Figures 2.1 and 4.2). The higher watersheds of each of these rivers are strongly controlled by geological structure, with northwest-southeast trending ridges and ravines typically confining the drainages to long and narrow valleys. The lower watersheds of the rivers, nearer to the coast below Kopi (Figures 2.1 and 4.2), are characterised by fluvial plains and fans.

The Hegigio-Kikori River system is one of the major river systems of PNG and drains the southern slopes of the Central Highlands. The mean catchment yield for the Kikori River (gauged upstream of Kikori) is around 1,500 m^3/sec. Lake Kutubu is drained by the Mubi River, which discharges to the Kikori River below Wassi Falls.

In some locations volcanic ash and debris has formed natural barriers to the watersheds, resulting in the formation of lakes such as Lake Kutubu (Figures 2.1 and 4.2) near the Kutubu Central Processing Facility.



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after NSR (1998)

PNG LNG Project
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UPSTREAM PROJECT AREA
DIGITAL ELEVATION MODEL

Figure
4.1
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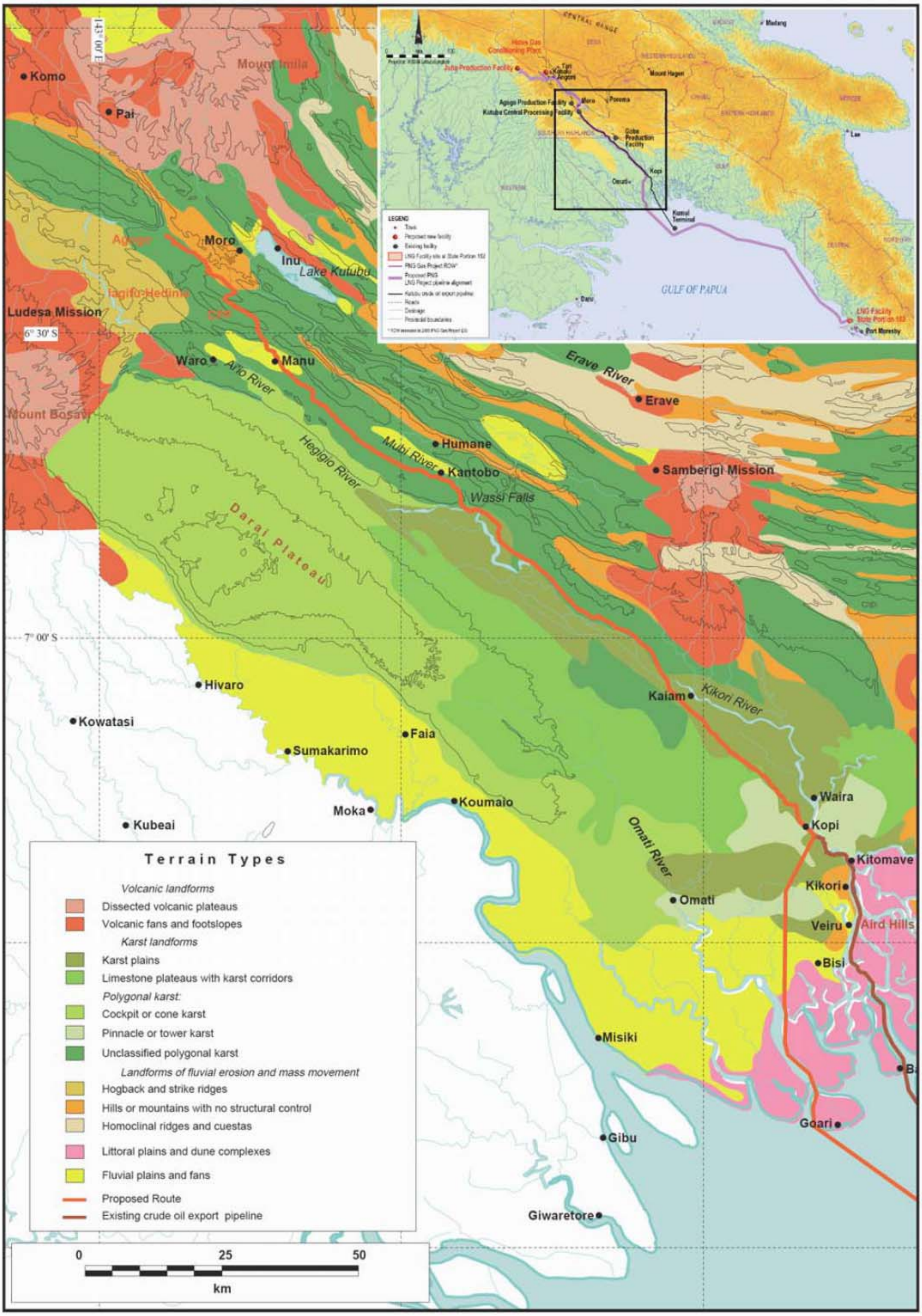

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after NSR (1998)

PNG LNG Project
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UPSTREAM PROJECT AREA
LANDFORM TERRAIN

Figure
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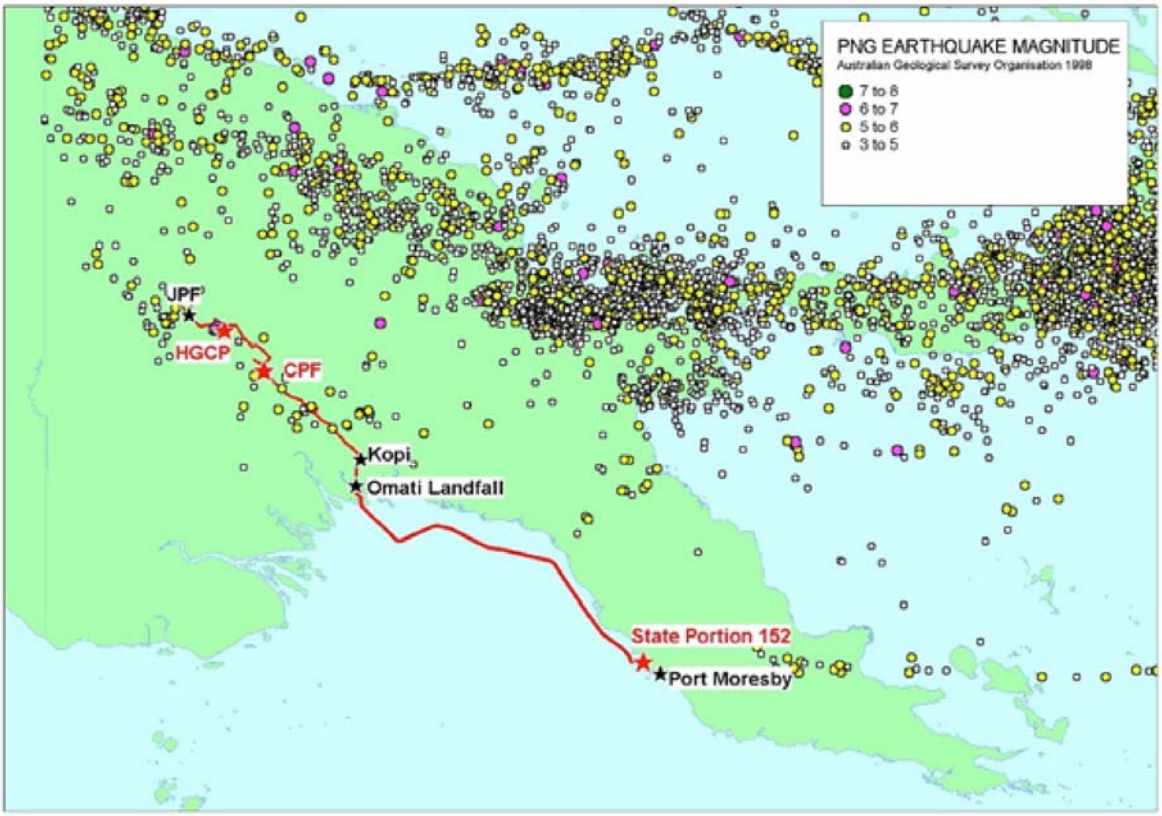

Figure 4.3 PNG seismic events map (1900-2002)

4.5 Hydrogeology

Karst aquifers are expected to dominate those parts of the Project area upstream of Kikori (Figures 2.1 and 4.2).

The karst limestone setting of the Study Area is an important control on the way surface water and groundwater interacts. The karst nature of the landscape means that rainfall runoff will quickly infiltrate the landscape to recharge underlying karst aquifers, and that the shallow soil profile will not greatly reduce recharge rates apart from where significantly weathered limestone has formed low plasticity clays. The movement of water through limestone results in solutional enlargement of bedding planes, faults and fractures, often resulting in highly permeable aquifers with variable (secondary) porosity. The solutional enlargement of porosity results in the landscape that is typical of karst terrain, e.g. dolines, swallow holes and caves.

The groundwater systems of the Project area are expected to be local groundwater flow systems, whereby recharge and discharge areas occur in close proximity. Groundwater baseflow to streams and rivers likely forms a very important source of stream flow during dryer times of the year. During flood events it is also probable that stream flows discharge to the groundwater system, with the 'recharged' water discharging back into the streams on flood recessions.

At the time of preparation of this report, there was no information available concerning aquifer hydraulic properties. However, experience from karst terrains around the world suggests that groundwater supply potential from the karst aquifers along the alignment of the gas flowline will be highly prospective.

Groundwater velocities can be expected to be relatively high (**m**/day rather than **mm**/day or **cm**/day) compared to those that might occur on Portion 152 (the site of the PNG LNG Plant) where the groundwater system is characterised by clayey and silty sediments (SKM, 2008).

It can be expected that groundwater quality in the karst terrain will be good, with low salinity concentrations (as a result of rapid recharge and discharge) and slightly alkaline conditions.

5. Groundwater Impact Assessment

5.1 Overview

In engineering terms, the upstream PNG LNG Project involves the establishment of various infrastructure associated with producing and distributing gas, and the construction and operation of gas processing facilities. With regard to the potential for operation of the upstream Project facilities (both utility and off-site) to impact upon groundwater resources there are a number of specific activities of importance, including:

- Gas production and processing facilities.
- Product transfer pipeline network.
- Construction camps and administration facilities.

Figure 1.1 presents a schematic of the Project, and Figure 2.1 presents a locality plan. This report addresses the potentially contaminating activities associated with each of the above, and presents a qualitative assessment of the risk posed to groundwater and, because of likely enhanced interconnectivity, surface water resources.

5.2 Risk assessment methodology

The impact assessment takes the form of a qualitative assessment of the scale of risk posed to groundwater resources by potential groundwater affecting activities associated with the upstream components of the Project. The assessment considers the potential for mitigation of adverse effects provided by engineering design and the natural environment (eg. soil conditions and depth to groundwater).

Consistent with risk assessments undertaken elsewhere on similar projects, the basic aim is to provide a measure of the potential for a receptor to be adversely impacted by a particular threat (or potential groundwater affecting activity). *Risk* (R) is usually defined as the product of *likelihood* (L) and *consequence* (C), i.e. $R=LxC$, where:

- *likelihood* comprises an analysis of *threat level* (how severe is the potential threat) and *association* (how much influence can a particular threat have on a potential receptor based on mitigation strategies and physical environment); and
- *consequence* is a measure of the seriousness of impact if it occurs.

The following considerations underpin the risk assessment:

- the karst nature of the groundwater systems associated with the upstream Project area; and
- the potential for earthquake damage to Project infrastructure and subsequent release of contaminants to the environment.

Table 5.1 describes the four risk categories used for the impact assessment, and Appendix A presents further details as to how the risk assessment has been undertaken.

Table 5.1 Groundwater impact assessment risk categories

Risk categories	Description
A	**Serious potential for adverse impact** ▪ poses a serious risk to groundwater resource condition ▪ possibly difficult to mitigate against and remediate accidental release
B	**Moderate potential for adverse impact** ▪ poses a moderate risk to groundwater resource condition ▪ possibly problematic to mitigate against and remediate accidental release
C	**Low potential for adverse impact** ▪ poses a low risk to groundwater resource condition ▪ likely to be straightforward to mitigate against and remediate accidental release
D	**Adverse impact unlikely** ▪ does not pose a real risk to groundwater resource condition

5.3 Gas production wells

Overview

Gas production for feed to the PNG LNG Plant located on Portion 152 will involve development of the Hides, Angore and Juha gasfields, in addition to the blowdown of the gas cap at the Kutubu, Agogo/Moran and Gobe oilfields.

The drilling and construction of gas production wells, and the workover of existing wells, will be undertaken in a number of phases within an overall program that includes the tie-in of gas wells from the Kutubu and Angore oilfields, the tie-in of condensate pipelines, as well as gas gathering and conditioning facilities:

- Phase 1 / Drilling campaign 1 – six new wells and the workovers on two wells in the Hides gasfield, first production in year 1.
- Phase 2 / Drilling campaign 2 – two additional Hides wells and two Angore wells, first production in year 5.
- Phase 4 / Drilling campaign 3 – four Juha wells, first production in year 10.

Figure 1.1 presents a schematic of the Project showing the conceptual locations of the gas (and oil) production facilities, as well as associated infrastructure.

In some cases more than one gas production well will be drilled on a wellpad, which will typically be constructed on ridges. Water to assist in drilling operations will be sourced from the valleys below the ridges, either from water courses or aquifers, with delivery either by a pipeline laid on the ground surface or by water trucks.

