Hazard and risk X

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SANTOS GLNG GAS FIELD DEVELOPMENT PROJECT

ENVIRONMENTAL IMPACT STATEMENT

PRELIMINARY HAZARD ANALYSIS

URS AUSTRALIA PTY LTD

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Title: **Santos GLNG Gas Field Development Project** **Environmental Impact Statement** **Preliminary Hazard Analysis**	**QA Verified:** **G. PEACH**
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ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
APIA	Australian Pipeline Industry Association
APLNG	Australia Pacific LNG
AS	Australian Standard
BOM	Bureau of Meteorology
EHP	Department of Environment and Heritage Protection
DG	Dangerous Goods
DNPRSR	Department of National Parks, Recreation, Sport and Racing
DoP	Department of Planning
EGIG	European Gas Pipeline Incident Data Group
EHS	Environment, Health and Safety
EHSMS	Environment, Health and Safety Management Standard
EIS	Environmental Impact Statement
ESD	Emergency Shutdown
GFD	GLNG Gas Field Development
GGL	Gas Gathering Line
GLNG	Gladstone Liquefied Natural Gas Project
GQAL	Good Quality Agricultural Land
GTL	Gas Transmission Pipeline
HAZOP	Hazard and Operability (Study)
HDPE	High Density Polyethylene
HGC	Hub Gas Compression
HIPAP	Hazardous Industry Planning Advisory Paper
HP	High Pressure
HSHS	Health Safety Hazard Standards
IGEM	Institution of Gas Engineers and Managers
IP	Ignition Probability
ISO	International Standard Organisation
LFL	Lower Flammability Limit
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MAOP	Maximum Allowable Operating Pressure
MNES	Matters of National Environmental Significance
MP	Medium Pressure
NGC	Nodal Gas Compression
NSW	New South Wales

NZS	New Zealand Standard
OGP	International Association of Oil and Gas Producers
PCBU	Person Conducting a Business or Undertaking
PE	Polyethylene
PHA	Preliminary Hazard Analysis
PPE	Personal Protective Equipment
QCLNG	Queensland Curtis LNG Project
QRA	Quantitative Risk Analysis
SHRR	Significant Hazard Risk Register
SPP	State Planning Policy
TEG	Triethylene glycol
TJ	Tera Joule
TOR	Terms Of Reference
UK	United Kingdom
UKOPA	UK Onshore Pipeline Operators Association
WHS	Work Health and Safety
VCE	Vapour Cloud Explosion

TERMINOLOGY

Term	Definition
As low as reasonably practicable (ALARP)	A level of risk that is below the intolerable level, and either the cost of further risk reduction is disproportionate to the benefit gained or where the solution is technically impractical to implement.
Coal seam water	Groundwater produced at the surface by the depressurisation of coal seams during gas production.
Consequence	Outcome or impact of an incident, including the potential for escalation.
Gas compression facility	A facility that houses multiple compressor units, either nodal or hub compressors or a mixture of both used to increase the pressure of gas for the purpose of transmission; may be collocated with a gas treatment facility and/or water management facility.
Gas gathering lines	High-density polyethylene pipelines through which natural gas flows from a wellhead to gas compression facility under low pressure.
Gladstone transmission pipeline	The 420 kilometre long gas pipeline that transmits compressed gas at high-pressure, typically 10 to 15 megapascals, from gas compression facilities in the gas fields to export facilities at Gladstone; part of the GLNG Project approved via the 2009 EIS.
Hazard	A source of energy that has the potential to cause harm, ill health or injury, or damage to property, plant or the environment.
Hazardous substance	A substance which, by virtue of its chemical properties, constitutes a hazard.
High pressure	Gas flow typically 10 to 15 megapascals such as the design pipeline pressure in the Gladstone gas transmission pipeline.
Hub gas compression facility	Second stage gas compression; compresses gas to the pressure required for transmission via the Gladstone gas transmission pipeline (or third party transmission pipeline); minimum inlet pressure is 1,500 kilopascals; typically operated remotely.
Hydraulic fracturing	Hydraulic fracturing involves pumping a fluid under pressure into a coal seam to open up and connect fractures within the coal, increasing the opportunity for gas to move within the coal seam and flow toward the well.
LNG facility	The gas liquefaction, storage and export facility of approximately 10 million tonnes per annum capacity on Curtis Island, Gladstone. A three-train LNG Facility was approved as part of the GLNG Project via the 2009 EIS, and a two-train facility is currently under construction.
Medium pressure	Compressed flow of gas between nodal and hub compressors or water under pumping pressure such as that in the infield transmission pipelines.
Medium Risk	A medium risk is defined as being acceptable provided it is as low as reasonably practicable (ALARP).
Multi-well lease	A well lease that hosts more than one production well.
Nodal gas compression	First stage gas compression; compresses gas collected in the gathering

facility	lines to the pressure required for transport via infield transmission pipelines to second stage compression; often co-located with hub compressors at gas compression facilities; typically operated remotely.
Production well	A well that is designed to extract gas from one or more natural underground reservoirs.
Puncture	A perforation or hole in a containment system as a result of impact.
Release	The discharge of energy or of a hazardous substance from its containment system.
Residual Risk	The risk level taking into account proposed control measures.
Risk	The chance of something happening that will have an impact upon the environment or health or safety. It is measured in terms of consequences and likelihood.
Off site	Areas extending beyond the site boundary. This includes both public and private holdings.
Transmission pipelines	Engineered pipelines used to transmit gas or water under pressure downstream of gas compression or water pumping process.
Wells	A structure that is designed to bore through the earth's surface in order to extract resources.
Water gathering line	High-density polyethylene lines through which coal seam water flows from a wellhead under low or medium pressure to water transfer, storage and/or treatment infrastructure.
Water management facility	Water storage is a regulated or unregulated structure that provides temporary storage and balancing of flow rates and quality characteristics between various points of water management infrastructure. To refer to a specific type of water storage facility, preface the descriptor before storage. For example: Brine storage; water management storage, coal seam water storage.
Water storage	Water storage is a regulated or unregulated structure that provides temporary storage and balancing of flow rates and quality characteristics between various points of water management infrastructure. To refer to a specific type of water storage facility, preface the descriptor before storage. For example: Brine storage; water management storage, coal seam water storage.
Well lease	Area where a well and associated surface infrastructure is located.
Well stimulation	Well stimulation techniques are sometimes used to increase the recovery of gas resources by increasing the permeability of a natural gas reservoir. Well stimulation techniques include hydraulic fracturing, fracture acidizing, and cavitation.

1. SUMMARY

1.1. Purpose and scope

Santos GLNG intends to further develop its Queensland gas resources to augment supply of natural gas to its existing and previously approved Gladstone Liquefied Natural Gas (GLNG) Project.

The Santos GLNG Gas Field Development Project (the GFD Project) is an extension of the existing approved gas field development and will involve the construction, operation, decommissioning and rehabilitation of production wells and the associated supporting infrastructure needed to provide additional gas over a project life exceeding 30 years.

URS Australia Pty Ltd (URS) was commissioned by Santos GLNG to deliver the environmental impact statement (EIS) for the GFD Project. URS subcontracted Sherpa Consulting Pty Ltd (Sherpa) to undertake a preliminary hazard analysis (PHA) as part of the technical appendix for the hazard and risk component of the GFD Project.

The purpose of the PHA is to address the hazard and risk component of the Terms of Reference (ToR) for the EIS. The PHA scope is consistent with the EIS and includes the following:

- Wells, monitoring wells and potentially gas storage injection wells
- Gas and water gathering lines
- Gas and water transmission pipelines
- Gas compression facilities
- Water storage and water management facilities
- Associated plant facilities (e.g. fuel/chemical storage, workshops and maintenance areas and power generation and distribution facilities)
- Accommodation facilities and associated services (e.g. sewage treatment)
- Borrow pits and quarries
- Communication infrastructure
- Access roads and tracks.

The PHA covers construction, operations and decommissioning stages of the GFD Project.

The PHA is undertaken at an early stage of the GFD Project as an input to the EIS. The study is based on an assessment of representative infrastructure. The project risk management processes will result in further risk assessment including updates as the GFD Project matures.

1.2. Methodology

The risk assessment methodology for the PHA was based on the NSW Department of Planning (DoP) guidelines, *Hazardous Industry Planning Advisory Paper (HIPAP) No. 6, Hazard Analysis* (Ref. 1) and *Multi-Level Risk Assessment Guideline* (Ref. 14). These are the most commonly applied guidelines for land use safety planning in Queensland in the absence of State specific guidelines. The methodology for the PHA comprised the following sequential stages:

- **Context setting** was undertaken to identify the background of the GFD Project, how it relates to other developments in the area and the legislative and corporate risk management framework and risk criteria.
- **Hazard identification** was undertaken to identify hazards associated with gas field infrastructure throughout each development phase. Based on an assessment of whether the identified hazards could potentially have off-site impacts on people or property, a list of scenarios was developed for further assessment and discussion.
- **Consequence analysis** was undertaken to further assess the scenarios identified with the potential for off-site impact. The result of the consequence assessment is to confirm the scenarios with consequences that extend off-site.
- **Likelihood estimation** was undertaken for those scenarios with consequences that extend off-site. The likelihood of an impact occurring to people or property was estimated and carried into the risk assessment.
- **Risk assessment** was undertaken to combine scenarios with off-site consequences with their associated likelihoods. Risks were assessed against relevant risk criteria. Risk controls for the GFD Project were incorporated into the assessment based on the existing processes and controls adopted in the approved management and regulatory framework for the Santos GLNG Project. The project and regulatory process recognises that this assessment will be supplemented in the future by further planning, risk assessment, engineering design and risk mitigation controls and measures to ensure that risks from the GFD Project are managed to levels that are as low as reasonably practicable (ALARP).