Drilling operations will require the use of fluids (air or liquid) to condition drill holes and lift cuttings from the drill holes. In areas where lost circulation is a problem, for example through karst limestone, air and foam will typically be used, which may necessitate drilling ‘blind’ (i.e. no return of cuttings to the ground surface). Where hydratable shales are encountered beneath the limestone overburden drilling fluids of suitable density and chemical makeup will be required to stabilise the drill holes. The mud programs employed in these instances will consist of potassium chloride (KCl, salt), glycol, polymers and bentonite, depending on the type of formation drilled and chemical stabilisation required.

Drilling waste (cuttings, muds, produced water) will be managed in accordance with the approved *Waste Management Plan* for the Project. In particularly sensitive areas, such as Hides Ridge, cuttings and mud pit contents will be dried before removal and burial within lined pits at the Hides Gas Conditioning Plant. If drilling wastes are confirmed as 'clean' (i.e. non-contaminated) the opportunity of disposing of them to lost circulation zones within karst limestone terrain will be considered, but only where there is a lack of interconnectivity with surface water systems.

Potential groundwater contaminants associated with construction of gas production wells

A number of aspects of the drilling campaigns, and the construction and commissioning of gas production wells have the potential to release contaminants to the environment. Table 5.2 presents the most important of these.

Table 5.2 Potential contaminants associated with the drilling, construction and development of gas production wells

Natural	Introduced
Cuttings [1]	Salt (KCl)
Produced water [2]	Barites / bentonite [1]
Hydrocarbons [3]	Glycol

Notes:
1. Potentially containing elevated concentrations of heavy metals (e.g. lead) and hydrocarbons
2. During development and air drilling
3. From formation, reporting to mud pits or burn pits

Drill cuttings, produced water and muds will be contained in specially constructed pits at each wellpad.

Impact assessment

Seismic design criteria will be utilized in the design of facilities associated with gas production to prevent or minimise the risk of contaminant release to the environment in the event of a seismic event.

Table B.1 (Appendix B) presents a qualitative assessment of operational and residual (following Project decommissioning) risk posed to groundwater systems by the drilling, construction and development of gas production wells as a result of potential contaminant release to the environment, along with a brief description of the contaminant and its source, the possible frequency of 'contaminant' production, factors that will mitigate either the release of the contaminant or its' environmental impact once released, and a qualitative assessment of the scale of risk posed to groundwater resources by potential contaminant release (in consideration of the mitigating factors).

5.4 Gas and condensate transfer systems

Overview

An extensive pipeline network will deliver gas and liquid products between the gas production facilities and the ‘downstream’ PNG LNG Plant. The onshore Project Gas Pipeline will extend around 190 km from the Hides Gas Conditioning Plant to Omati River Landfall, from where it runs offshore through the Gulf of Papua to the PNG LNG Plant located on Portion 152.

The gathering systems for each wellpad in the respective gasfields will comprise a number of flowlines, a spineline and a mono-ethylene glycol (MEG) pipeline:

- Spinelines collect well fluids from flowlines at each wellpad for transport to the processing and/or conditioning facilities (e.g. the Hides Gas Conditioning Plant and Juha Production Facility).
- The MEG pipeline (termed the Hides-Juha MEG Pipeline) delivers MEG from the processing and/or conditioning facilities to the wellpads for injection into the spinelines. MEG prevents hydrate formation within the spinelines during product delivery to the processing and/or conditioning facilities. The MEG pipeline will be installed in the same trench as the spineline.

The Juha Gas Production Facility will deliver rich gas and liquids to Hides Gas Conditioning Plant via dedicated pipelines (termed the Juha-Hides Rich Gas Pipeline and Juha-Hides Liquids Pipeline, respectively). Gas pipelines from the Agogo, Kutubu and Gobe oilfields will connect to the PNG LNG Project Gas Pipeline to transfer gas to the PNG LNG Plant. A liquids pipeline from the Hides Gas Conditioning Plant will transfer stabilised condensate to existing oils storage and offloading facilities at the Kutubu Central Processing Facility.

Figure 1.1 presents a schematic of the Project showing the conceptual alignments of gas, condensate and oil pipelines, as well as associated infrastructure.

Potential groundwater contaminants associated with the gas and condensate transfer systems

Table 5.3 presents a list of primary constituents of feed gas arising from production wellpads that will be transferred via the PNG LNG Project Gas Pipeline network to gas processing and conditioning facilities, and the PNG LNG Plant on Portion 152. Whilst MEG forms part of the initial conditioning process it is included here as it will form a constituent of feed gas being transferred away from the wellpads.

The organic compounds comprising the feed gas are all volatile, meaning that their vapour pressures will result in significant volatization under normal conditions. As a consequence, these compounds are not considered as primary constituents of concern with regard to the potential to contaminate groundwater resources in the Project area. Although, some of the feed gas constituents do have the potential to contaminate groundwater if released to the environment in liquid form, particularly the heavier end organic compounds likely to be present within the gas stream, such as benzene, toluene and xylene (BTEX).

With the exception of mercury (Hg), the non-organic compounds listed in Table 5.3 do not form a primary source of potential contamination of the Project area's groundwater resources. For example:

- Water (H_2O) is a contaminant within the PNG LNG process but is not a direct potential environmental contaminant, other than the fact that water may form the solute for transfer of other contaminants (such as hydrocarbons and heavy metals) to the environment and (ultimately) groundwater.
- Carbon dioxide (CO_2), hydrogen sulphide (H_2S) and nitrogen (N_2) are also contaminants within the PNG LNG process but, being gases, are not considered as potential groundwater contaminants.

Table 5.3 Feed gas chemical constituents (design)

Organic compounds	Non-organic compounds
Gas stream from wells [1]	
Methane (87.89)	Water (0.01)
Ethane (6.75)	Carbon dioxide (0.49)
Butane (2.45)	Nitrogen (0.77)
i-Butane (0.51)	Hydrogen sulfide (0.0)
n-Butane (0.64)	Mercury (0.0)
i-Pentane (0.22)	
n-Pentane (0.16)	
Hexane (0.6)	
Heptane (0.03)	
Octane (0.01)	
Benzene (tbd)	
Toluene (tbd)	
Xylene (tbd)	
Introduced to gas stream at the wellpad	
MEG (tbd)	

Notes:
1. SKM, 2008
2. MOL% in ( )
3. tbd;' to be determined'

Hg is a heavy metal that may be present in the recovered gas stream. It can bio-accumulate and has the potential to contaminate groundwater resources if released to the environment. However, treatment of gas for the removal of Hg does not occur within the upstream components of the Project thereby mitigating its potential contaminant status.

MEG is not normally considered toxic to humans under normal industry conditions, and this is also likely to be the case for other fauna if the compound is released to the environment (Sabic, 2008).

Pipeline pigs are another activity that is directly associated with product transfer that have the potential to contaminate groundwater resources if not properly managed. All pipelines other than the MEG pipelines will be capable of running pigs.

Impact assessment

Seismic design criteria will be utilized in the design of facilities associated with product transfer systems to prevent or minimise the risk of contaminant release to the environment in the event of a seismic event.

Table B.2 (Appendix B) presents a qualitative assessment of operational and residual (following Project decommissioning) risk posed to groundwater systems by the gas and condensate transfer system as a result of potential contaminant release to the environment. The assessment of the scale of risk posed to groundwater resources by potential contaminant release (in consideration of the mitigating factors) follows the approach presented in Section 4.2.

5.5 Gas processing and conditioning facilities

Description

At the commencement of gas production, infrastructure necessary for the conditioning and processing of the gas stream will need to be brought on line in a number of phases:

- Phase 1 – Hides gathering system and Hides Gas Conditioning Plant, year 1.
- Phase 2 – Angore gathering system and expansion of the Hides gathering system, year 5.
- Phase 3 – inlet booster compression at the Hides Gas Conditioning Plant, year 6.
- Phase 4 – Juha gathering system and Juha Production Facility (Juha Gas Production Facility), year 10.
- Phase 5 – upgrades of Agogo Production Facility, Kutubu Central Processing Facility and tie-in of gas pipelines.

Figure 1.1 presents a schematic of the Project showing the conceptual locations of the gas processing and conditioning facilities.

The Hides Gas Conditioning Plant is required from year 1 to stabilise condensate to specified vapour pressures, and gas to an acceptable water and hydrocarbon dew point. Process systems at the Hides Gas Conditioning Plant will include:

- An inlet slug catcher.
- Gas and liquid separation.
- Condensate export system.

The Juha Gas Production Facility is required from around year 10 to separate gas and liquids from the Juha gasfield prior to gas transfer to the Hides Gas Conditioning Plant for further processing. To reduce the potential for corrosion of the compression and rich gas pipeline to the Hides Gas Conditioning Plant, CO_2 will be removed from the gas stream using tri-ethylene glycol (TEG). Other Juha Gas Production Facility process systems will include:

- Gas and liquid separation.
- Rich gas export compression.
- Liquid export system.

Additional gas processing facilities will not be required for the recovery of a gas stream from existing oilfield facilities, apart from managing the water and hydrocarbon dewpoint of gas within the pipelines and spinelines. In the event of Hides Gas Conditioning Plant shutdown, the gas stream from these existing facilities will be diverted for re-injection to the gas / oil reservoir. The Kutubu Central Processing Facility will store and export stabilised condensate from the Hides Gas Conditioning Plant to the Kumul Platform in the Gulf of Papua for offloading.

Other activities directly associated with the gas processing and conditioning facilities that have the potential to contaminate groundwater resources include the following:

- Hides Gas Conditioning Plant and JFP
  - Flare system.
    A high and low pressure flare system to provide for the safe disposal of hydrocarbon fluids from pressure safety valves (PSVs) and blowdown valves during process upsets.
  - Heating Medium system.
    The Hides Gas Conditioning Plant will incorporate a hot oil heating medium system.
  - MEG storage and regeneration system, and vent gas incinerator.
    The MEG system comprises flash drums, storage tanks, and injection and transfer pumps. MEG regeneration produces vent gas (mostly water, but also BTEX) which will be incinerated or released to the atmosphere in the event of incinerator shut-down.
  - Diesel storage and transfer system.
    Diesel is required to run essential power generators, fire pumps and mobile equipment. Diesel storage will be sufficient to provide 5-days supply.
  - Open drain system.
    The open drain system comprises a hazardous drain that collects stormwater, washdown and fire water from sealed and bunded areas within the hazardous parts of the Hides Gas Conditioning Plant, and a non-hazardous drain that collects liquids from non-hazardous areas. The drains will discharge to an open drain sump, which is fitted with a Corrugated

Plate Interceptor (CPI) to assist in oil-water separation prior to passing the treated water to the retention pond, which also collects stormwater from other parts of the Plant. Water will be discharged off-site from the retention pond in accordance with permit requirements and conditions.

  - Closed drain system.
    The closed drain system will collect fluids that are manually released from Plant systems for disposal to a flare drum prior to transfer, along with used lube oils, to inlet separators.
  - Gas dehydration system.
    A TEG contactor and regeneration package will be used to mitigate materials issues associated with wet gas. Condensed water from the JFP will be disposed to the Hides Gas Conditioning Plant MEG incinerator.
  - Liquids export.
    Liquids from the inlet separator will be transferred from JFP to Hides Gas Conditioning Plant via a dedicated liquids pipeline.
- Oilfield tie-ins gas dehydration system, which will require TEG system upgrades.
- Wellpads
  - Each of the dedicated gas production facility wellpads (Hides, Angore and Juha) will be equipped with MEG and corrosion inhibitor injection facilities, and serviced by an open drain sump.
- Demineralised Water system
  A demineralised water system will possibly be required for the gas turbines (e.g. for washing of blades) depending on in-situ groundwater quality, and will incorporate a reverse osmosis unit and a demineraliser unit, as well as a water storage tank.

The utility water system will source water from a small wellfield, with wells fitted with electro-submersible pumps , for use in the Hides Gas Conditioning Plant facility (e.g. for potable, fire and truckwash purposes). Bottled water will be used at JFP.

Potential groundwater contaminants associated with gas production and processing

Seismic design criteria will be utilized in the design of facilities associated with gas processing and conditioning systems to prevent or minimise the risk of contaminant release to the environment in the event of a seismic event.

Table 5.3 presents a list of primary constituents of feed gas arising from production wellpads that will be transferred via the PNG LNG Project Gas Pipeline network to gas processing and conditioning facilities, and the PNG LNG Plant on Portion 152. MEG, which is not normally considered toxic to humans under normal industry conditions, will be regenerated at the upstream process facilities and pumped back to the injection points, and so will not be a constituent of the feed gas stream delivered to the PNG LNG Plant. In addition:

- TEG presents an acute toxicity hazard to humans, but terrestrial fauna show lower levels of toxicity to the compound. Aquatic fauna and the potential for bioaccumulation has not been determined (Huntsman, 2008).
- As discussed in Section 4.2, some of the organic compounds that may be present in the gas stream (such as BTEX) present a potential groundwater contaminant source if released to the environment in liquid form.
- Hydrocarbon residues may collect within burn pits from where release to the environment may occur.
- The hot oil medium is hydrocarbon-based and may be toxic to humans and fauna (Oxford University, 2008).

Table 5.4 presents a list of potential contaminants that may arise from operation of the upstream utility systems associated with the conditioning and processing of gas.