1.3. Study findings

The hazard assessment identified that three types of infrastructure facilities associated with the proposed development could result in scenarios with the potential for off-site impact. These were:

- Wells
- Compression facilities
- Gas pipelines.

The likelihood of a loss of containment and subsequent harm has been assessed in the PHA to determine the risk associated by the facility. The main findings are summarised for each type of facility.

Risk rankings are based on the risk matrix in Section 9.2.1. The risk rankings are the residual risk considering that the existing processes and controls adopted in the approved management and regulatory framework for the Santos GLNG Project have been adopted by the GFD Project.

1.3.1. Wells

A loss of containment from a well is assessed as having a medium residual risk level. The medium risk is based on an assessment that the consequence of a release from a well site has the potential to impact beyond the site boundary, but the likelihood is sufficiently low based on the proposed controls to present a medium risk.

Medium risks levels are acceptable provided they can be demonstrated to be ALARP.

Risks will be managed to ALARP throughout the GFD Project's lifecycle using existing controls as documented in *Santos GLNG Environment, Health, and Safety Management Standard EHSMS09: Managing Environment, Health and Safety Risks* (EHSMS09) (Ref.10) and supporting process (e.g. planning and engineering design).

1.3.2. Gas compression facility

A loss of containment from a gas compression facility is assessed as having a medium residual risk level. The medium risk is based on an assessment that the consequence of a release from a gas compression facility has the potential to impact beyond the site boundary, but the likelihood is sufficiently low based on the proposed controls to present a medium risk.

Medium risks levels are acceptable provided they can be demonstrated to be ALARP.

Risks will be managed to ALARP throughout the GFD Project's lifecycle using existing controls as documented in EHSMS09 and supporting process (e.g. planning and engineering design).

1.3.3. Gas pipelines

A loss of containment from a gas pipeline (gathering or transmission) is assessed as having a medium residual risk level. The medium risk level is based on an assessment that the consequence of a release has the potential to extend beyond the immediate vicinity of the pipeline, but the likelihood is sufficiently low based on the proposed controls to present a medium risk.

The pipeline risk assessment was supported by a Quantitative Risk Assessment (QRA) compared against criterion relating to sensitive land use. The risks associated with the proposed pipelines are below the risk acceptance criteria with the exception of the risk to sensitive land uses from the high pressure (HP) gas transmission pipeline.

Sensitive land uses include hospitals, child care facilities and old age housing. Given the rural nature of the infrastructure locations, the likelihood of the pipelines passing such facilities is low.

The risk to sensitive land uses can be mitigated through appropriate pipeline routing and maintaining separation distances.

1.4. Conclusions

A PHA of the proposed infrastructure for the GFD Project has been completed. The PHA has been undertaken early in the GFD Project as an input to the EIS. As such the PHA is based on selecting a set of representative facilities and operating conditions.

The assessment takes account of the hazard and risk management framework adopted by Santos for the GLNG Project. Key aspects of the framework are detailed in Section 4.

Based on the outcomes of the PHA conducted for the GFD Project, it is concluded that:

- Existing mitigation and controls are sufficient to manage risk to people and property associated with the wells, gas gathering and compression facilities. The existing controls include further risk assessments, planning, engineering design, material selection, security and signage.
- Based on the proposed controls and appropriate route selection and separation distances between the high pressure pipeline and sensitive land uses the risks levels from the pipelines can be managed.
- Ongoing management of the risk and demonstration of ALARP will be achieved by the GFD Project through the implementation of EHSMS09 and supporting processes including:
  - the development of the Significant Hazards Risk Register (SHRR) for the GFD Project
  - update of the SHRR as the GFD Project matures
  - implementation of Integrity Management Plans to assure the asset integrity and risk controls remain effective over the life of the GFD Project.

2. INTRODUCTION

2.1. Background

Santos GLNG intends to further develop its Queensland gas resources to augment supply of natural gas to its existing and previously approved GLNG Project.

The GFD Project is an extension of the approved gas field development and will involve the construction, operations, decommissioning and rehabilitation of wells and the associated supporting infrastructure needed to provide additional gas over a project life exceeding 30 years.

URS has been commissioned by Santos GLNG to deliver the EIS for the GFD Project. URS has requested Sherpa to deliver the technical appendix for the hazard and risk component of the GFD Project.

2.2. Study objective

The purpose of this study is to address the hazard and risk component of Terms of Reference for the EIS. Specific objectives of the study are to:

- Undertake a PHA of the GFD Project. The PHA will be prepared in accordance with NSW Department of Planning guidance: *Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 'Guidelines for Hazard Analysis'* (Ref. 1) and HIPAP No. 4, '*Risk Criteria for Land Use Safety Planning*'[1] (Ref. 2).
- Use existing relevant information from the previous EISs undertaken for the GLNG Project
- Satisfy the requirements of the terms of reference for a preliminary risk assessment or hazard study.

The document is a *Preliminary* Hazard Analysis and has been undertaken in support of the EIS to demonstrate that the risk to people and property can be managed effectively to meet relevant risk criteria over the life of the GFD Project. The PHA is only one step in managing the risk associated with the proposed infrastructure. EHSMS09 details the lifecycle approach to risk management for the infrastructure.

2.3. Study scope

The scope of the PHA is consistent with the EIS, and includes the following:

- Production wells
- Fluid injection wells, monitoring bores and potentially underground gas storage wells
- Gas and water gathering lines

[1] These guidelines are accepted for use in Queensland for the preparation and review of EIS in the absence of State published guidelines and criteria for land use planning.

- Gas and water transmission pipelines
- Gas compression facilities
- Water storage and water management facilities
- Associated plant facilities (e.g. fuel/chemical storage, workshops and maintenance areas and power generation and distribution facilities)
- Accommodation facilities and associated services (e.g. sewage treatment)
- Borrow pits and quarries
- Communications and infrastructure
- Access roads and tracks.

The PHA covers the following stages of the GFD Project:

- Construction (and commissioning)
- Operations
- Decommissioning.

Rehabilitation involves land reforming and revegetation (not removal of pipelines) and is not considered to represent an additional hazard risk for the purposes of this assessment.

2.4. Exclusions and limitations

The following exclusions and limitations should be noted:

- This study is based on drawings, process conditions and information supplied by URS and/or Santos GLNG.
- Transport hazards other than those involving dangerous goods are excluded from the PHA (refer Cardno (2014): *Traffic and Transport Assessment Technical Report – Gas Field Development Project, Environmental Impact Statement*. Santos GLNG Cardno Traffic and Transport Assessment Technical Report, Ref. 3).
- Long-term health risk and long-term environmental impacts excluded from the PHA.

3. DESCRIPTION OF THE PROPOSED DEVELOPMENT

3.1. Location

The GFD Project will continue to progressively develop the Arcadia, Fairview, Roma and Scotia gas fields across 35 Santos GLNG petroleum tenures in the Surat and Bowen basins, and associated supporting infrastructure in these tenures and adjacent areas. The location of the GFD Project area and primary infrastructure is shown in Figure 3.1.

Specifically, the GFD Project seeks approval to expand the GLNG Project's gas fields tenure from 6,887 km^2 to 10,676 km^2 to develop up to an additional 6,100 production wells beyond the currently authorised 2,650 wells; resulting in a maximum of 8,750 production wells.

For the purposes of the GFD Project EIS, a scenario based on the maximum development case was developed at the approval of the TOR. This scenario assumed that production from the wells and upgrading of the gas compression facilities in the Scotia gas field would commence in 2016, followed by the GFD Project wells in the Roma, Arcadia and Fairview gas fields in mid-2019. This schedule is indicative only and was used for the purpose of the impact assessment in this EIS.

3.2. Surrounding land uses and planned projects

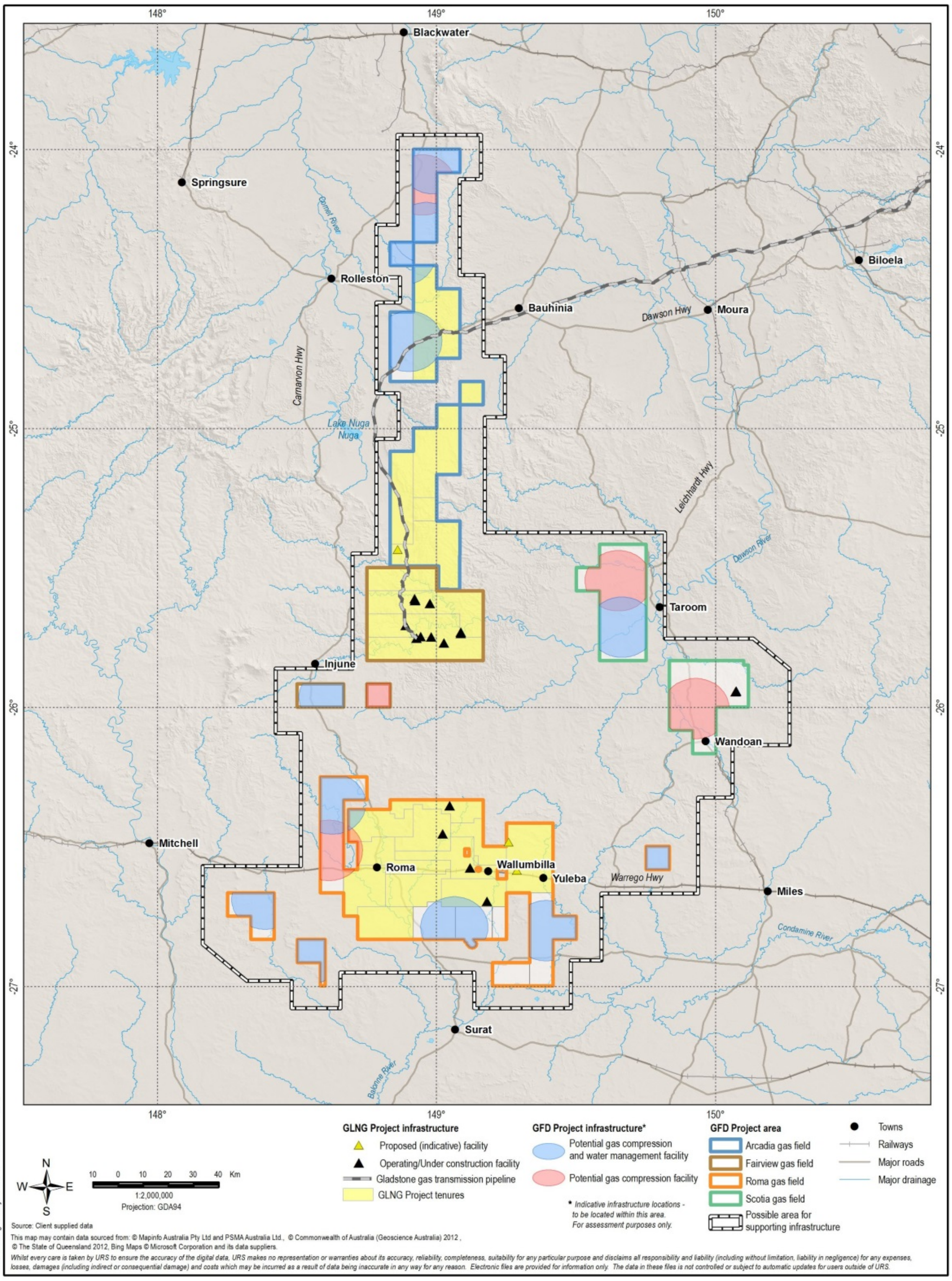
Land use surrounding the GFD Project area is predominantly agricultural but also includes mine sites, various reserves, parks and state forests, as well as some towns (including Roma, Surat, Wallumbilla, Miles, Taroom, Wandoan, Injune and Rolleston).

The vicinity around the GFD Project area also includes a variety of major developments currently being assessed or approved and being implemented, as shown in Table 3.1. These include:

- Coal mines, such as the Wandoan Coal Project, the North Surat–Collingwood Coal Project and North Surat–Taroom Coal Project.
- Gas and energy projects, such as the existing GLNG Project, APLNG Project and Arrow Energy Project.
- Major infrastructure projects, such as the Nathan Dam Project, the Surat Basin Railway Project and the Spring Gully Power Station.

The surrounding land uses and major projects have been taken into consideration in the assessment of risks to property and the cumulative impact assessment (Sections 9.4 and 9.5 of this report).

Figure 3.1: GFD Project area



Source: URS, 2014; File No: 42627064-g-1051j.mxd

Table 3.1: Major projects relevant to the GFD Project area

Project	Proponent	Location	Description	EIS current status	Proposed construction dates	Estimated construction jobs	Estimated operational jobs	Lifespan	Relationship to GFD Project
Australia Pacific LNG (APLNG)	Origin Energy and Conoco Phillips	Gas fields: Walloons gas fields, stretching from Injune to Millmerran. Pipeline: from gas fields to Gladstone. LNG plant and export terminal: Curtis Island, near Gladstone.	Integrated LNG project. Development of ~10,000 wells over ~5,700 km^2. 450 km gas transmission pipeline. LNG plant and export facility (4 trains with a total capacity of up to 18 Mtpa of LNG).	Approved Nov 2010	Gas fields: 2010 to 2027 Pipeline: mid-2012 to late-2013. LNG facility: 2011 to 2014	Gas fields: 2,100 Pipeline: 800 LNG facility: 2,100	Gas fields: 700 Pipeline: 20 LNG facility: 100 for 1 train and 75 for each additional train.	30 years	APLNG tenure lay north-west to south-east within 50 km buffer area. Gas fields development periods will overlap.
Arcturus Coal Mine Project	Springsure Creek Coal	~40 km south of Emerald and 60km south-west of Blackwater	Open cut and underground mine and associated infrastructure.	EIS in preparation	Unknown	300	150	30 years	Located ~50 km west of Arcadia North.
Blackwater to Emerald Power line Replacement	Ergon Energy	Preferred 76km route identified between the Blackwater the Emerald.	Upgrade the existing aged power line from Blackwater to Emerald to 66kV or 132kV dual circuit concrete pole line.	Draft design underway	2014	Unknown	Unknown	30-40 years	Northwest of Arcadia gas field.

Project	Proponent	Location	Description	EIS current status	Proposed construction dates	Estimated construction jobs	Estimated operational jobs	Lifespan	Relationship to GFD Project
Blythedale, Fairview and Fairview South Substations Project	Powerlink	Three locations in area between Wandoan and Injune	Three 132kV substations are proposed to supply future gas compression facilities at Santos GLNG's Roma and Fairview gas fields.	EIS completed in July 2013, and is now released for public comment	2014	Unknown	Unknown	40-50 years	Located near and will supply electricity to facilities within Roma and Fairview gas fields.
Bowen Gas Project	Arrow Energy	Extends from Blackwater north to near Glenden	Gas project. 6,625 wells and associated infrastructure over ~8,000 km^2	Public notification of EIS	Commence construction of facilities 2015, initial well drilling commencing 2016, and commence production 2017.	1,540	597	40 years	ATP 1025 is located ~40 km north of Arcadia North. Gas field development period will overlap.
Bundi Coal Project	Metro Coal	~20 km south-west of Wandoan	Underground coal mine and associated infrastructure. 5 Mt/y of product coal.	EIS in preparation	Commence construction 2013, with operations to commence 2015.	300	150	20 years	Located ~20 km south of Scotia.
Dingo West Coal Mine	Dingo West Coal	~6 km west of Dingo and ~120 km east of Emerald	Open cut coal mine. 1 Mt/y of product coal	EIS in preparation	Unknown	220	120	30 years	Located ~45 km north-east of Arcadia North.
Elimatta Project	Taroom Coal	~45 km south-west of Taroom and 380 km north-west of Brisbane	Open cut coal mine. 5 Mt/y product coal	Public notification of EIS	Commence construction mid-2013 to mid-2015	500	300	40 years	Located ~25 km west of Scotia and ~25 km south of Scotia West

Project	Proponent	Location	Description	EIS current status	Proposed construction dates	Estimated construction jobs	Estimated operational jobs	Lifespan	Relationship to GFD Project
Eurombah to Fairview Transmission pipeline Project	Powerlink	From the proposed Eurombah Substation to a proposed substation at Fairview South, then continuing north to the proposed Fairview Substation.	Two proposed transmission pipelines to supply power to proposed substations at Fairview and Fairview South to supply power to future gas processing facilities.	Draft EIS has been prepared. Submissions being reviewed before final EIS is prepared.	2014	Unknown	Unknown	30-40 years	Located near and will supply power to facilities within Roma and Fairview gas fields.
Gladstone LNG Project	Santos GLNG	Gas fields: extend from Rolleston in the north to Roma in the south and Taroom to the east. Pipeline: from gas fields to Gladstone. LNG facility: Curtis Island, near Gladstone	Development of ~2,650 wells over ~6,900 km^2. 435 km gas transmission pipeline. LNG facility of ~10 Mtpa capacity	Approved May 2010	Commence construction 2010 to 2022	Gas fields: 960 Pipeline: 1,000	Gas fields: 820 Pipeline: 20	25 years	Makes up approved development area of GFD Project. Gas field development periods will overlap.
Minyango Coal Project	Blackwater Coal	Directly south of Blackwater	Underground coal mine. 7.5 Mt/y of product coal	EIS in preparation	Information not available	Information not available	Information not available	40 years	Located 40 – 45 km north of Arcadia North.

Project	Proponent	Location	Description	EIS current status	Proposed construction dates	Estimated construction jobs	Estimated operational jobs	Lifespan	Relationship to GFD Project
Nathan Dam and Pipelines	Sunwater	Dam: 35 km north-east of Taroom Pipeline: from dam, through the Surat Basin to Dalby	888,000 megalitre dam, with an annual yield of 66,000 ML. 260 km trunk pipeline	Website states that SEIS is in preparation but it has been announced that the project has been shelved.	Commence construction July 2013 to June 2016.	425	5	100 years	Dam: Located 30 km east of Scotia West. Pipeline: runs from dam, through Scotia to Dalby.
Norwood Coal Project	Metro Coal	~30 km south-west of Wandoan-	Underground coal mine. 5 Mt/y of product coal	EIS in preparation	Commence construction 2015, with operations commencing 2017	300	150	20 years	Located 5 to 10 km north of Roma and 45 km south of Fairview.
North Surat - Collingwood Coal Project	Cockatoo Coal	12 km north-east of Wandoan and 340 km south-west of Rockhampton.	Open cut coal mine. 6 Mt/y thermal coal.	EIS in preparation	Commence construction Q2 2014 to Q4 2015	1,000	400	20 years	Located immediately east of Scotia.
North Surat Taroom Coal Project	Cockatoo Coal Limited	3 km south-east of Taroom and 310 km south-west of Rockhampton.	Open cut coal mine. 8 Mt/y thermal coal.	EIS in preparation	Commence construction Q4 2013 to Q2 2015	1,000	550	25 years	Located 10 km east of Scotia West.