Table 5.4 Potential contaminants associated with gas conditioning and processing utilities

Hydrocarbons (from Hot Oil, Fuel Gas systems, flares / burn pits, and pig launching / receiving)	**Hydrocarbons** (from Effluent, Flare and Vent, Drain, Storm Water & Diesel Storage and Delivery systems)
Hydrocarbons (from condensate pipelines)	**Hazardous and dangerous chemicals** (from Effluent, Drain & Storm Water systems)
MEG and TEG systems (between Juha Gas Production Facility-Hides Gas Conditioning Plant and Hides Gas Conditioning Plant-wellpads)	**Brine** (from Demineralised Water system)

In addition to the potential for groundwater contamination, there is the potential for groundwater drawdowns associated with groundwater supply development to impact on continued water access by existing users, including humans and environment. Operating production wells have the potential to 'interfere' with neighbouring wells causing lower pumping water levels which might impair the ability of other groundwater users to pump groundwater. In addition production wells have the potential to reduce groundwater discharge to aquatic ecosystems.

Impact assessment

Table B.3 (Appendix B) presents a qualitative assessment of operational and residual (following Project decommissioning) risk posed to groundwater systems by the gas processing and conditioning facilities as a result of potential contaminant release to the environment. The assessment of the scale of risk posed to groundwater resources by potential contaminant release (in consideration of the mitigating factors) follows the approach presented in Section 4.2.

5.6 Associated infrastructure

Description

In addition to the pipeline network, a variety of support (offsite) infrastructure is required for the upstream Project. Infrastructure types include:

- A network of access tracks and roads.
- Bridges.
- Airfields and helipads.
- Wharf facilities.
- Telecommunication facilities.
- Waste disposal sites.
- Permanent and temporary contractor camps.
- Industrial Parks and laydowns.

Apart from the storage and distribution of fuels, oils, and other hazardous and dangerous goods associated with Project transport / construction / operation / maintenance, the operation of personnel camps and administration facilities involve activities having the potential to contaminate groundwater resources, e.g. sewage treatment, incinerators and landfills. Industrial Parks and laydown areas may also be a source of potential ground water contaminants, such as heavy metals and hydrocarbons.

It is also possible that potable and camp water supplies may be drawn from shallow (karst or fluvial) aquifers underlying the different facilities.

Potential groundwater contaminants associated with temporary and permanent infrastructure

Table 5.5 presents a list of potential contaminants that may arise from operation of offsite systems.

Table 5.5 Potential contaminants associated with offsite systems

Hydrocarbons (from Fuel Storage and Distribution, Stormwater and Wastewater systems)	**Putrescible wastes** (from Camp Landfills)
Brine (from possible Water Treatment system)	**Hazardous and dangerous chemicals** (from Effluent, Drain & Stormwater systems)
Biological and Pharmaceutical (from Sewage system)	**Heavy metals** (from Industrial Parks)

In addition to the potential for groundwater contamination, there is the potential for groundwater drawdowns associated with groundwater supply development to impact on continued water access by existing users, including humans and environment.

Impact assessment

Seismic design criteria will be utilized in the design of facilities associated with offsite systems to prevent or minimise the risk of contaminant release to the environment in the event of a seismic event.

Table B.4 (Appendix B) presents a qualitative assessment of operational and residual (following Project decommissioning) risk posed to groundwater systems by the offsite support facilities and activities as a result of potential contaminant release to the environment. The assessment of the scale of risk posed to groundwater resources by potential contaminant release (in consideration of the mitigating factors) follows the approach presented in Section 4.2.

6. Conclusions and recommendations

6.1 Conclusions

6.1.1 General

The issues of most importance in respect to the upstream Project's potential to cause adverse impact to groundwater resources are associated with seismic events (the potential to cause leaks and failure of containment systems such as pipelines, product and fuel storage tanks, and mud pits) and the predominantly karst nature of the groundwater systems (potential contaminants will be highly mobile in the environment and there is likely strong interconnectivity with surface water resources). Consequently, engineering design will play a large role in reducing the threat associated with these aspects of the physical environment within which the Project will be constructed and operated. To this end, the ExxonMobil Engineering Practices System (EMEPS) will serve as the basis for Project Design Specifications (PDS), and ExxonMobil Development Company (EMDC) guidelines and environmental standards will be applied to the Project as appropriate.

Where there is an accidental uncontrolled release of contaminants that has the potential to impact on groundwater resource condition, karst aquifer conditions mean that it will possibly be difficult to remediate the groundwater system prior to environmental and third party receptors becoming exposed to contaminants. Consequently, a strong focus on engineered controls will need to feature in all design work.

Alternatively, the expected relatively high transmissivity of the karst aquifers and high rainfall mean that dilution potential for contaminants along the groundwater discharge flowpath may be significant, and serve to mitigate against adverse environmental affects.

Many of the constituents of the gas stream are volatile organic compounds, although condensate will be generated at the Hides Gas Conditioning Plant. Under normal conditions (temperature, wind etc.) these volatile compounds when released to the environment will volatilise, thereby greatly reducing their potential for contaminating groundwater resources in the upstream Project area. However, in liquid form some of the gas constituents (BTEX compounds in particular) may pose a risk of groundwater contamination if released to the environment. Other materials associated with the conditioning and transfer of product and offsite activities also have the potential to contaminate groundwater, e.g. oily waste water, brines, heavy metals and hydrocarbon residues.

Groundwater supply potential from the (expected) widely occurring karst aquifers of the upstream Project area is considered prospective, but on-ground investigations would be required to confirm this.

6.1.2 Operational impact assessment

Groundwater resources form a viable water resource to support upstream Project activities and processes. However, the need to confirm available yields (vs demand) and undertake some form of treatment prior to certain uses (such as turbine wash and potable camp supplies) needs to be considered at the earliest.

To mitigate against release of potential groundwater contaminants to the environment and impacts associated with groundwater supply development, it will be important for Esso to apply international best practice engineering design and management principals in all parts of the Project (including utility and offsite components). This will need to be underpinned by an understanding of Project area conditions, adherence to appropriate codes and standards, and implementation of quality assurance procedures and protocols.

A number of aspects of the upstream Project present a moderate to serious risk of impacting adversely on groundwater resources if engineered controls are not implemented in design, including:

- Condensate pipeline and storage tank failure has the potential to release large volumes of hydrocarbons to the environment (serious risk).
- MEG and TEG system failure has the potential to release potentially toxic glycol compounds to the environment, but the potential to impact adversely on human health or aquatic ecosystems is unknown (moderate risk).
- Fuel storage and distribution system failure has the potential to also release large volumes of hydrocarbons, but engineered solutions (e.g. bunds) will mitigate against release to the environment (moderate risk).

A number of other aspects of the Project present a low risk of impacting adversely on groundwater resources, including:

- Gas production facilities (drilling, construction and development).
- Flares and vent systems
- Dehydration units.
- Demineralised water systems.
- Effluent disposal system (non-hazardous and hazardous waste containment).
- Drain systems (hydrocarbon effluent release).
- Storm water system (hydrocarbon effluent release).
- CPI oil sump (hydrocarbon effluent release).
- Groundwater supply development.
- Industrial parks.

6.1.3 Residual impact assessment

Decommissioning of the Project facilities will reduce the risk of adverse impact to upstream Project area groundwater resources by removing contaminant sources and cessation of groundwater supply (if developed).

With the exception of the condensate storage tanks and transfer system, all of the former site facilities are unlikely to continue to contribute any residual risk to groundwater resources. Depending on the performance of the condensate storage and transfer system during operation of the Project (i.e. whether there have been contaminant releases or not and, if so, the results of cleanup efforts), there is low potential for ongoing adverse impact to groundwater resources following Project decommissioning.

6.2 Recommendations

To mitigate against release of potential groundwater contaminants to the environment and impacts associated with groundwater supply development, it will be important for the operators to apply good practice engineering design and management principals in all parts of the upstream Project, including gas production, conditioning, storage and transfer, as well as support operations (such as camp facilities and industrial parks). This will need to be underpinned by an understanding of site conditions, adherence to appropriate codes and standards, and implementation of quality assurance procedures and protocols. In particular:

a) an environmental management plan (EMP) should be prepared for the Project and, based on expected enhanced groundwater – surface water interactions, consideration should be given to the development of a specific groundwater management plan (GMP) that outlines management strategies / contingencies and responsibilities should contaminant events occur and identifies nearby and downstream groundwater users (environmental and human) that need to be considered in design;
b) the installation of below ground liquid product (or waste) storage vessels and delivery systems should be avoided;
c) suitable containment bunding be provided for all components of the Project plant where hazardous or dangerous goods are stored or used; and
d) spill response plans should be developed for the Project and personnel involved in operating and maintaining the different components of the Project should receive adequate training in the implementation of the plans.

An appropriately designed groundwater monitoring network should be installed within and downstream of infrastructure forming potential contaminant sources (eg. condensate storage tanks, fuel storage facilities, and MEG and TEG storage facilities). The monitoring network will provide early warning of any potential groundwater contaminant events and allow implementation of remedial works prior to contaminants migrating and impacting on offsite receptors. Operation of the monitoring network should include:

a) collection of baseline data prior to commencement of construction (if possible) and commissioning;
b) inclusion in the GMP schedules that identify the timing of monitoring events, the parameters to be monitored for (eg. groundwater levels and salinity, hydrocarbons and metals), and sample collection, preservation and chain-of-custody protocols; and
c) data evaluation and reporting procedures.

Water supply wellfield design will need to consider the influence of wellfield operation on neighbouring users of the resource.

A number of mitigation strategies are proposed to assist the operators in addressing issues associated with the Project that have the potential to impact on groundwater resource condition (water quality as well as water availability for ecosystems and existing users). The following lists suggested mitigation measures for the Project:

Issue	Recommended mitigation measure
Heavy metal contamination from bentonite/barites-based drilling fluids (gas production well)	▪ Drilling fluids and additives to be sourced from reputable suppliers.
Hydrocarbon contamination from well development and work-overs	▪ Well development waters will be captured within mud pits and make-up water pits or similar. Where warranted alternative methods of disposal can be implemented, e.g. via reinjection. ▪ Wastewater streams associated with drilling, such as water-based, non-toxic whole drilling fluids and completion drilling fluids, will be discharged in accordance with permit requirements. ▪ Combustible wastes will be incinerated at Project-specified sites.
Groundwater drawdown and salinisation of aquifers as a result of groundwater supply development	▪ Water supply wells utilised temporarily. ▪ Likely high permeability and recharge reduces potential for impact to be extensive.
Hydrocarbon contamination of water from process	▪ Flowline pigging - effluent collected in bunded area, stabilised and disposed of by licensed third parties. ▪ Dehydration unit - recovered water treated in waste water system or flared. ▪ Flare and vent systems - waste gases and liquid hydrocarbons flared and other wastes fully incinerated in purpose built facility.
Contamination from effluents (i.e. stormwater and oily wastes)	▪ Effluents treated to appropriate standard and disposed of to combined outfall. For example stormwater and oily wastes treated in CPI facility to appropriate standard prior to disposal in retention pond, in addition sufficient time is allowed for sediment and solids to settle within the pond prior to final offsite discharge in accordance with waste discharge permit.
Heavy fraction hydrocarbon contamination from heating medium system	▪ Interception and treatment of runoff potentially containing hydrocarbons.

Issue	Recommended mitigation measure
Hydrocarbon contamination (diesel storage and distribution system)	▪ Diesel storage system will be purpose-built, above ground and within double-walled tanks or containment bunds. Oil spill prevention and response plans will be in place.
Hydrocarbon contamination due to condensate release (gas and condensate storage tanks and product transfer system)	▪ MEG slop storage tanks will be purpose-built full-containment tanks and bunded. ▪ Waste gases and liquid hydrocarbons flared and other wastes fully incinerated in purpose built facilities. ▪ Hydrocarbon spill prevention and response plan will be in place.
Biological and pharmaceutical contamination from office and camp facilities (sanitary sewage system)	▪ Biological, pharmaceutical and medical wastes will be treated and disposed of using appropriate technologies, which will be detailed in the environmental management plan. ▪ Sewage treatment plants will be operated in accordance with the manufacturer's specifications and will comply with the conditions for discharge quality (including disinfection) specified in the relevant waste discharge permits.
Stormwater and wastewater discharges	▪ All water and wastewater discharges will be treated to comply with conditions for discharge quality specified in the relevant water discharge permits. ▪ All bunded open drain areas at facility sites will be concreted, kerbed and sloped to drain catchpits. The catchpits will feed to interception pits for separation of oil and water. The de-oiled water will be transferred to retention ponds for treatment as appropriate prior to disposal in accordance with the waste discharge permit. Waste oil that is collected from the interception pits and other facility sumps will be recycled by reinjection into the condensate being sent to the Kutubu Central Processing Facility where practicable. ▪ Non-equipment areas at plant facilities will be graded and sloped to allow uncontaminated storm water to drain naturally via the stormwater drains prior to routing offsite.

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Limitation statement

The sole purpose of this report and the associated services performed by Sinclair Knight Merz (SKM) is to provide an assessment of groundwater impacts that may arise as a result of development of the Project, in accordance with the scope of services set out in the contract between SKM and *Coffey Natural Systems* ('the Client'). That scope of services was defined by the Client.

SKM derived the data in this report primarily from that provided by the Client. The passage of time, manifestation of latent conditions or impacts of future events may require further exploration at the site and subsequent data analysis, and re-evaluation of the findings, observations and conclusions expressed in this report.

In preparing this report, SKM has relied upon, and presumed accurate, certain information (or absence thereof) relative to the information provided by the Client. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information.

The findings, observations and conclusions expressed by SKM in this report are not, and should not be considered, an opinion concerning the quality of the Project system design. No warranty or guarantee, whether express or implied, is made with respect to the data reported or to the findings, observations and conclusions expressed in this report. Further, such data, findings, observations and conclusions are based solely upon information and drawings supplied by the Client, and information available in the public domain in existence at the time of the investigation.