Project	Proponent	Location	Description	EIS current status	Proposed construction dates	Estimated construction jobs	Estimated operational jobs	Lifespan	Relationship to GFD Project
Queensland Curtis LNG (QCLNG)	Queensland Gas Company	Gas fields: extend from ~30 south-west of Wandoan to ~30 km west of Dalby. Pipeline: transmission pipeline from gas fields to Gladstone. LNG facility: Curtis Island, near Gladstone	Development of ~6,000 wells over ~4,700 km^2. 380 km of gas transmission pipeline. LNG facility on Curtis Island with operating capacity of 12 Mtpa.	Approved Jun 2010	Commence construction Q2 2010 to Q3 2013.	4,000	1,000	20 years	Located ~30 km south-west of Scotia and ~25 km north-east of Roma. Gas field development period will overlap.
Rolleston Coal Expansion Project	Rolleston Coal Joint Venture	~25 km west of Rolleston, 270 km west of Gladstone and 120 km south-east of Emerald.	Expansion of existing Rolleston Coal mine. 10 open cut pits Expansion from 10 Mt/y to 20 Mt/y.	EIS in preparation.	Information not available	Information not available	Information not available	Information not available	Located ~50 km west of Arcadia North.
Spring Gully Power Station	Origin Energy Power Limited	80 km north-east of Roma	A 1,000 MW combined-cycle gas-fired power station, constructed in two 500 MW stages	Approved 14 Sep 2009	Unknown	400	17	Information not available	Located ~25 km south of Fairview.
Springsure Creek Coal Project	Springsure Creek Coal	~40 km south-east of Emerald	Underground coal mine. 9 Mtpa of Run of Mine (ROM) coal	Public notification of EIS	Unknown	350	585	30 years	Located ~50 km north-west of Arcadia North.

Project	Proponent	Location	Description	EIS current status	Proposed construction dates	Estimated construction jobs	Estimated operational jobs	Lifespan	Relationship to GFD Project
Surat Gas Project	Arrow Energy	Gas fields: Extending from Wandoan (north) to Dalby and Millmerran (east) and Goondiwindi (south)	Gas project. 7,500 wells and associated infrastructure over ~8,600 km^2.	SEIS in preparation	Commence construction 2013 to 2035	1,000	400	35 years	Located immediately adjacent to Scotia and extends south-east towards Dalby. Gas field development period will overlap.
Surat Basin Railway	Surat Basin Rail	To run from just outside Wandoan (230 km north-west of Toowoomba) to just outside Banana (130 km west of Gladstone).	A 214 km railway in the Surat Basin that will connect the Western Railway system to the Moura Railway system.	Approved 9 Dec 2010	Unknown	1,000	-	50 years	Rail line commences in the southern portion of Scotia and runs north-east through Scotia.
Surat to Gladstone Pipeline Project	Arrow Energy	Near Dalby to Gladstone	470 km long pipeline from Dalby to Gladstone.	Approved Jan 2010	Unknown	300	10	40 years	Located ~5 to 10 km east of Scotia.
'The Range' Project	Stanmore Coal	25 km south-east of Wandoan	Open cut coal mine. 7 Mt/y product coal	Public notification of EIS	Unknown	300	500	25 years	Located ~25 km south-east of Scotia.
Wandoan Coal Project	Wandoan Joint Venture	5 km west of Wandoan	Open cut thermal coal mine. 30 Mt/y.	Approved Nov 2010	Unknown	1,375	50	30 years	Located in south-west corner of Scotia.

Project	Proponent	Location	Description	EIS current status	Proposed construction dates	Estimated construction jobs	Estimated operational jobs	Lifespan	Relationship to GFD Project
Wandoan South to Eurombah Transmission Network Project	Powerlink	From Yuleba, transmission pipeline to run west to Wandoan (Section 1), south to Clifford Creek (Section 2) and northwest to Eurombah (Section3).	Yuleba North Substation and a 275kV transmission pipeline from the proposed substation to Powerlink's substations at Wandoan , Clifford Creek and Eurombah.	Final EIS released	2014	Unknown	Unknown	30-40 years	Located near Scotia gas field.

3.3. Project components

The GFD Project will include the following components:

- Production wells
- Fluid injection wells, monitoring bores and potentially underground gas storage wells
- Gas and water gathering lines
- Gas and water transmission pipelines
- Gas compression and treatment facilities
- Water storage and management facilities
- Access roads and tracks
- Accommodation facilities and associated services (e.g. sewage treatment)
- Maintenance facilities, workshops, construction support, warehousing and administration buildings
- Utilities such as water and power generation and supply (overhead and/or underground)
- Laydown, stockpile and storage areas
- Borrow pits and quarries
- Communications.

The final number, size and location of the components will be determined progressively over the GFD Project life and will be influenced by the location, size and quality of the gas resources identified through ongoing field development planning processes, which include consideration of land access agreements negotiated with landholders, and environmental and cultural heritage values. The PHA has been undertaken for a representative field development.

Where practicable, the GFD Project will utilise existing or already approved infrastructure (e.g. accommodation camps, gas compression and water management facilities) from the GLNG Project or other separately approved developments. The GFD Project may also involve sourcing gas from third-party suppliers, as well as the sharing or co-location of gas field and associated facilities with third parties.

For the purposes of transparency this EIS shows an area off-tenure that may be used for infrastructure such as pipelines and temporary camps (supporting infrastructure area). While not assessed specifically in this EIS, any infrastructure that may be located within this area would be subject to further approval processes separate to this EIS.

Approved exploration and appraisal activities are currently underway across the GFD Project's petroleum tenures to improve understanding of the available gas resources. As the understanding of gas resources improves, investment decisions will be made about the scale, location and timing of the next stages of field development.

3.3.1. Wells

The well lease design comprises one or more wellheads, one or two production separators, a flare/vent stack, gas and water gathering lines and means to connect to water and gas gathering systems. Multi-well leases flow into the production separator via dual manifolds; one gas and one water.

During construction, a well lease (the area cleared for each well) will be developed to accommodate the necessary drilling equipment and support services. Wells become operational once they are connected to the gas and water gathering systems for delivery to the gas compression and water management facilities. Wells are expected to be operational for 30 years or longer.

Where required, well stimulation techniques will be used to improve gas flow rate. Well stimulation may be carried out as part of the completion of a well, and some wells may be subject to multiple stimulation events over their operational life. In addition to the standard hydraulic fracturing process, Santos GLNG is continually evaluating innovative techniques for enhancing gas production and minimising impacts. These techniques include pneumatic techniques and fluid systems with even lower concentrations of chemicals.

Wells will be monitored and controlled remotely. Information on separator pressure, and gas and water flow rates will be transmitted via radio telemetry or communication cables to enable gas and water production rates to be controlled remotely. Wells and well lease equipment will be routinely inspected visually and maintained as required. Well workover (the major servicing of a well) will generally be required multiple times through the life of a well.

3.3.2. Gas and water gathering lines

Gas and water extracted from a well will be separated at the surface and flow via gathering lines, provided for collecting gas and water from each well lease to nodal gas compressors or water management facilities. Gathering systems typically comprises gathering lines, manifolds and risers; and for gas gathering systems, low point drains on the gas gathering lines and high point vents on the water gathering lines.

The gas and water gathering lines will either be laid on the ground or buried. Gas gathering lines will be designed and constructed to comply with *AS2885 – Pipelines Gas and Liquid Petroleum* (Ref. 4) and the Australian Pipeline Industry Association (APIA) *Code of Environmental Practice* (Ref. 5). Santos GLNG will use existing gathering lines within petroleum tenures, where practical. Alternatively, new gas and water gathering lines will be constructed.

3.3.3. Gas and water transmission pipelines

A network of transmission pipelines will be constructed to transmit gas and water under pressure from gas compression or water management facilities. Transmission pipelines will collect gas from nodal compressors within the gas fields and transport gas under pressure to centralised hub compressors, and then deliver the gas to the Gladstone gas transmission pipeline (or third party transmission pipeline), which form part of the broader GLNG Project.

The transmission pipelines will comprise 100 mm to 750 mm diameter buried pipe, usually less than 50 km in length. Santos GLNG will use existing transmission pipelines within petroleum tenures, where practical. Alternatively, new transmission pipelines will be constructed. Where practical, the transmission pipelines will be co-located with other linear infrastructure.

3.3.4. Gas compression facilities

Nodal compressors will be installed where required to compress gas to the pressure required for transmission via steel transmission pipelines to the hub compressors at the gas compression facilities. Nodal compressors will be operated on a continuous basis and will be fully automated. Nodal compressors can be designed entirely as unmanned facilities with routine maintenance and inspection.

A typical nodal gas compression facility includes the following equipment:

- Inlet separators
- Gas compressors
- Fuel gas skid
- Compressor oil recovery system
- Black start and emergency systems generator.

Additional equipment (such as gas dehydration or a flare system) may be installed at specific locations. The risk assessments will be updated as the field development matures to reflect the equipment and gas processing conditions.

Gas compression facilities will be developed in each of the gas fields (Arcadia, Fairview, Roma and Scotia) and provide the necessary pressure for the gas to enter the high pressure gas transmission pipeline to markets. In the majority of cases, triethylene glycol (TEG) dehydration will be used to reduce the water vapour content of the gas prior to compression in a hub compressor, and if required, after the hub compressor before the gas enters the high pressure gas transmission pipeline. For gas compression facilities comprising both nodal and hub compressors, TEG dehydration is conducted only once in the process.

Hub compressors will be operated on a continuous basis and will be fully automated. They can be either unmanned facilities or staffed during the day with plants operated and monitored remotely at night. Where the facilities are manned, the operators will generally live near the site and commute to work.

A typical hub gas compression facility includes the following equipment:

- Inlet separators
- Gas compressors
- Separators
- TEG units
- Fuel gas skid
- Black start generator
- Flare.

3.3.5. Water storage and water management facilities

Facilities to manage water produced from wells will be constructed across the four gas fields. Where practicable, Santos GLNG will use existing water storage structures (e.g. fluid storage) and other infrastructure to assist in the management of the GFD Project's coal seam water. However, the GFD Project will also require the construction of new water management infrastructure. This will include water gathering lines and transmission pipelines, as well as the following:

- Water management dams for storage of coal seam water and provide temporary storage and balancing of water quantity and quality
- Transmission pipelines for pumping water from water management dams to water treatment facilities
- Water treatment facilities, including but not limited to:
  - Water amendment facilities, which use chemical dosing to amend pH and the ionic balance of the water prior to use
  - Desalination treatment facilities (e.g. reverse osmosis and ion exchange resin).
- Brine storage to contain the concentrated waste produced by desalination (if reverse osmosis is used)
- Water transmission pipelines for transfer to beneficial use areas
- Beneficial use facilities (e.g. irrigation).

The water management facilities will operate 24 hours a day, with short periods of shutdown to facilitate scheduled maintenance.

3.3.6. Associated plant facilities

For the purposes of this study, associated plant facilities comprise the following:

- **Fuel/chemical storage, workshops and maintenance areas:** A component of the GFD Project construction and operational activities will be the fuelling, maintenance, inspection and testing of equipment. These facilities will be established at major construction and operational centres including laydown areas, stockpile and storage areas, accommodation camps and gas compression and water management facilities. The fuelling facilities will be constructed as modular tank and pump facilities and will be relocatable between facilities. About half of the fuel storage facilities will have capacities greater than 10,000 litres. Fuel storage will comply with appropriate Australian Standards.
- **Stockpile, laydown and/or storage areas:** General construction, maintenance and laydown yards will be established to support construction activities. The laydown yards will be located close to construction areas; they will be temporary and only used for the construction phase (a maximum of three years). During operations, a smaller number of maintenance and laydown yards will be required to support ongoing operational activities.
- **Borrow pits and quarries:** Borrow pits will be required to source sand, gravel and other materials that are needed for the field development program. Santos GLNG does not anticipate that blasting will be required to source fill materials. The borrow pits will be used intensively during the construction program and most will be rehabilitated following the completion of this program. However, a number of pits may be maintained to provide sand and gravel for ongoing road and site maintenance activities.
- **Power generation and distribution facilities:** Power for the gas field operations will be generated by gas-fired alternators or serviced by grid connections, where available. The energy sources, including potential gas-fired power options, will be investigated during the field development phase for the GFD Project, and may include the following:
    - Where reticulated power is unavailable, gas-fired alternators will be provided at the well lease to power the pumps to extract water from the coal seams.
    - Gas turbines for power generation will be installed at gas compression and water management facilities; however in some cases, power may be supplied from reciprocating gas engines or via direct drive gas engines on equipment.
    - Diesel driven alternators will be used at temporary facilities with diesel stored in above-ground storage tanks and regularly delivered by tanker truck to site.

- Where connection to the grid is the preferred option, a transmission network service provider may be engaged to construct gas transmission pipelines and other associated infrastructure to enable Santos GLNG to use electricity from the grid. In such cases, the major gas compression facilities will be used as the connecting point for the electricity that would subsequently be distributed to the remote facilities.

- Regardless of the power source options selected, the power will be reticulated throughout the GFD Project area via a combination of above and below ground power lines which where practicable will be co-located with other infrastructure such as water and gas gathering lines, infield transmission pipelines or roads.

- **Other external infrastructure** such as transport, water supply and telecommunications.

3.3.7. Accommodation facilities

Local residents employed on the GFD Project will already have local housing in the regional towns such as Roma, Wallumbilla, Taroom, Wandoan, Injune and Rolleston. Non-resident workers will be housed in purpose-built accommodation facilities (known as camps) close to work sites.

3.3.8. Access roads and tracks

Roads and access tracks will be required for construction and operations activities. Access roads will be built to allow servicing of well leases and access to other infrastructure (e.g. wells, gas compression facilities, accommodation camps, etc.). Wherever practicable, the GFD Project will use existing tracks, including access tracks and roads used by the GLNG Project, or already disturbed areas. Upgrades of existing access tracks and roads may be required to accommodate the construction and operational traffic associated with the GFD Project.

3.4. Hazardous materials

Hazardous materials associated with the GFD Project encompass dangerous goods as well as non-dangerous goods materials, as summarised in APPENDIX A: Quantities of hazardous materials. The hazardous materials include the following:

- Gas, at a range of pressures up to transmission pipeline pressure of approximately 15 MPa
- TEG, which is used in the removal of water from the gas prior to compression and injection into the pipeline system
- Diesel fuel
- Chemicals for treatment of coal seam water. Typical chemicals include common acids and alkalis, hypochlorite, biocides and various inorganic salts that might be found in naturally occurring water sources

- Chemicals used for drilling and well stimulation, including common acids and alkalis, salts, biocides and various gelling agents, sands and proppants.

3.5. Environmental and meteorological data

Based on a review of Bureau of Meteorology (BoM) data for Roma, Taroom, Rolleston and Injune, the following environmental conditions have been used in this study:

- Ambient temperature: 24°C [2]
- Relative humidity: 60%.

Meteorological data is used as an input to model the dispersion of natural gas following a release. Meteorological data used in this PHA is based on BoM data for Roma airport, Station 043091 (Ref. 6). More detailed meteorological data has been collected for air quality modelling, however the level of detail selected for the PHA is appropriate for this preliminary study. The data used and the resulting wind rose are shown in Table 3.2 and Figure 3.2 respectively. The wind is predominantly from the northern and north eastern directions; the following three representative wind speeds and Pasquill weather stability classes were used in this study (Ref. 6):

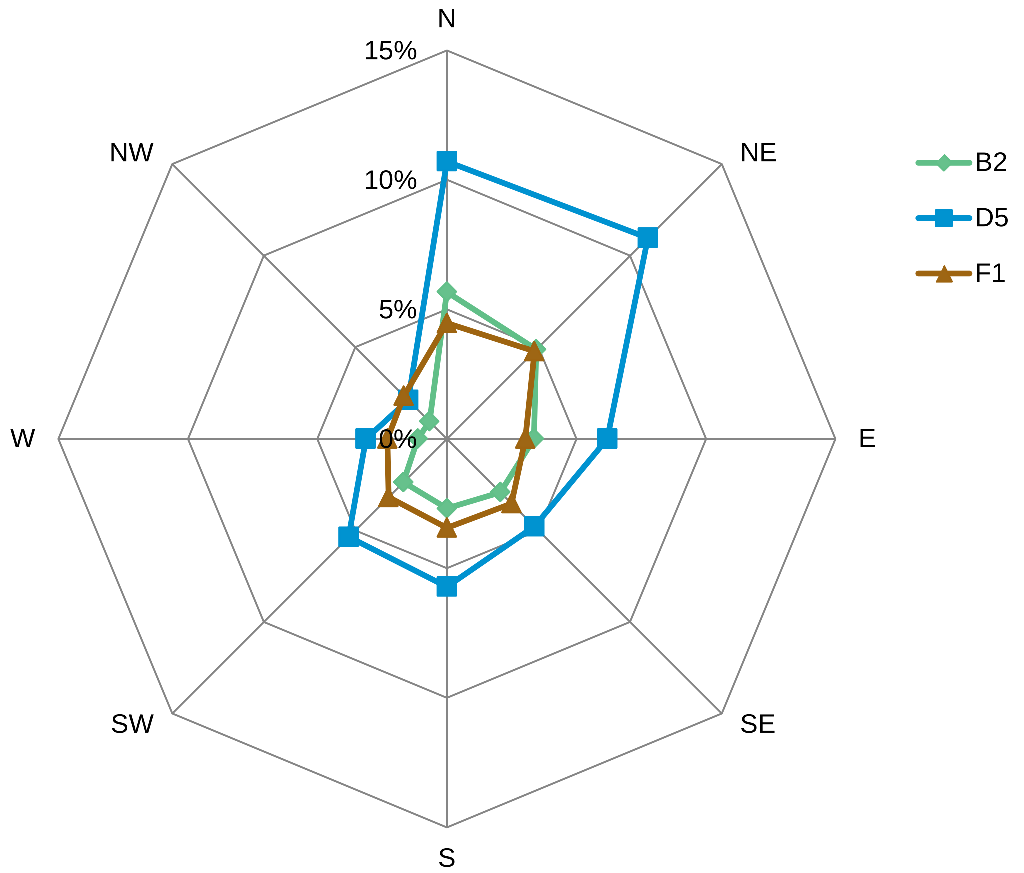
- Moderately unstable conditions (Pasquill Stability Class B) with a wind speed of 2 m/s (B2)
- Neutral conditions (Pasquill Stability Class D) with a moderate wind speed of 5 m/s (D5)
- Moderately stable conditions (Pasquill Stability Class F) with a low wind speed of 1 m/s (F1).

Table 3.2: Meteorological data (from Roma airport)

Stability class	Average wind speed (m/s)	Occurrence (%)	Distribution of stability class by wind direction from (%)							
			N	NE	E	SE	S	SW	W	NW
B	2	24.0	5.7	4.9	3.4	2.9	2.7	2.4	1.1	1.0
D	5	49.0	10.7	11.0	6.2	4.8	5.7	5.4	3.1	2.1
F	1	27.1	4.5	4.8	3.0	3.5	3.4	3.2	2.3	2.3

[2] The ambient temperature represents an average temperature used for consequence analysis in Section 7; it does not have a significant effect on the consequence results, as compared to the wind speed and stability class discussed in this section.
Extreme weather conditions (including extreme temperatures) are considered in Section 6.4 of this report.

Figure 3.2: Wind rose (from Roma airport)



4. HAZARD AND RISK MANAGEMENT PROCESSES

4.1. Overview

As detailed in Section 2.2, the objective of the PHA is to address the hazard and risk component of the EIS terms of reference.

The PHA is undertaken at an early study in the hazard and risk management process while the GFD Project is still in concept stage. EHSMS09 provides details of the lifecycle approach to hazard management.