This report has been prepared on behalf of and for the exclusive use of the Client and Esso Highlands, and is subject to and issued in connection with the provisions of the agreement between SKM and the Client. SKM accepts no liability or responsibility whatsoever for or in respect of any use of or reliance upon this report by any third party.

APPENDIX A
RISK ANALYSIS DESCRIPTION

Risk assessment methodology

The impact assessment takes the form of a qualitative assessment of the scale of risk posed to groundwater resources by potential groundwater affecting activities associated with the LNG facility and water supply development.

Consistent with risk assessments undertaken elsewhere on similar types of projects, the basic aim is to provide a measure of the potential for a receptor to be adversely impacted by a particular threat (or potential groundwater affecting activity).

Risk (R) is usually defined as the product of likelihood (L) and consequence (C), i.e. R=LxC, where:

- likelihood comprises an analysis of threat level (how severe is the potential threat) and association (how much influence can a particular threat have on a potential receptor based on mitigation strategies and physical environment); and
- consequence is a measure of the seriousness of impact if it occurs, in the case of the project, the level of effort that is likely required to manage impacts and remediate.

	L	*C*
1	unlikely	routine
2	low	moderate
3	moderate	problematic
4	serious	difficult

	R	
A	(L xC ranges above 7.5)	high potential for adverse impact
B	(L xC ranges between 5 and 7.5)	moderate potential for adverse impact
C	(L xC ranges between 2.5 and 5)	low potential for adverse impact
D	(L xC ranges below 2.5)	adverse impact unlikely

APPENDIX B
TABULATED RESULTS OF RISK ANALYSIS

Table B.1 Analysis of potential for adverse groundwater impact arising from the drilling, construction and testing of Project gas production wells, and water supply development [1]

Facility	Potential impact	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for contamination						
Gas production well	KCl	Salt-based drilling fluids	Once	Salt based muds to be used in shale sequences where mud losses are expected to be minimal. Demudding of holes will occur to specially constructed and contained mud pits.	**C**	**D**
	Heavy metals	Bentonite/barites-based drilling fluids	Once	Drilling fluids and additives to be sourced from reputable suppliers.	**D**	**D**
	Hydrocarbons	Well development and work-overs	Infrequent	Well development waters will be captured within mud pits and make-up water pits. Where warranted alternative methods of disposal can be implemented, e.g. via re-injection. Wastewater streams associated with drilling, such as water-based, non-toxic whole drilling fluids and completion drilling fluids, will be discharged in accordance with permit requirements. Combustible wastes will be incinerated at Project-specified sites.	**C**	**D**

Table B.1 Analysis of potential for adverse groundwater impact arising from the drilling, construction and testing of Project gas production wells, and water supply development [1] (cont.)

Facility	Potential impact	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for reduced water access by existing users (including environment)						
Water supply	Groundwater drawdown due to pumping	Access to groundwater by existing users removed	Infrequent	Water supply wells utilised temporarily. Likely high permeability and recharge reduces potential for impact to be extensive.	**C**	**D**
	Salinisation due to drawing poor quality groundwater into aquifer	Beneficial use of groundwater impaired				

Notes:
1. Engineering design to consider risk posed to facilities by seismic events. Risk analysis recognises contaminant transport potential via groundwater as a result of karst conditions and likely enhanced groundwater-surface water interaction.
2. During project life.
3. Following project decommissioning.

Table B.2 Analysis of potential for adverse groundwater impact arising from the transfer of upstream Project product (gas and condensate) [1]

Facility	Potential contaminant	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for contamination						
Pipelines	Hydrocarbons	Condensate transfer, potential large volumes	Infrequent	Pipelines will be purpose built and engineered and operated to meet appropriate guidelines and standards. Product spill prevention and response plans are in place	**A**	**C**
	Hg	Gas transfer	Infrequent	Hg recovery is not undertaken within upstream components of the Project.	**D**	**D**
Flare and Vent systems	Hydrocarbons	Gas conditioning and storage wastes	Continuous	Waste gases and liquid hydrocarbons flared and other wastes fully incinerated in purpose built facilities.	**D**	**D**
MEG and TEG pipelines and associated facilities	Ethylene glycol compounds	Gas conditioning within pipelines	Infrequent	Pipelines will be purpose built and engineered and operated to meet appropriate guidelines and standards. Product spill prevention and response plans are in place	**B**	**D**

Table B.3 Analysis of potential for adverse groundwater impact arising from the processing and conditioning of upstream Project gas stream [1]

Facility	Potential impact	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for contamination						
Gas Separators, and wellpads	Hydrocarbon contaminated process water	Effluent from flowline pigging	Intermittent	Effluent collected in bunded area, stabilised and disposed of by licensed third parties.	**C**	**D**
Heating Medium system	Heavy fraction hydrocarbons	Heavy hydrocarbon release	Continuous	Hot oil held within closed process. Accidental contaminant release will occur to paved and drained catchment.	**D**	**D**
Dehydration unit	Hydrocarbon contaminated process water	Water recovered from dried gas stream	Continuous	Recovered water treated in waste water system or flared.	**C**	**D**
Demineralised Water system	Brine	RO reject water	Intermittent	Generation of a substantial brine stream unlikely due to expected good groundwater quality. Brine collected within process for appropriate disposal.	**C**	**D**
Effluent Disposal system	Non-hazardous putrescibles and non-putrescibles	Office and camp wastes	Intermittent	Wastes are to be treated to appropriate standard and disposed of in accordance with best practice.	**C**	**D**
	Hazardous materials and chemical wastes, hydrocarbon effluent	Gas conditioning and process wastes				

Table B.3 Analysis of potential for adverse groundwater impact arising from the processing and conditioning of upstream Project gas stream [1] (cont.)

Facility	Potential impact	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for contamination (cont.)						
Flare and Vent systems	Hydrocarbons	Gas conditioning and process, and storage wastes	Continuous	Waste gases and liquid hydrocarbons flared and other wastes fully incinerated in purpose built facility.	**D**	**D**
Drain systems	Sediment	Gas conditioning and process effluent collection	Intermittent	Effluents treated to appropriate standard and disposed of to combined outfall.	**D**	**D**
	Hydrocarbon effluent	Gas conditioning and process effluent collection			**C**	**D**
Storm Water system	Suspended solids and sediment	Unpaved areas	Intermittent	Oily wastes treated in CPI facility to appropriate standard prior to disposal to retention pond for final offsite discharge.	**D**	**D**
	Hydrocarbon effluent	Paved areas			**C**	**D**
CPI Oil Sump	Hydrocarbon contaminated effluent	Oil and water separation	Intermittent	Separated oil contained on site, water treated to appropriate standard prior to disposal to retention pond for final offsite discharge.	**C**	**D**
Diesel Storage and Distribution system	Hydrocarbons	Hydrocarbon release	Continuous	Diesel storage system will be purpose built, above ground and within containment bunds. Oil spill prevention and response plans are in place.	**B**	**D**

Table B.3 Analysis of potential for adverse groundwater impact arising from the processing and conditioning of upstream Project gas stream [1] (cont.)

Facility	Potential impact	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for contamination (cont.)						
Gas and condensate storage tanks, and product transfer system	Hydrocarbons	Condensate release	Infrequent	Product storage tanks will be purpose built full containment tanks. Condensate tanks will also be purpose built and bunded. Oil spill prevention and response plan is in place.	**A**	**C**

Notes:

1. Engineering design to consider risk posed to facilities by seismic events. Risk analysis recognises contaminant transport potential via groundwater as a result of karst conditions and likely enhanced groundwater-surface water interaction.
2. During project life.
3. Following project decommissioning.

Table B.4 Analysis of potential for adverse groundwater impact arising from upstream Project offsite facilities and activities [1]

Facility	Potential contaminant	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for contamination						
Sanitary Sewage system	Biological and pharmaceutical	Office and camp facilities	Continuous	Wastes treated using latest bio-technologies prior to disposal at combined outfall. Medical wastes to be excluded from sewage system.	**C**	**D**
Effluent Disposal system	Non-hazardous putrescibles and non-putrescibles	Office and camp wastes	Intermittent	Wastes are to be treated to appropriate standard and disposed of in accordance with best practice.	**C**	**D**
	Hazardous materials and chemical wastes, hydrocarbon effluent	Industrial Parks				
Drain systems	Sediment	Offsite effluent collection	Intermittent	Effluents treated to appropriate standard and disposed of to combined outfall.	**D**	**D**
	Hydrocarbon effluent	Offsite effluent collection			**C**	**D**
Storm Water system	Suspended solids and sediment	Unpaved areas	Intermittent	Oily wastes treated in CPI facility to appropriate standard prior to disposal to retention pond for final offsite discharge.	**D**	**D**
	Hydrocarbon effluent	Paved areas			**C**	**D**

Table B.4 Analysis of potential for adverse groundwater impact arising from upstream Project offsite facilities and activities [1] (cont.)

Facility	Potential contaminant	Source description	Frequency of release	Suggested mitigation of contamination [1]	Operational risk [2]	Residual risk [3]
Potential for contamination (cont.)						
CPI Oil Sump	Hydrocarbon contaminated effluent	Oil and water separation	Intermittent	Separated oil contained on site, water treated to appropriate standard prior to disposal to retention pond for final offsite discharge.	**C**	**D**
Fuel Storage and Distribution system	Hydrocarbons	Hydrocarbon release	Continuous	Diesel storage system will be purpose built, above ground and within containment bunds. Oil spill prevention and response plans are in place.	**B**	**D**
Industrial parks	Various (hydrocarbons, hazardous materials and heavy metals	Storage compounds	Continuous	Industrial parks will have a composite of potential contaminant sources associated with construction, operation and maintenance activities. Hazardous materials stored in purpose built areas, bunded where necessary and with spill response plans.	**C**	**D**
Potential for reduced water access by existing users (including environment)						
Water supply	Groundwater drawdown due to pumping	Access to groundwater by existing users removed	Infrequent	Water supply wells utilised whilst construction (temporary) or permanent camp/administrative facilities exist. Demand will be variable between facilities, but will be in the order of 200 to 400 L/person/day. Likely high permeability and recharge reduces potential for impact to be extensive.	**C**	**D**
	Salinisation due to drawing poor quality groundwater into aquifer	Beneficial use of groundwater impaired				

Notes:
1. Engineering design to consider risk posed to facilities by seismic events. Risk analysis recognises contaminant transport potential via groundwater as a result of karst conditions and likely enhanced groundwater-surface water interaction.
2. During project life.
3. Following project decommissioning..

APPENDIX C
RISK SPREADSHEETS

Likelihood analysis

☐ Likelihood comprises an analysis of threat level (T; i.e. how severe is the potential threat) and association (A; i.e. how much influence can a particular threat have on a potential receptor based on mitigation strategies and physical environment)

L=TxA

Upstream project facilities (operational risk)

Gas production wells (muds/develop't)

	Muds (KCl)	Muds (metals)	Work overs
THREAT to groundwater resource condition	2	1	2
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	2	1	2
CONSEQUENCE (management effort)	2	1	2
Risk category	C	D	C

Gas production wells (water supply)

	Drawdown	Salinisation
THREAT to groundwater resource condition	1	1
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	1	1
CONSEQUENCE (management effort)	1	1
Risk category	D	D

Product transfer system

	Condensate	Gas
THREAT to groundwater resource condition	2	1
ASSOCIATION (mitigation potential)	2	1
LIKELIHOOD of affect	4	1
CONSEQUENCE (management effort)	3	1
Risk category	A	D

Product transfer system

	Flares & vents	MEG & TEG
THREAT to groundwater resource condition	1	2
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	1	2
CONSEQUENCE (management effort)	2	3
Risk category	D	B

Processing & conditioning

	Separators/well pads	Heating system	Dehydration
THREAT to groundwater resource condition	2	2	2
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	2	2	2
CONSEQUENCE (management effort)	2	1	2
Risk category	C	D	C

Processing & conditioning

	Demineralised water	Effluent disposal
THREAT to groundwater resource condition	2	2
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	2	2
CONSEQUENCE (management effort)	2	2
Risk category	C	C

Likelihood analysis

- Likelihood comprises an analysis of threat level (T; i.e. how severe is the potential threat) and association (A; i.e. how much influence can a particular threat have on a potential receptor based on mitigation strategies and physical environment)

L=TxA

Upstream project facilities (operational risk)

Processing & conditioning	Drains (sediment)	Drains (hydrocarbons)	Storm water
THREAT to groundwater resource condition	1	2	2
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	1	2	2
CONSEQUENCE (management effort)	2	2	2
Risk category	D	C	C

Processing & conditioning	CPI	Diesel storage
THREAT to groundwater resource condition	2	2
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	2	2
CONSEQUENCE (management effort)	2	3
Risk category	C	B

Processing & conditioning	Condensate	Water supply
THREAT to groundwater resource condition	2	1
ASSOCIATION (mitigation potential)	2	1
LIKELIHOOD of affect	4	1
CONSEQUENCE (management effort)	3	1
Risk category	A	D

Offsite	Sewage	Effluent disposal	Drains (hydrocarbons)
THREAT to groundwater resource condition	2	2	2
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	2	2	2
CONSEQUENCE (management effort)	2	2	2
Risk category	C	C	C

Offsite	Storm water	CPI	Diesel storage
THREAT to groundwater resource condition	2	2	2
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	2	2	2
CONSEQUENCE (management effort)	2	2	3
Risk category	C	C	B