At this stage of the GFD Project, the PHA allows an assessment of whether the risk associated with the infrastructure will be able to meet relevant risk criteria. Santos GLNG's hazard and risk management processes ensure the effective and continued management of risks through the lifecycle of a project. This section provides an overview of the hazard and risk management processes and best engineering practices to be implemented for the GFD Project. This is based on the existing processes and practices contained within the approved environmental management and regulatory framework that Santos GLNG has already developed and implemented for the GLNG Project.

4.2. Legislation

The *Petroleum and Gas (Production and Safety) Act 2004* (Qld) (P&G Act) and the *Petroleum Act 1923* (Qld) regulate petroleum and natural gas exploration and development in Queensland. They aim to facilitate petroleum activities and the development of a safe, efficient and viable petroleum and fuel gas industry with minimal land use conflict.

The *Work Health and Safety Act 2011* (Qld) (WHS Act) (Ref. 7) aims to provide a balanced framework to secure the health and safety of workers and workplaces and protect persons from harm to the highest level that is reasonably practicable. The WHS Act provides a framework for the protection of the health, safety and welfare of workers at work and the general public.

It is noted that the WHS Act generally excludes operating plant, within the meaning of the P&G Act. However, it does provide a framework for the protection of the health, safety and welfare of workers at work and the general public. As such the general principles of hazard identification and risk management were considered in the PHA.

A range of additional legislation applies to various aspects of the GFD Project. For example the *Electrical Safety Act 2002* (Qld) establishes a legislative framework for electrical safety in Queensland. Aspects of the act may be relevant to the GFD Project to the extent that electrical work, as defined, is performed. It is noted that the *Electrical Safety Act 2002* (Qld) details a number of excluded provisions with respect to petroleum plant that is operated under the P&G Act.

It is not the purpose of the PHA to identify and demonstrate compliance with relevant legislation. Legislative compliance will be managed through the project approvals process and EHSMS09. The above is a summary of key legislation that applies in whole or partly to the management of hazard and risk and is provided to support the context of the PHA in terms of identifying and assessing hazards and risks.

4.3. Policy framework

Santos GLNG has an established integrated risk management system, the Santos GLNG Environment, Health and Safety Management System, which complies with:

- AS 4801: Occupational health and safety management systems – Specification with guidance for use (Ref. 8).
- AS/NZS ISO 14001: Environmental management systems – Specification with guidance for use (Ref. 9).

The Environment, Health and Safety Management System provides a clear set of EHS expectations so that there is a consistent and efficient approach across Santos GLNG. It describes the requirements for effective environmental, health and safety practices across Santos GLNG activities and operations. The Environment, Health and Safety Management System requirements address the management of risk associated with high frequency/low consequence events (the focus of traditional environment, health and safety management systems) as well as low frequency/high consequence events which are typically dealt with by a process safety management system. It is a dynamic system that is continually being improved to ensure it is current and aligned with the changing nature and demands of Santos GLNG's business.

The application of the Environment, Health and Safety Management System enables Santos GLNG to achieve the objectives detailed in its environment, health and safety policies. The system consists of three primary layers:

- Environment, health and safety management standards (EHSMS) – identify how to systematically manage environmental health and safety risks
- Environmental hazard standards (EHS) – identify and provide controls to manage the environmental risks associated with specific activities.
- Health and safety hazard standards (HSHS) – identify and provide controls to manage the health and safety risks associated with specific activities.

The corporate risk assessment system is described in the EHSMS09 (Ref. 10). It outlines the requirements to:

- Identify EHS hazards, assess their risk and control them to as low as reasonably practicable.
- Identify significant EHS hazards and document how they are being managed to as low as reasonably practicable.

- Have a system to escalate EHS significant hazards to management for approval for continued operation and for management to sign off on WHS significant hazards, controls and how critical controls will be checked.
- Meet legislative requirements that require certain EHS hazards and risks to be managed.

These requirements are aligned with the EIS TOR.

The full list of management standards is provided below:

- EHSMS01: EHS policies
- EHSMS02: Legal obligations and other requirements
- EHSMS03: EHS objectives, targets and improvement plans
- EHSMS05: EHS responsibility and accountability
- EHSMS06: Training and competency
- EHSMS07: Consultation and communication
- EHSMS08: Documents and records management
- EHSMS09: Managing EHS risks
- EHSMS10: Contractor engagement and management
- EHSMS11: Operations integrity
- EHSMS12: Management of change
- EHSMS13: Emergency preparedness
- EHSMS14: Monitoring, measurement and reporting
- EHSMS15: Incident investigation and response
- EHSMS16: EHS audit and inspection
- EHSMS17: Management review
- EHSMS18: Sustainability
- EHSMS19: Climate change.

The list of EHS are as follows:

- EHS01 Biodiversity and land disturbance
- EHS02 Underground storage tanks and bunds
- EHS03 Produced (coal seam) water
- EHS04 Waste
- EHS05 Air emissions

- EHS06 Environmental impact assessment and approvals
- EHS07 Energy efficiency
- EHS08 Contaminated sites
- EHS09 Pest plants and animals
- EHS10 Water resources
- EHS11 Cultural heritage
- EHS12 Noise emissions.

The HSHS are as follows:

- HSHS01: Hand Safety
- HSHS02: Land Transportation
- HSHS03: Air transportation
- HSHS04: Health and wellbeing
- HSHS05: Working in hot environments
- HSHS06: Electrical safety
- HSHS07: Working at heights
- HSHS08: Chemical management and dangerous goods
- HSHS09: Radiation
- HSHS10: Food safety
- HSHS11: Manual handing and ergonomics
- HSHS12: Occupational noise
- HSHS13: Working alone in remote locations
- HSHS14: Legionella
- HSHS15: Security
- HSHS16: Lifting equipment
- HSHS17: Personal protective equipment
- HSHS18: Entry to confined spaces
- HSHS19: Excavations
- HSHS20: Plant safety.

4.4. Post-environmental impact statement field planning and development process

The constraints approach is based upon the GFD Project environmental protocol for constraints planning and field development (Constraints protocol) (Ref. 11). The Constraints protocol applies to all gas field related activities. The scope of the Constraints protocol is to:

- Enable Santos GLNG to comply with all relevant State and Federal statutory approvals and legislation
- Support Santos' environmental policies and the General Environmental Duty (GED) as outlined in the Environmental Protection Act 1994 (Qld) (EP Act)
- Promote the avoidance, minimisation, mitigation and management of direct and indirect adverse environmental impacts associated with land disturbances
- Minimise cumulative impacts on environmental values.

The Constraints protocol details the process that Santos GLNG will use to identify, assess and manage potential impacts to the environment during field planning and development. This process has been successfully used for the approved GLNG Project, which increases the certainty of GFD Project environmental outcomes.

The general principles of the Constraints protocol, in order of preference, are to:

- Avoid — avoid direct and indirect impacts
- Minimise — minimise potential impacts
- Mitigate — implement mitigation and management measures to minimise adverse impacts
- Remediate and rehabilitate — actively remediate and rehabilitate impacted areas
- Offset — offset residual risk in accordance with regulatory requirements.

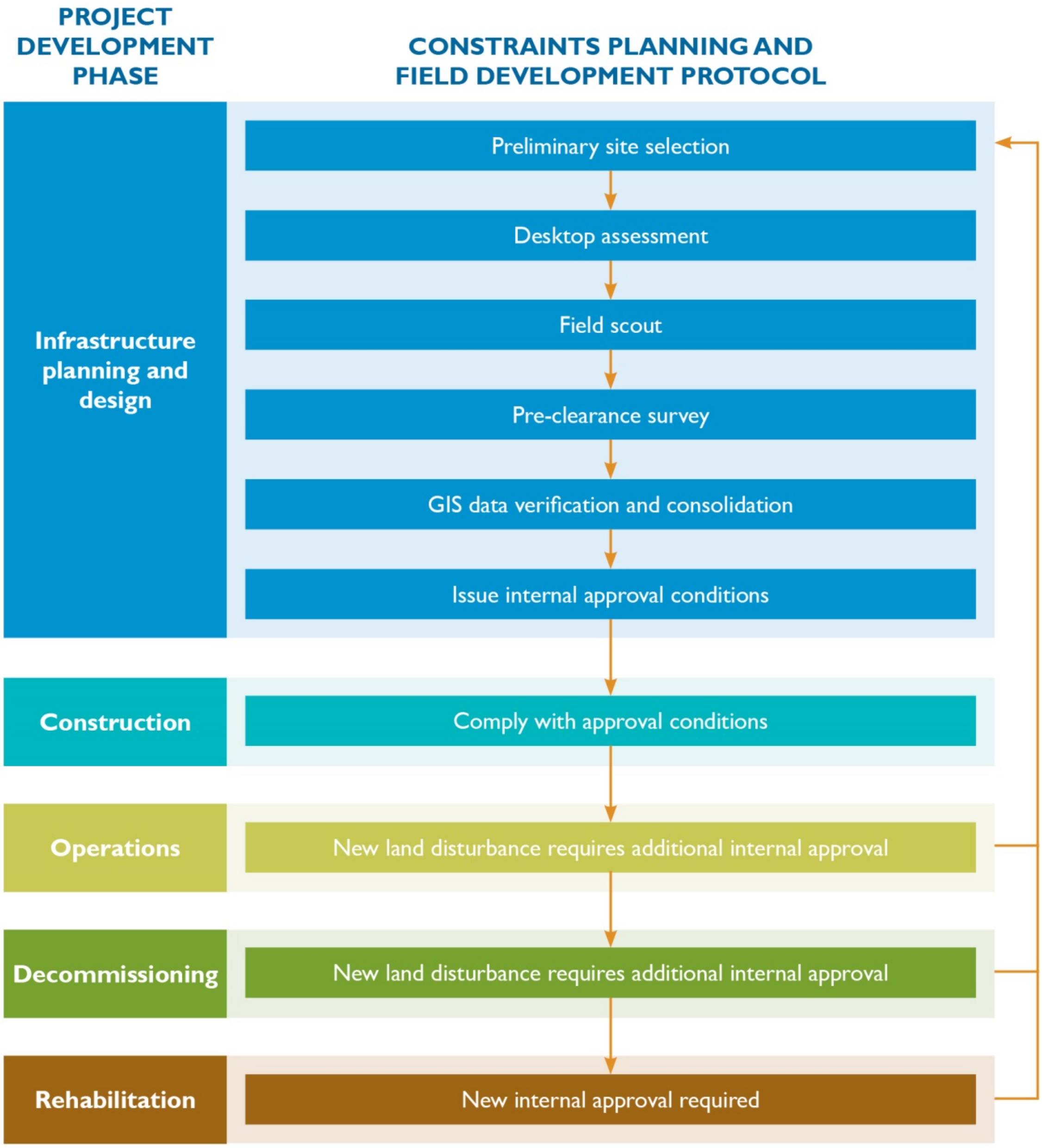
Consistent with Santos GLNG's environmental management hierarchy, the Constraints protocol prioritises avoidance of environmental impact during field planning by identifying those areas that are not amenable to development. This includes areas of high environmental value as identified in regulatory frameworks and Santos GLNG's baseline surveys. For areas that are considered appropriate to develop, Santos GLNG will identify impacts to environmental values that could potentially occur due to the construction, operations and decommissioning activities of the GFD Project, and determine pre-mitigated impacts (i.e. those that would occur without mitigation).