Offsite	Water supply	Industrial Parks
THREAT to groundwater resource condition	1	2
ASSOCIATION (mitigation potential)	2	1
LIKELIHOOD of affect	2	2
CONSEQUENCE (management effort)	1	2
Risk category	D	C

Likelihood analysis

☐ Likelihood comprises an analysis of threat level (T; i.e. how severe is the potential threat) and association (A; i.e. how much influence can a particular threat have on a potential receptor based on mitigation strategies and physical environment)

L=TxA

Upstream project facilities (residual risk)

Gas production wells (muds/develop't)	Muds (KCl)	Muds (metals)	Work overs
THREAT to groundwater resource condition	1	1	1
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	1	1	1
CONSEQUENCE (management effort)	2	1	2
Risk category	D	D	D

Gas production wells (water supply)	Drawdown	Salinisation
THREAT to groundwater resource condition	1	1
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	1	1
CONSEQUENCE (management effort)	1	1
Risk category	D	D

Product transfer system	Condensate	Gas
THREAT to groundwater resource condition	2	1
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	2	1
CONSEQUENCE (management effort)	2	1
Risk category	C	D

Product transfer system	Flares & vents	MEG & TEG
THREAT to groundwater resource condition	1	1
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	1	1
CONSEQUENCE (management effort)	1	2
Risk category	D	D

Processing & conditioning	Separators/well pads	Heating system	Dehydration
THREAT to groundwater resource condition	1	1	1
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	1	1	1
CONSEQUENCE (management effort)	2	2	2
Risk category	D	D	D

Processing & conditioning	Demineralised water	Effluent disposal	Flares & vents
THREAT to groundwater resource condition	1	2	1
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	1	2	1
CONSEQUENCE (management effort)	1	1	1
Risk category	D	D	D

Likelihood analysis

☐ Likelihood comprises an analysis of threat level (T; i.e. how severe is the potential threat) and association (A; i.e. how much influence can a particular threat have on a potential receptor based on mitigation strategies and physical environment)

L=TxA

Upstream project facilities (residual risk)

Processing & conditioning	Drains (sediment)	Drains (hydrocarbons)	Storm water
THREAT to groundwater resource condition	1	1	1
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	1	1	1
CONSEQUENCE (management effort)	1	2	1
Risk category	D	D	D

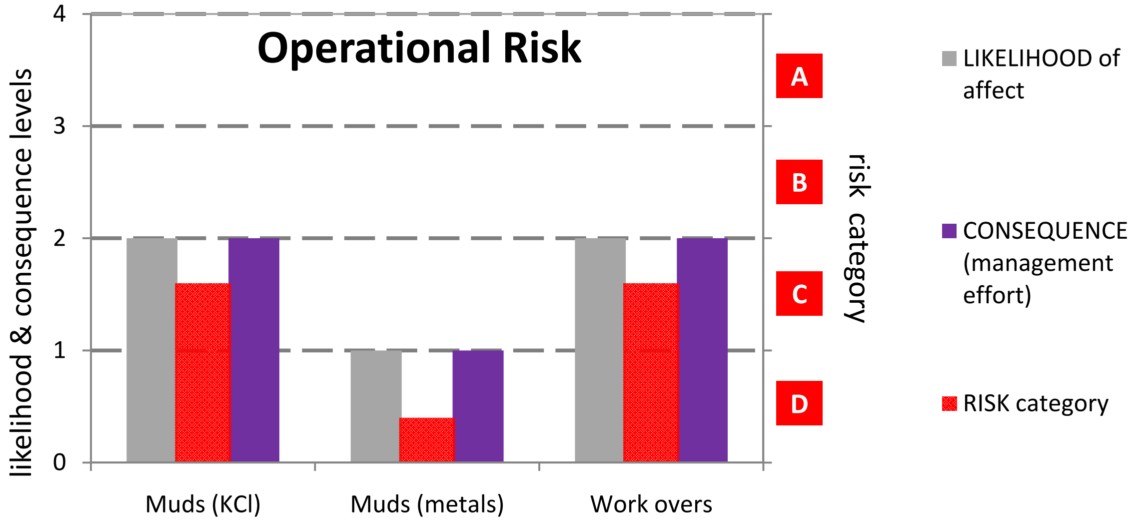
Processing & conditioning	CPI	Diesel storage
THREAT to groundwater resource condition	1	1
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	1	1
CONSEQUENCE (management effort)	1	2
Risk category	D	D

Processing & conditioning	**Condensate**	Water supply
THREAT to groundwater resource condition	2	1
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	2	1
CONSEQUENCE (management effort)	2	1
Risk category	C	D

Offsite	Sewage	Effluent disposal	Drains (hydrocarbons)
THREAT to groundwater resource condition	2	2	1
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	2	2	1
CONSEQUENCE (management effort)	1	1	2
Risk category	D	D	D

Offsite	Storm water	CPI	Diesel storage
THREAT to groundwater resource condition	1	1	1
ASSOCIATION (mitigation potential)	1	1	1
LIKELIHOOD of affect	1	1	1
CONSEQUENCE (management effort)	1	1	2
Risk category	D	D	D

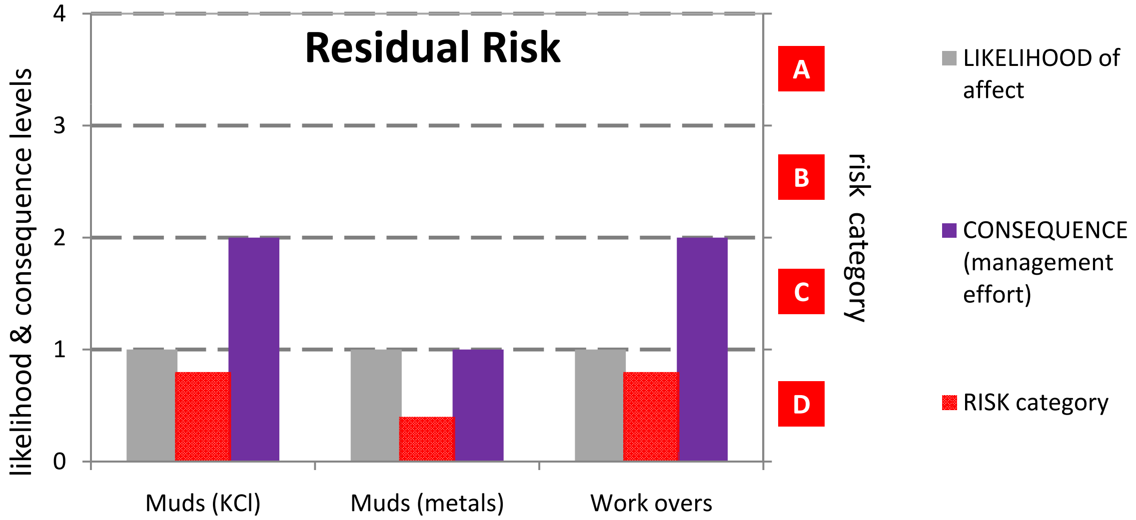
Offsite	Water supply	Industrial Parks
THREAT to groundwater resource condition	1	1
ASSOCIATION (mitigation potential)	1	1
LIKELIHOOD of affect	1	1
CONSEQUENCE (management effort)	1	2
Risk category	D	D



Drilling fluids: *KCl-based mud program - contained with mud pits*

Drilling fluids: *metals contaminated barites/bentonite mud program - not utilised*

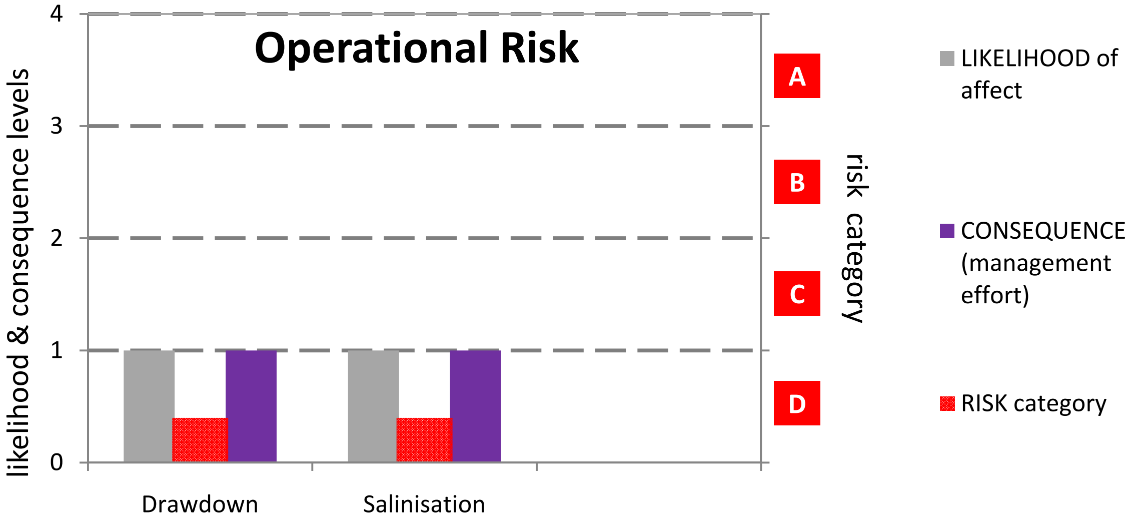
Work overs & development: *hydrocarbons produced - development and work over fluids contained within mud pits and make-up water pits*



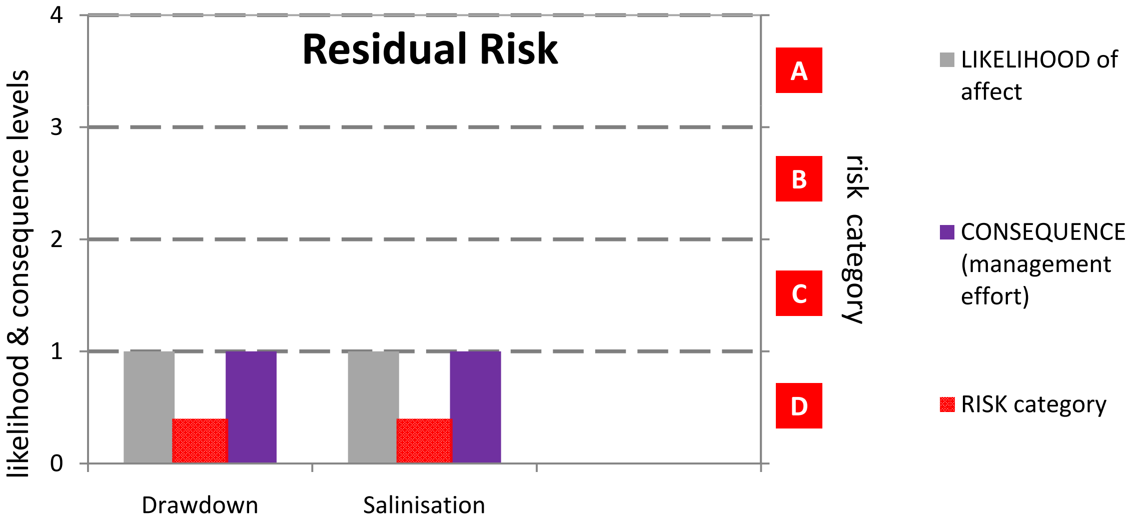
Drilling fluids: *KCl-based mud program - mud pits rehabilitated*

Drilling fluids: *metals contaminated barites/bentonite mud program - not utilised*

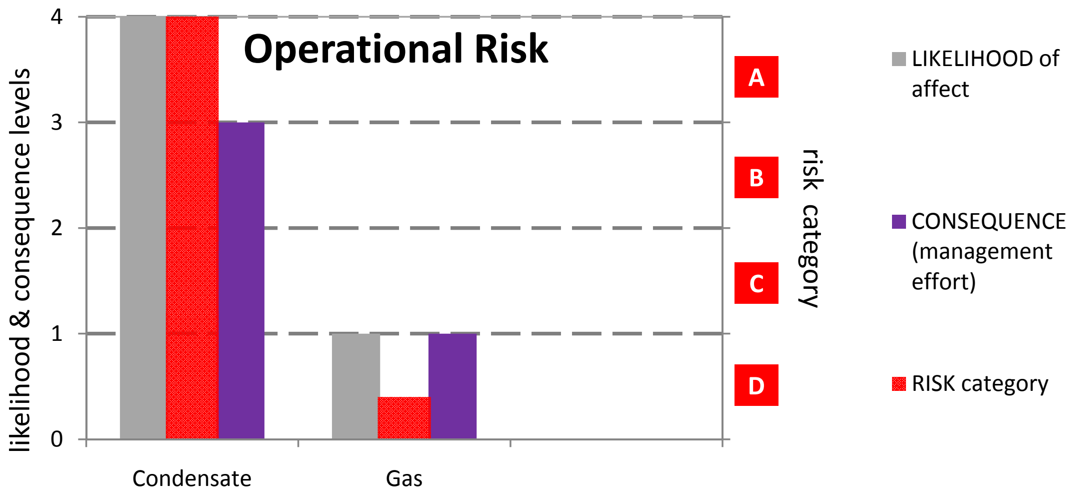
Work overs & development: *hydrocarbons produced - pits rehabilitated*



Water supply: *drawdown & salinisation* *- potential high transmissivity aquifer mitigates potential for excessive drawdowns, large rainfall mitigates potential for salinisation*