Relevant mitigation and management measures based on the approved environmental management framework already implemented for the GLNG Project are then applied to the pre-mitigated impacts to identify the mitigated (residual) impacts. This process increases certainty about potential impacts by identifying those areas that are not amenable to development, and for those areas where development could occur, how development should proceed.

The post-EIS field development process is a continuation of the field planning process and will be ongoing throughout the life of the GFD Project. The field development process will inform the GFD Project's design, together with a range of other factors including technical feasibility, cost and risk as required by standards applicable to the design, construction, operations, decommissioning and rehabilitation of gas developments. This information will be used to support the subsequent approvals process such as environmental approval application and the plan of operations.

The tasks involved in the field development process are summarised in Figure 4.1.

Figure 4.1: Field development process



The assessment increases certainty about potential impacts by identifying those areas that are not amenable to development, or if they were to be developed, how development should proceed. This occurs by identifying the constraints to development that exist within the GFD Project area and the hazard and risk management controls to be applied to GFD Project activities in these constrained areas. In this way, Santos GLNG can optimise environmental outcomes, by avoiding sensitive receptors (such as towns and homesteads) wherever possible. Where avoidance is not possible, Santos GLNG will use a range of management and mitigation measures to minimise the impact of the GFD Project. This hierarchy will be maintained throughout the phases of the GFD Project, providing multiple opportunities for refinement of scope and execution. Constraint classifications are summarised in Table 4.1.

Table 4.1: Constraint classifications relevant to hazard and risk

<table>
<tr><th>Level of constraint</th><th>Constraint layer</th></tr>
<tr><td rowspan="4">No-go area</td><td>Category A environmentally sensitive areas including national parks[1], conservation parks, and forest reserves (NC Act).</td></tr>
<tr><td>EPBC Act-listed spring vents and complexes including primary 200 m buffer.</td></tr>
<tr><td>Wetlands of national importance including 200 m buffer.</td></tr>
<tr><td>Wetlands of high ecological significance or high conservation value (Map of Referrable Wetlands).</td></tr>
<tr><td rowspan="3">Surface development exclusion area</td><td>Primary 200 m buffer for Category A environmentally sensitive areas.</td></tr>
<tr><td>The following Category C environmentally sensitive areas[3]:
• Nature refuges (NC Act)
• Koala habitat areas (Nature Conservation (Koala) Conservation Plan 2006)
• Declared catchment areas (Water Act 2000 (Qld)).</td></tr>
<tr><td>The following Category B environmentally sensitive areas:
• Coordinated conservation areas (NC Act).
• State forest park /special forestry areas (Forestry Act 1959 (Qld) (Forestry Act)).
• Ramsar sites listed as wetlands of international importance.</td></tr>
<tr><td rowspan="3">High constraint area</td><td>Watercourses (stream orders) including 100 m buffer.</td></tr>
<tr><td>Wetland defined as ‘general ecologically significant wetland’ or ‘wetland of other environmental value’ (Map of Referrable Wetlands).</td></tr>
<tr><td>Spring vents and complexes (not protected under the EPBC Act) including primary 200 m buffer.</td></tr>
<tr><td rowspan="7">Moderate constraint area</td><td>Secondary 100 m buffer for Category A environmentally sensitive areas.</td></tr>
<tr><td>Secondary 100 m buffer for spring vents and complexes (EPBC Act).</td></tr>
<tr><td>Matters of national environmental significance including habitats (threatened species habitat and migratory species habitat), threatened communities (derived from state regional ecosystem mapping or verified from field surveys), and flora species.</td></tr>
<tr><td>State forests and timber reserves.</td></tr>
<tr><td>Endangered regional ecosystems including primary 200 m buffer.</td></tr>
<tr><td>The following Category C environmentally sensitive areas:
• Essential habitat including primary 200 m buffer (NC Act).
• Essential regrowth habitat including primary 200 m buffer (NC Act).
• Of concern regional ecosystems including primary 200 m buffer.
• Resource reserve (NC Act)[2].
• State forests/timber reserves (Forestry Act)</td></tr>
<tr><td>Endangered, vulnerable and near-threatened species (NC Act)</td></tr>
</table>

Level of constraint	Constraint layer
Low constraint areas	High value regrowth (endangered and of concern regional ecosystems)
	No concern at present regional ecosystems
	Type A species (NC Act)
	Existing Santos GLNG infrastructure
	Existing road, rail, pipeline and other infrastructure.
	Remaining areas once other constraints have been applied.

[1] Specific and mutually beneficial activities in a (limited depth) national park may be allowed with express written permission from Department of National Parks, Recreation, Sport and Racing. Santos GLNG will only seek permission to enter a (limited depth) national park on limited occasions where no other feasible option exists.

[2] **Low impact petroleum activities** means petroleum activities which do not result in the clearing of native vegetation, earthworks or excavation work that cause either, a significant disruption to the soil profile or permanent damage to vegetation that cannot be easily rehabilitated immediately after the activity is completed. Examples of such activities include (but are not necessarily limited to) chipholes, coreholes, geophysical surveys, seismic surveys, soil surveys, topographic surveys, cadastral surveys, ecological surveys, installation of environmental monitoring equipment (including surface water).

[3] **Linear infrastructure** means linear infrastructure including (but not limited to) gas and water gathering lines, low and high pressure gas and water pipelines, powerlines, communication, roads and access tracks (associated with limited petroleum activities and petroleum activities).

[4] **Limited petroleum activities** means any low impact petroleum activity and single well sites (includes observation, pilot, injection and production wells) and associated infrastructure (water pumps and generators, sumps, flare pits or dams) located on the well site, multi-well sites and associated infrastructure (water pumps and generators, sumps, flare pits, dams or tanks) located on the well sites, construction of new access tracks that are required as part of the construction or servicing a petroleum activity, upgrading or maintenance of existing roads or tracks, power and communication lines, gas gathering lines from a well site to the initial compression facility, water gathering lines from a well site to the initial water storage or dam, and camps within well site that may involve sewage treatment works that are a no release works.

[5] **Petroleum activities** include low impact petroleum activities or limited petroleum activities and all other GFD Project activities including major facilities such as permanent accommodation camps, gas treatment facilities, air strips, water facilities including dams, water storage infrastructure, water treatment and amendment facilities, gas hubs, and nodal compressors.

4.5. Best engineering practices

Hazards and risks associated with the GFD Project will be managed by implementation of measures based on best engineering practices through each phase of the GFD Project. The measures applied have been based on the existing measures that Santos GLNG has already developed and implemented for the GLNG Project. Applying the same measures from the GLNG Project to the GFD Project will ensure a consistent approach by construction and operational personnel and a common understanding for both regulators and the community of the measures to be applied.

The hazard and risk measures for the GFD Project are described in this section and are consistent with the hierarchy of control detailed in the EHSMS09*:* (Ref. 10), as follows:

- Elimination (e.g. by eliminating inventories of dangerous goods)
- Substitution (e.g. by using a less hazardous material in place of a more hazardous material)

- Engineering (e.g. compliance with internal and external standards)
- Isolation (e.g. erection of physical barriers)
- Administrative (e.g. emergency procedures)
- Protective (e.g. use of personal protective equipment (PPE)).

4.5.1. Elimination and substitution

To eliminate potential impacts to/from the GFD Project, the following will be applied when locating and designing GFD Project infrastructure, in line with the Constraints protocol:

- Exclusion of major infrastructure (including hubs and accommodation camps) from flood prone areas, based on flood impact assessments. Wells and linear infrastructure (roads, tracks, pipelines and gathering lines) will be located outside flood prone areas where it is practicable.

Other elimination and substitution measures to be considered when locating and designing GFD Project infrastructure include the following:

- Wells and gas compression facilities are located away from towns, residences or other sensitive land use (such as a school or community facility) where people normally gather.
- GFD Project infrastructure (including hubs and accommodation camps) will not be located in areas mapped as natural hazard management areas under regional council or other planning schemes, in accordance with State Planning Policy (SPP) issued December 2013 (Ref. 12).
- Within the other constraints that must be considered, transmission pipelines will be located to minimise risk to landholders and communities in the event of damage or a leak.
- Restricted stimulation fluids will not be used in hydraulic fracturing. Chemicals used in hydraulic fracturing will be subject to continual review, with a view to replacing or substituting with less hazardous chemicals, if necessary.