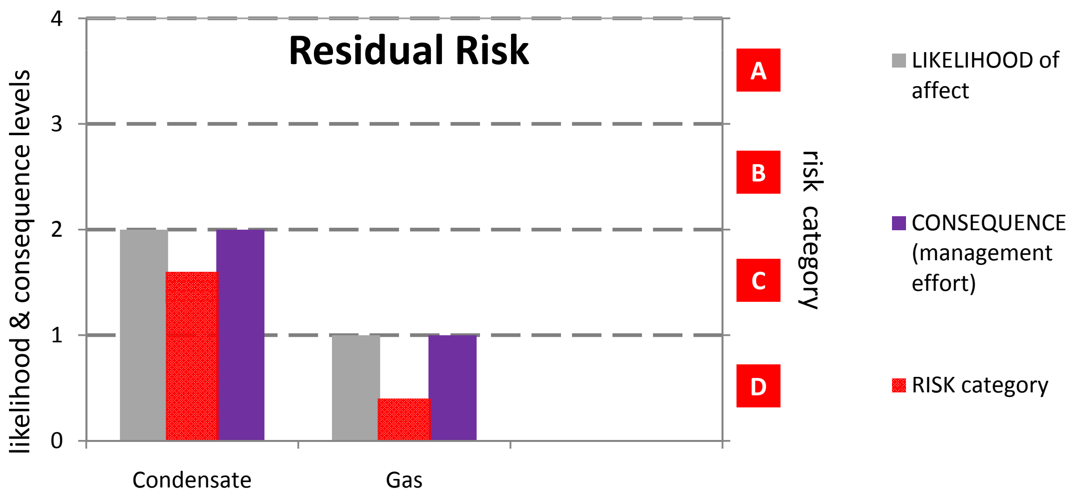


Water supply: *drawdown & salinisation* *- low potential for residual affects*



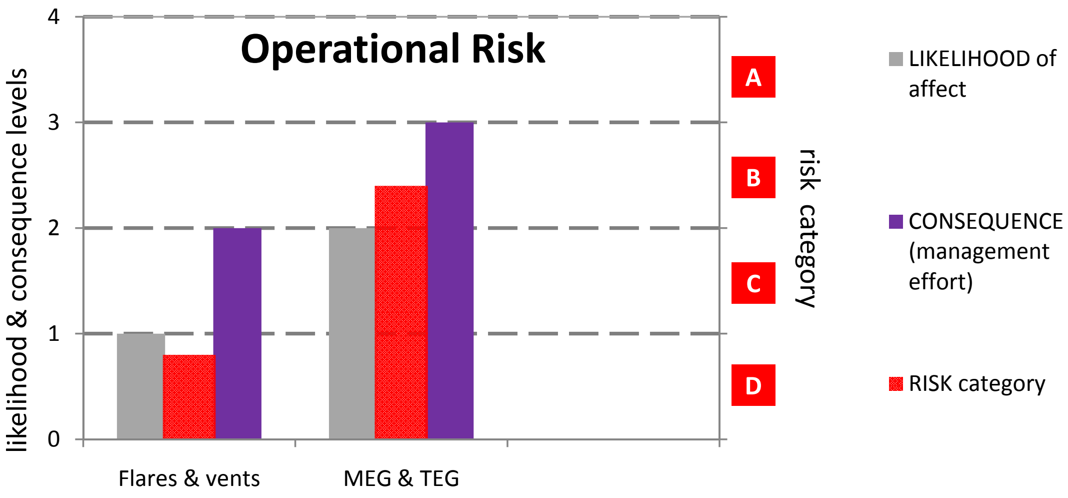
Condensate transfer: _hydrocarbons_ - *karst groundwater system sensitive to free product release, and potentially very mobile*

Gas transfer: volatile _hydrocarbons_ - *limited contamination potential as not in liquid form*



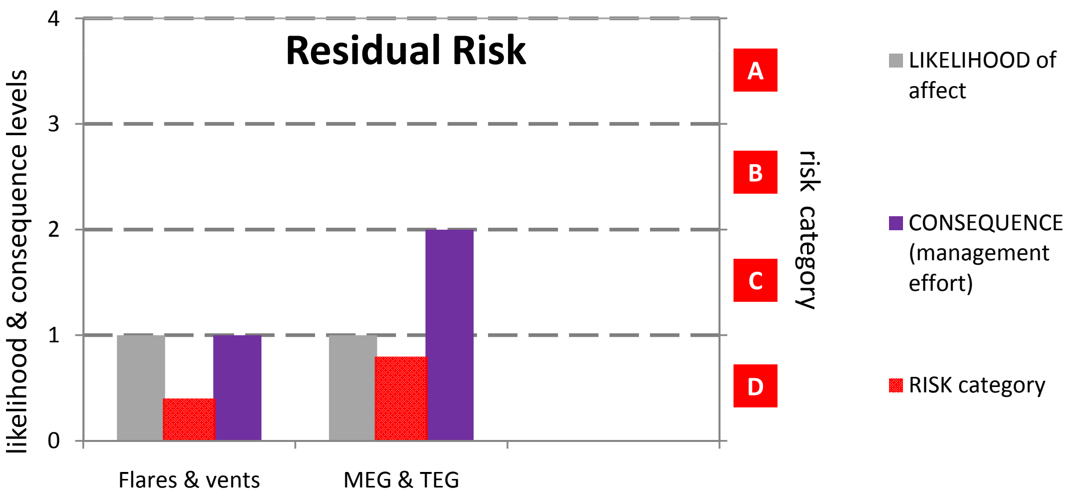
Condensate transfer: _hydrocarbons_ - *karst groundwater system sensitive to free product release, residual contamination will ameliorate over time due to flushing and biological controls*

Gas transfer: volatile _hydrocarbons_ - *limited residual contamination potential*



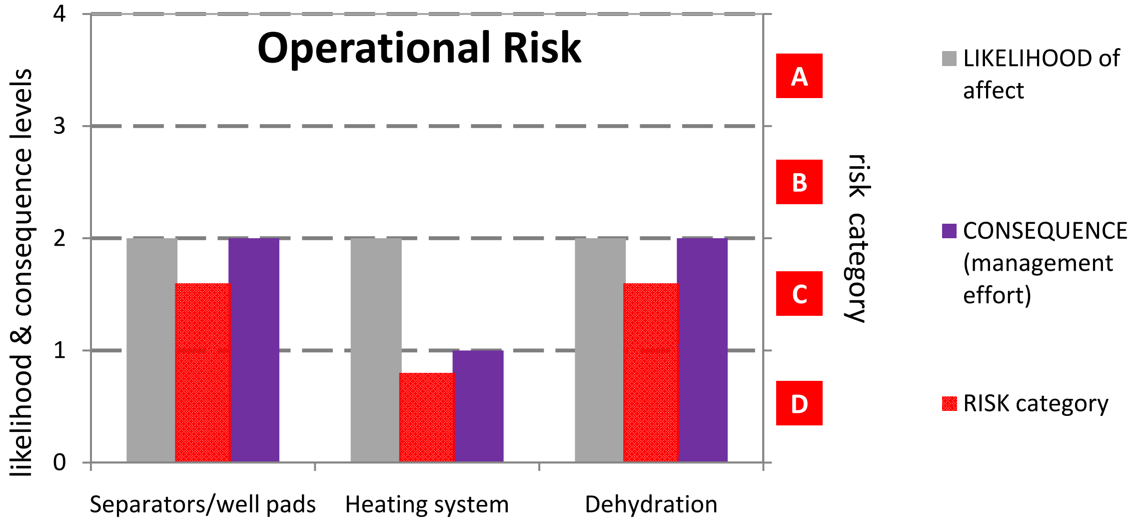
Flare & vent system: *<u>hydrocarbons</u> - any free product will be flared*

MEG & TEG: Glycol compounds - *relatively small volumes, uncertainty as to environmental risk but karst groundwater system sensitive to release, and potentially very mobile*



Flare & vent system: *<u>hydrocarbons</u> - low potential for residual contamination*

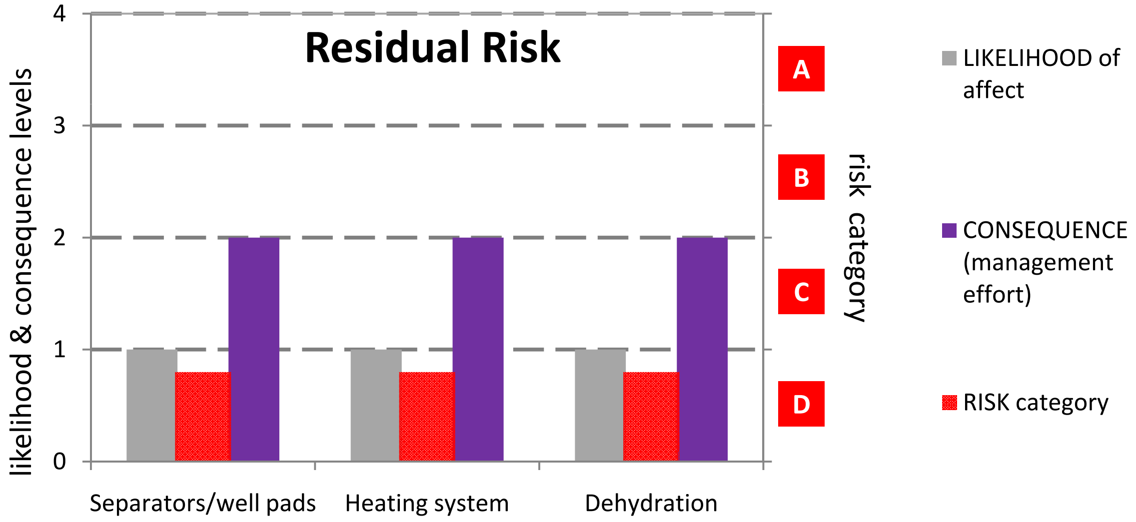
MEG & TEG: *Glycol compounds - karst groundwater system sensitive to compound release, residual contamination will ameliorate over time due to flushing and dilution*



Gas separators & well pads: *Hydrocarbons from pigging - low volumes of possible free product*

Heating system: *heavy hydrocarbons - low volumes of possible free product*

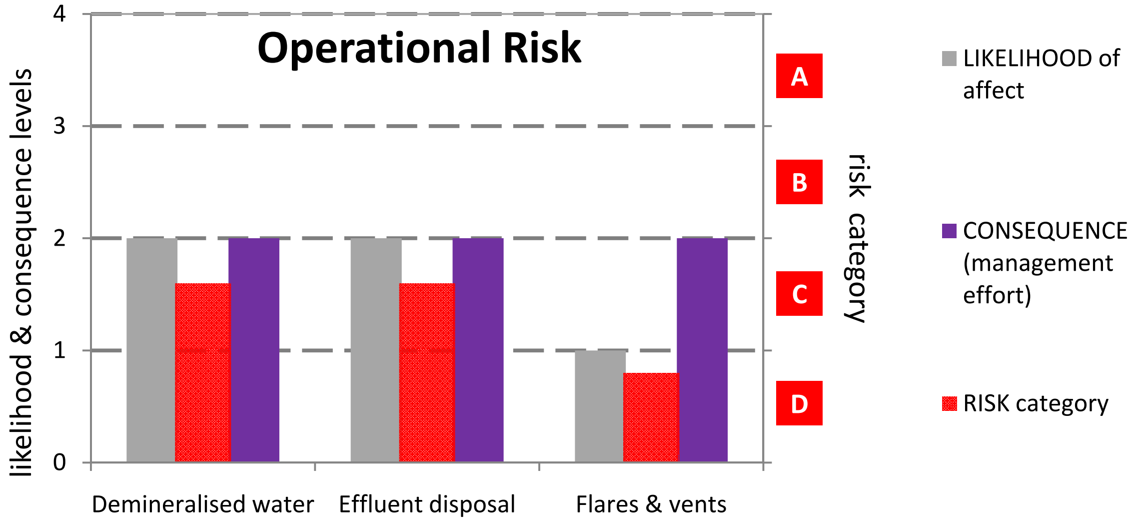
Dehydration unit: *hydrocarbon contaminated process water - low volumes of potentially contaminated water, large dilution potential*



Gas separators & well pads: *Hydrocarbons from pigging - low potential for residual contamination*

Heating system: *heavy hydrocarbons - low potential for residual contamination*

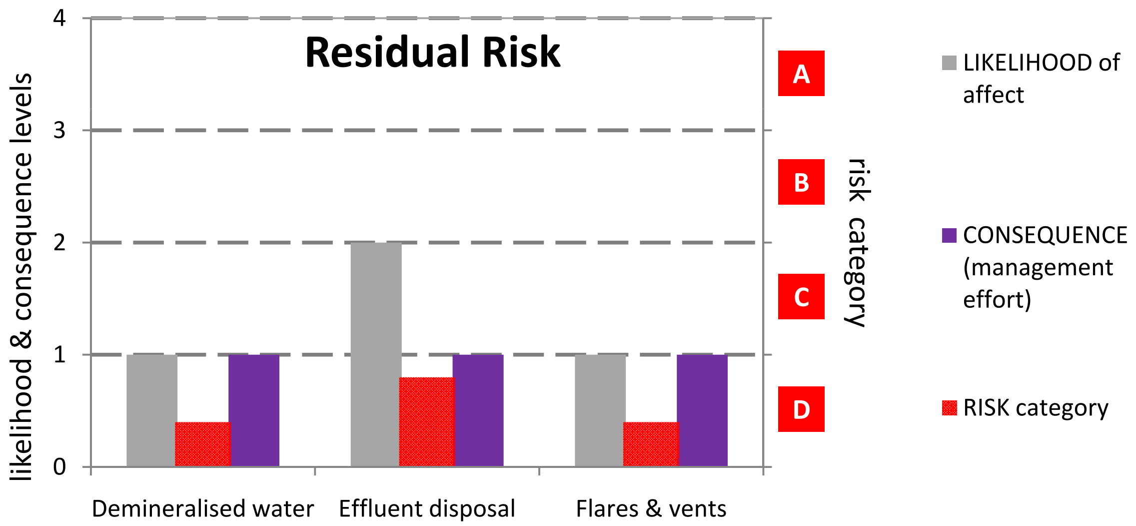
Dehydration unit: *hydrocarbon contaminated process water - low potential for residual contamination*



Demineralised water system: *RO reject water (saline)* *- low volumes of saline slugs*

Effluent disposal: *non-hazardous and hazardous materials* *- possible release of liquid wastes, intermittent only*

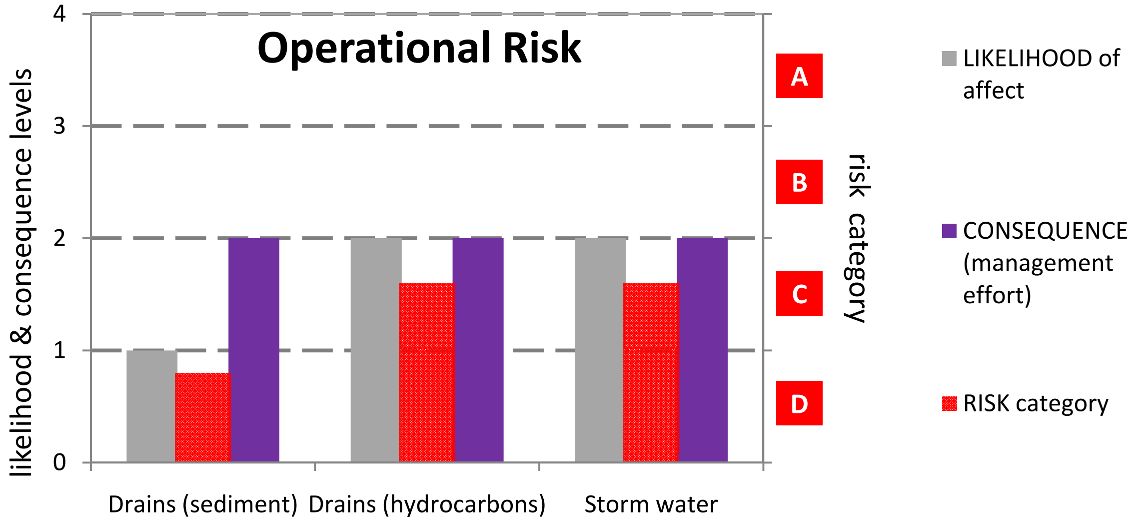
Flare & vent system: *hydrocarbons* *- any free product will be flared*



Demineralised water system: *RO reject water (saline)* *- flushing of aquifers will mitigate residual effects*

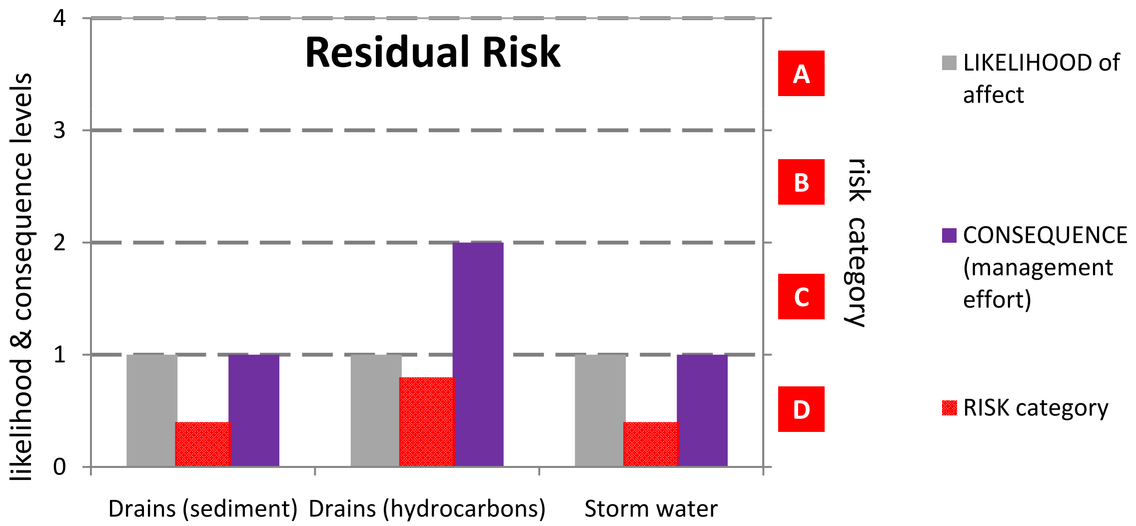
Effluent disposal: *non-hazardous and hazardous materials* *- residual source exists after decommissioning and rehabilitation*

Flare & vent system: *hydrocarbons* *- low potential for residual contamination*



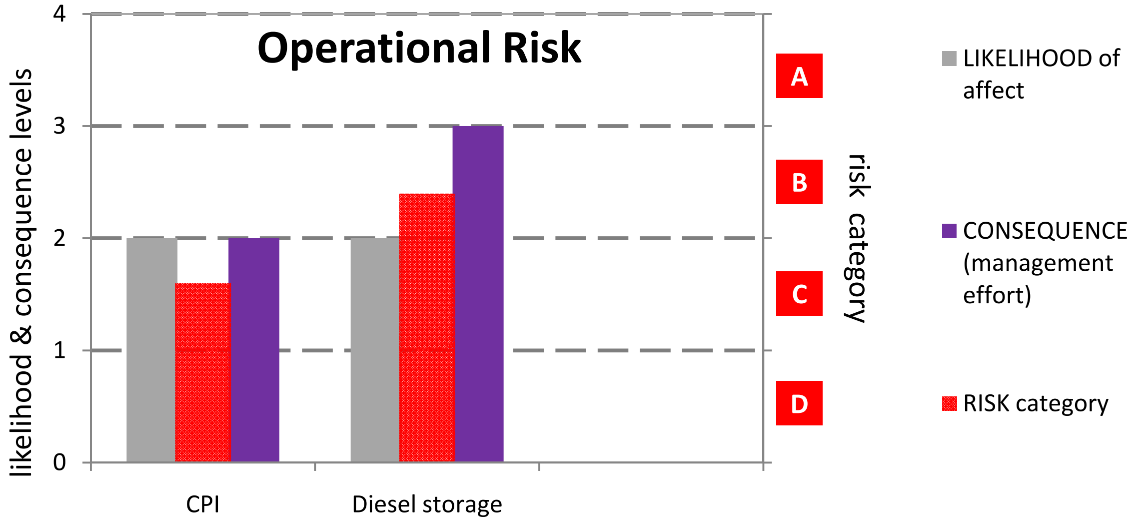
Drain system: *sediment & hydrocarbons* *- treatment on site, hydrocarbons present gretaest risk, karst system promotes mobility but also dilution potential*

Stormwater system: *sediment & hydrocarbons* *- treatment on site, potential contaminant loading will be less than drain syste,hydrocarbons present gretaest risk, karst system promotes mobility but also dilution potential*



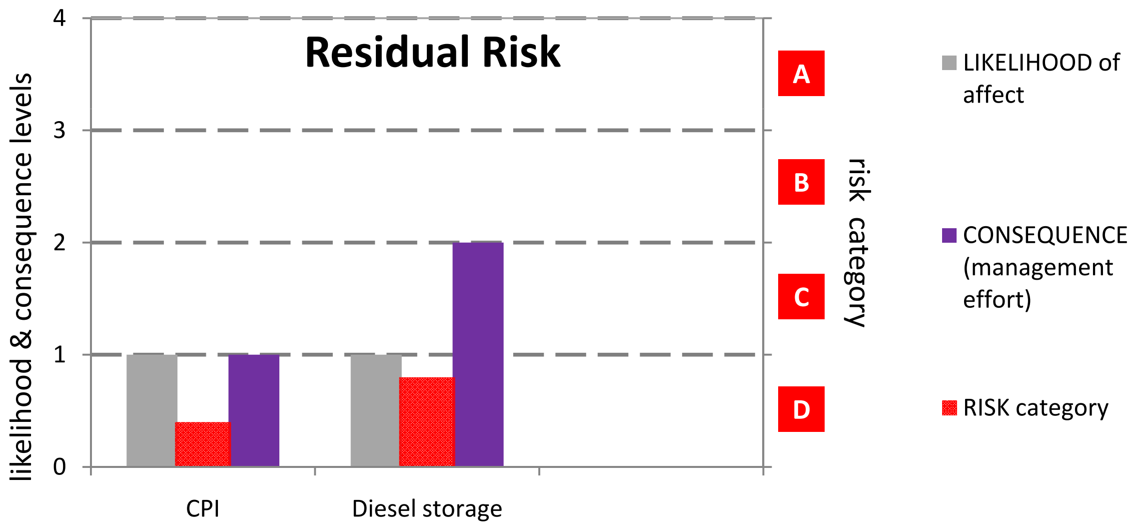
Drain system: *sediment & hydrocarbons* *- low potential for residual contamination*

Stormwater system: *sediment & hydrocarbons* *- low potential for residual contamination*



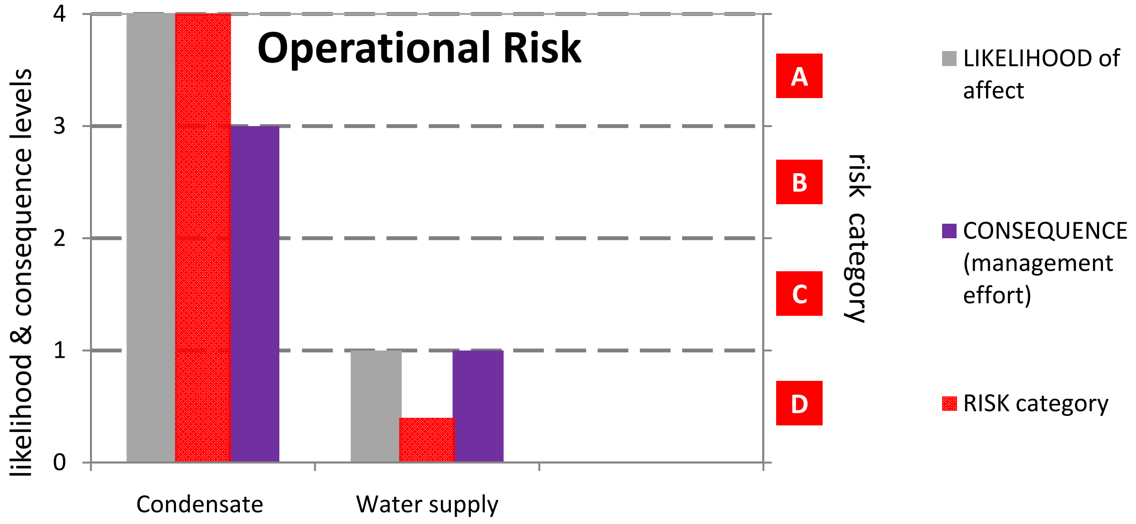
CPI oil sump: *hydrocarbons - potential low volumes of waste water, karst aquifer presents potential for mobility & also dilution*

Diesel storage & transfer: *hydrocarbons - risk mitigated by above ground storage, karst system presents potential for mobility & also dilution*



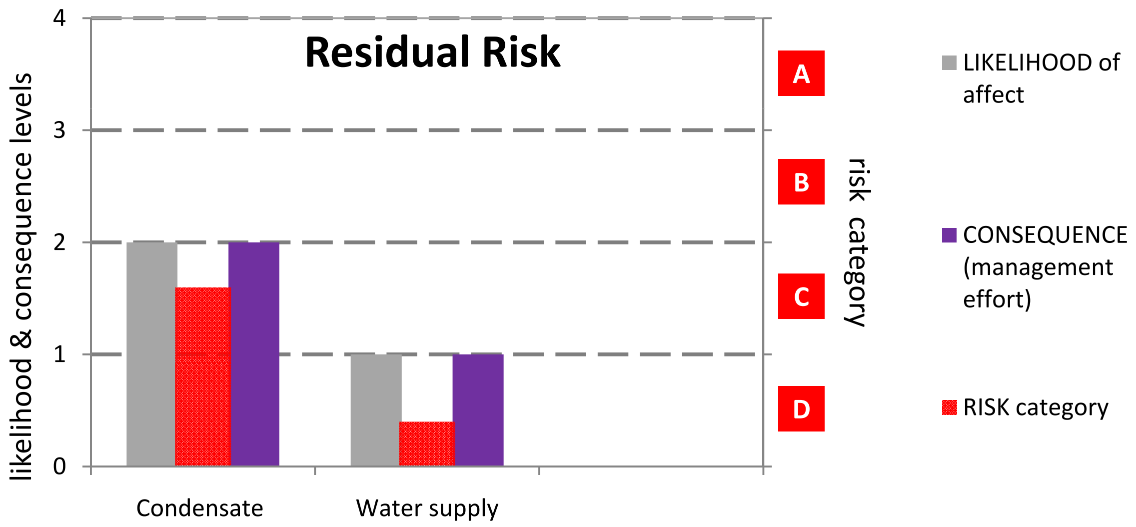
CPI oil sump: *hydrocarbons - low potential for residual contamination*

Diesel storage & transfer: *hydrocarbons - source removed on decommissioning, residual contamination if present has potential for flushing from system*



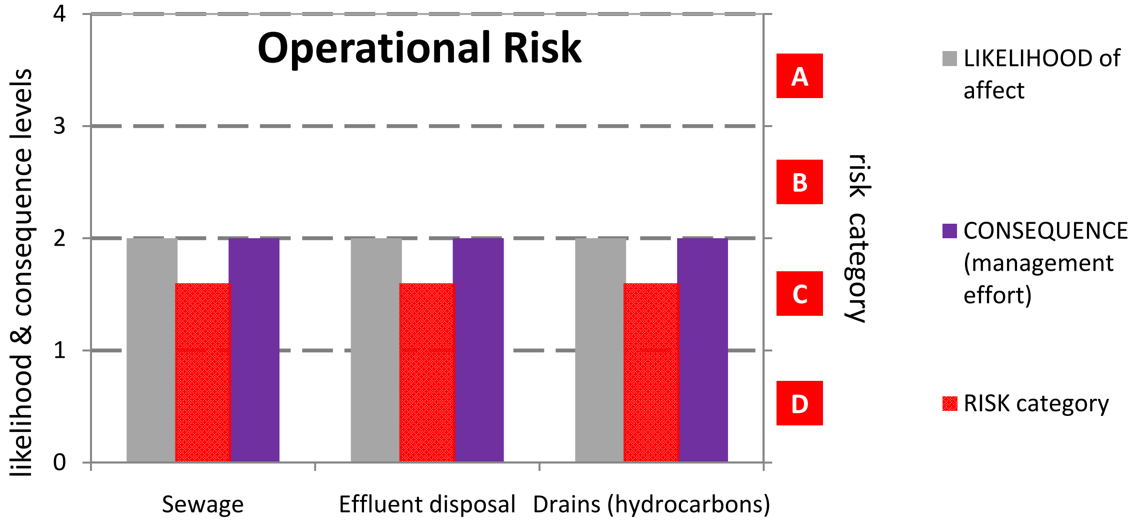
Condensate transfer: _hydrocarbons_ - *karst groundwater system sensitive to free product release, and potentially very mobile*

Water supply: _drawdown & salinisation_ - *potential high transmissivity aquifer mitigates potential for excessive drawdowns, large rainfall mitigates potential for salinisation*



CPI oil sump: _hydrocarbons_ - *low potential for residual contamination*

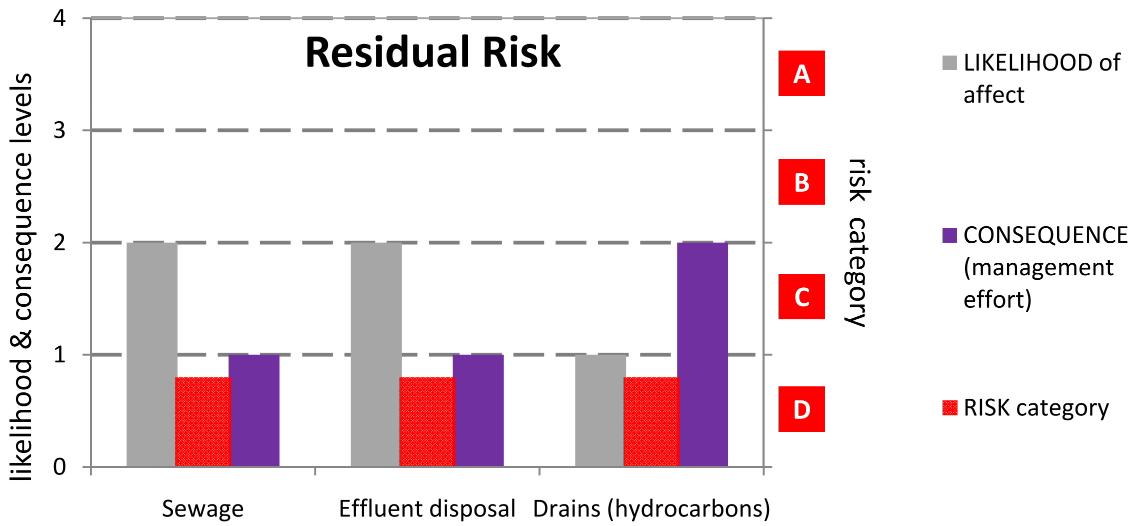
Water supply: _drawdown & salinisation_ - *low potential for residual affects*



Sewage disposal: *biological & pharmaceutical - possible release of treated wastes, pharmaceuticals excluded from sewage*

Effluent disposal: *non-hazardous and hazardous materials - possible release of liquid wastes, intermittent only*

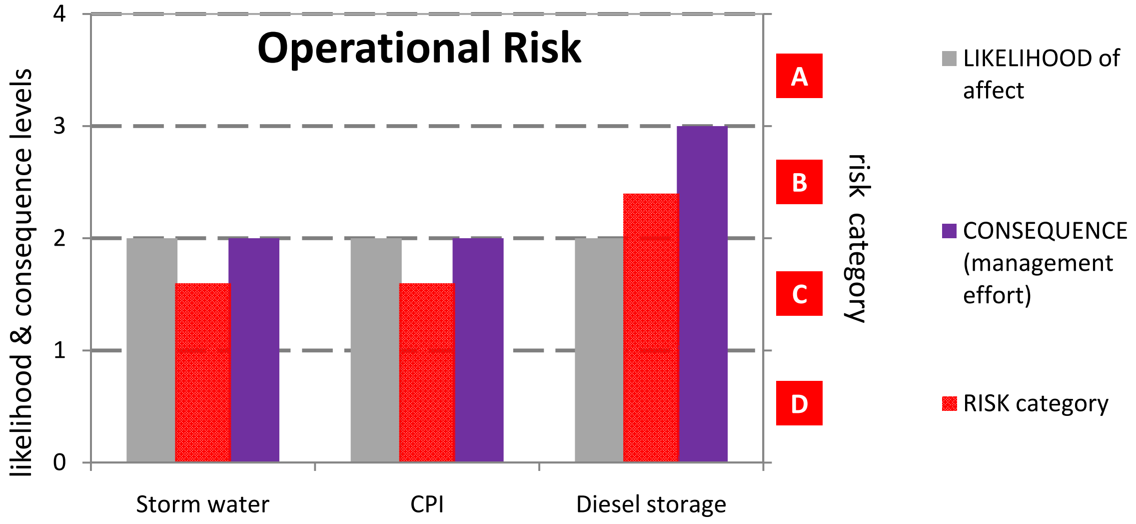
Drain system: *sediment & hydrocarbons - treatment on site, hydrocarbons present gretaest risk, karst system promotes mobility but also dilution potential*



Sewage disposal: *biological & pharmaceutical - residual source exists after decommissioning and rehabilitation*

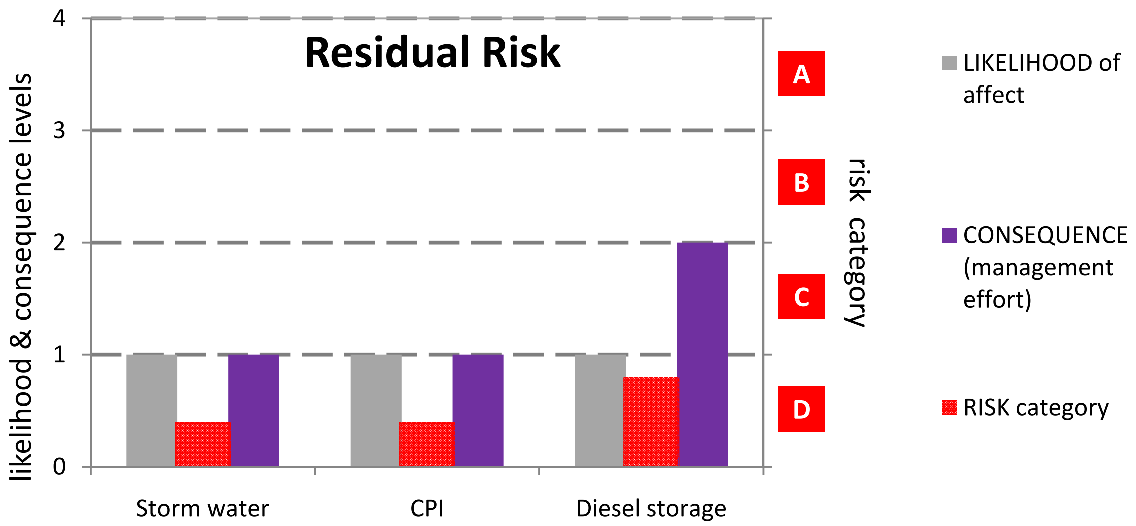
Effluent disposal: *non-hazardous and hazardous materials - rresidual source exists after decommissioning and rehabilitation*

Drain system: *sediment & hydrocarbons - low potential for residual contamination*



Stormwater system: *<u>sediment & hydrocarbons</u> - treatment on site, potential contaminant loading will be less than drain syste,hydrocarbons present gretaest risk, karst system promotes mobility but also dilution potential*
CPI oil sump: *<u>hydrocarbons</u> - potential low volumes of waste water, karst aquifer presents potential for mobility & also dilution*

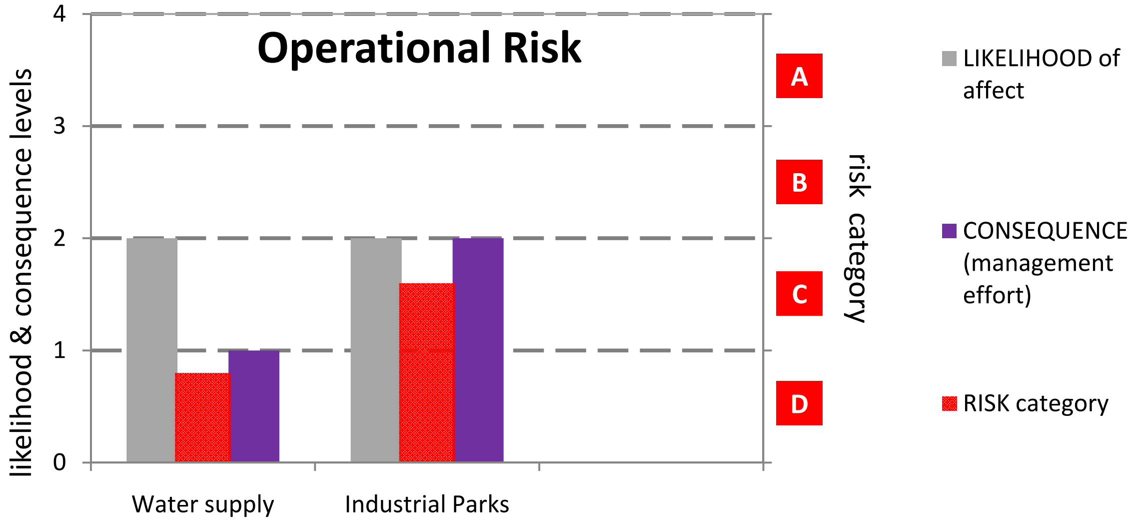
Diesel storage & transfer: *<u>hydrocarbons</u> - risk mitigated by above ground storage, karst system presents potential for mobility & also dilution*



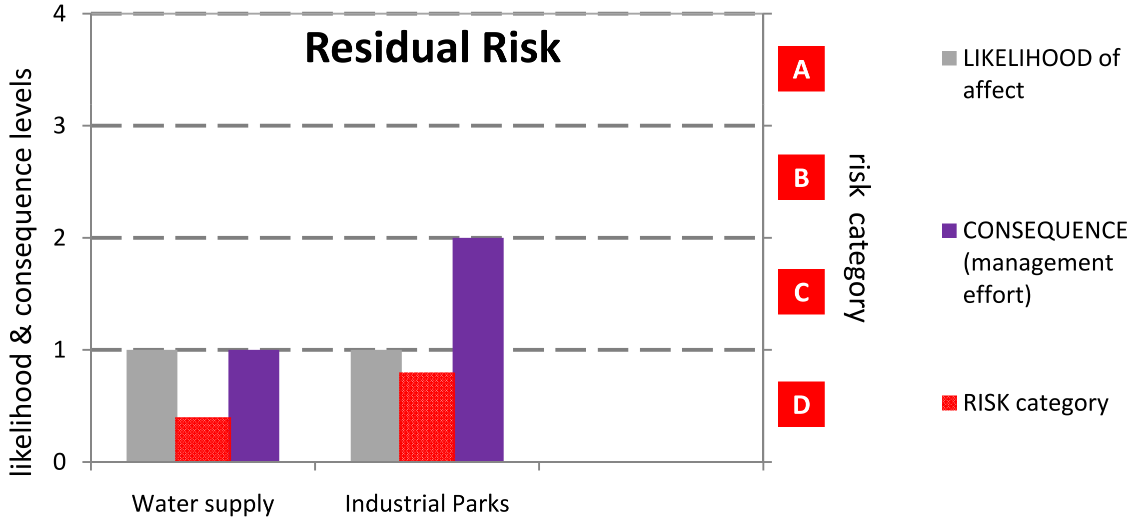
Stormwater system: *<u>sediment & hydrocarbons</u> - low potential for residual contamination*

CPI oil sump: *<u>hydrocarbons</u> - low potential for residual contamination*

Diesel storage & transfer: *<u>hydrocarbons</u> - source removed on decommissioning, residual contamination if present has potential for flushing from system*



Water supply: *<u>drawdown & salinisation</u> - potential high transmissivity aquifer mitigates potential for excessive drawdowns, large rainfall mitigates potential for salinisation; risk related to size of demand*



Water supply: *<u>drawdown & salinisation</u> - low potential for residual affects*