4.5.2. Engineering

Detailed engineering design of the GFD Project will be developed on the basis of regulatory standards. The design and construction of the GFD Project facilities will be in accordance with relevant Australian Standards. Other standards and codes will also be considered. In line with Santos GLNG's safety policy, the GFD Project is committed to comply with or exceed relevant legislation and standards.

Standards that particularly apply for hazards and risks associated with the GFD Project include AS 2885.1 – Australian Standard for Pipelines; Gas and Liquid Petroleum, Part 1 Design and Construction.

Examples of standards and reference documents include those listed in Table 4.2. Standards and documents will be complied with where regulated and used as guidance in other cases.

In addition, the GFD Project facilities will be required to comply with the following corporate standards:

- EHSMS and HSHS, as listed in Section 4.3. In particular, the design of GFD Project facilities will be subjected to relevant Santos GLNG Environment, Health and Safety Management System risk assessment processes, including EHSMS09, in order to minimise inherent risks associated with plant design and the materials that are handled.
- Design practices for regulated structures:
  - Gas Satellite Emergency Shutdown (ESD) Systems
  - Gas Wellhead Connection Design
  - Depressuring Systems
  - East Queensland (Surat) Area Design Data
  - Fireproofing of Equipment
  - Flares
  - Relief Device Sizing
  - Relief Systems
  - Vents to Atmosphere
  - Safety Instrumented Systems
  - Hazardous Area Classification
  - Hazardous Area Electrical Design.
- Work Practices for HAZOP studies and risk assessments for buried gas gathering lines and transmission pipelines in remote areas.

Table 4.2: Examples of relevant engineering design standards and reference documents

Organisation	Standard/Document
Australian/New Zealand Standards	• *AS/NZS ISO 31000:2009 Risk Management* • *Managing Environment-related risk (HB203:2012) (Ref. 13)*
National Fire Protection Association (NFPA)	• NFPA 30: *Flammable and Combustible Liquids Code* • NFPA 58: *Storage and Handling of Liquefied Petroleum Gases* • NFPA 59: *Storage and Handling of Liquefied Petroleum Gases at Utility Gas Plants* • NFPA 70*: National Electrical Code* • NFPA 77: *Static Electricity* • NFPA780*: Lightning Protection Code* • NFPA 307*: Construction and Fire Protection at Marine Terminals, Piers and Wharves* • NFPA 497A*: Classification of Class I Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* • NFPA 497B: *Classification of Class II Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*
American Petroleum Institute (API)	• API RP 620*: Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks* • API RP 2003: *Protection Against Ignitions Arising Out of Static, Lightning and Stray currents* • API Std.2510: *Design and Construction of Liquefied Petroleum Gas (LPG) Installations.* • API RP 500*: Classification of Locations for Electrical Installations at Petroleum Facilities* • API RP 520: *Sizing, Selection and Installation of Pressure-Relieving Devices in Refineries* • API RP 521*: Guide for Pressure- Relieving and Depressurising Systems* • API Pub. 2510A*: Fire Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities.*

4.5.3. Isolation

Isolation measures to be implemented for the GFD Project facilities include the following:

- Fencing, demarcation and buffers will be provided around hazardous areas, as follows:
  - A barrier fence to demarcate the area in which hazardous atmospheres may be present.
  - Facilities have security fencing and large buffers around process units.
- Hazardous materials, including combustible liquids, will be stored and handled in accordance with the relevant Australian Standard where such is available.

- Stored liquids that have the potential to cause environmental harm will have an effective secondary containment system to prevent the release of liquids to water and or land as detailed in the Santos GLNG *Upstream Chemical and Fuel Management Plan,* as follows:
  - Bunding will be provided for storage facilities of environmentally hazardous materials (including hydrocarbons) and facilities for materials transfer.
  - Spill containment pallets will be used for minor storage (i.e. less than 1,000 L). The pallets would be used in a level area (to ensure full spill storage capacity).
- Portable plant and equipment fitted with combustion engines (e.g. welders, temporary air compressors and generator packages) will be fitted with adequate provisions to ensure that spills or leaks during routine operation or refuelling are contained. This can be provided by using suitable drip trays and/or drainage systems.

4.5.4. Administrative and protective

An extensive range of operating procedures will apply to the construction, commissioning, normal operations, decommissioning and handling of process deviations. These include:

- Procedures for drilling and testing well integrity
- Procedures for monitoring of gas pressure and flow
- Procedures for routine inspection and testing of equipment, including detailed inspection and testing of the well, well head and pipework
- Procedures for equipment maintenance
- Signage
- Routine inspections
- Security patrols and cameras
- Maintenance of buffers and fire breaks
- Procedures for disconnection, depressurisation, flushing and purging of piping and flow lines as part of decommissioning.

Santos GLNG will employ skilled operators and personnel for the GFD Project. Training will be provided in line with the Santos GLNG Competency Based Training Program to effectively fulfil their roles and responsibilities. *EHSMS06: Training and Competency* details the key requirements and support the health and safety policy, safety management and emergency plans.

Santos GLNG employees and contractors are responsible for contributing to a safe workplace. This means conducting day-to-day activities according to the EHSMS which in part focus on the continual identification of hazards and implementing effective risk control measures. Everyone is encouraged to suggest ways Santos GLNG can improve its safety performance via toolbox meetings, EHS committee meetings or by contacting their Supervisor, their Health and Safety Representative, an EHS adviser or Santos GLNG's Corporate EHS&S Department.

4.6. Management framework

To facilitate the consistent management of hazards and risks for the GLNG Project and the GFD Project, Santos GLNG has implemented a number of management plans and procedures, which are summarised in Table 4.3.

Table 4.3: Management plans relevant to hazard and risk

Management Plan	Commitments
GFD Project environmental protocol for constraints planning and field development (the Constraints protocol)	The Constraints protocol applies to all gas field related activities. The scope of the Constraints protocol is to: • Enable Santos GLNG to comply with all relevant State and Federal statutory approvals and legislation • Support Santos GLNG's environmental policies and the General Environmental Duty (GED) as outlined in the EP Act • Promote the avoidance, minimisation, mitigation and management of direct and indirect adverse environmental impacts associated with land disturbances • Minimise cumulative impacts on environmental values. The Constraints protocol provides a framework to guide placement of infrastructure and adopts the following management principles: • Avoidance — avoiding direct and indirect impacts • Minimisation — minimise potential impacts • Mitigation — implement mitigation and management measures • Remediation and rehabilitation — actively remediate and rehabilitate impacted areas • Off-set — offset residual adverse impacts in accordance with regulatory requirements. The Constraints protocol enables the systematic identification and assessment of environmental values and the application of development constraints to effectively avoid and / or manage environmental impacts.
Hydraulic fracturing risk assessment: Compendium of assessed fluid systems	The Hydraulic fracturing risk assessment report synthesises the hydraulic fracturing risk assessments completed on various hydraulic fracturing fluids and provides a framework for including new fluid systems within the risk assessment document. The body of the report provides generalised information, including the geology and hydrogeology of the area, risk assessment methodologies (qualitative and quantitative) and a high level understanding of current results. The appendices include risk assessments of individual hydraulic fracturing fluid systems.

Management Plan	Commitments
Queensland incident management plan (QIMP)	The QIMP describes the use of the Santos GLNG incident management framework, including the procedures and systems that apply to the Santos GLNG operations and activities. The Queensland Incident Management Plan clearly defines and documents the framework that is to be applied in response to an incident. The Plan adopts the following principles of effective incident management: • Prevention - identify and minimise risks and threats • Preparedness - prepare plans, training and testing • Response - activate plans, contain and communicate • Recovery - regain normal operations. In accordance with EHSMS13 Emergency preparedness an emergency response plan is to be developed for each asset or activity.
Emergency response plan (ERP)	The ERP forms part of Santos GLNG's overall emergency response, is supplementary to the Queensland Incident Management Plan and provides the necessary information to deal with emergencies at the site and asset level. Santos GLNG will engage with Queensland Ambulance Service and Queensland Fire and Emergency Services across the life of the GFD Project concerning joint responsibilities for emergency response.
Contingency plan for emergency environmental incidents (Contingency plan)	The Contingency plan details the management practices in place within Santos GLNG to minimise environmental harm during an emergency environmental incident. The plan identifies potential incidents, and provides response actions, including escalation, communication, reporting and monitoring. The plan links to the Emergency Response Plan and Queensland Incident Management Plan, to ensure a consistent response regardless of whether incidents are environmental or otherwise in nature.
Social impact management plan (SIMP)	The SIMP established for the GLNG Project will be implemented across the GFD Project. The plan outlines the roles, responsibilities and rights of Santos GLNG, the government, impacted communities and other stakeholders in relation to the GFD Project. In particular, it outlines the framework for community engagement, management strategies to avoid, mitigate or minimise potential impacts and to maximise opportunities and benefits arising throughout the life of the GFD Project, as well as a monitoring and reporting process. • The GLNG Project SIMP will be supplemented by issue action plans relating to the GFD Project that focus on the following key areas as agreed with the Coordinated Project Delivery Division of the Coordinator-General's office:Water and environment • Community safety • Social infrastructure • Community wellbeing and liveability • Local industry participation and training • Aboriginal engagement and participation. The SIMP is an operational document that is updated to reflect the ongoing needs of Santos GLNG and the communities it operates in. It is available on the web at: http://www.santosglng.com/resource-library/community/social-impact-management-plan-community-handbook.aspx

Management Plan	Commitments
Decommissioning and abandonment management plan (DAMP)	The DAMP describes the management framework in place for when petroleum activities cease. The objectives of the plan are to: • Undertake decommissioning or rehabilitation of assets in a manner that complies with regulatory requirements and minimises the risk of environmental harm • Undertake decommissioning and rehabilitation activities in a manner that meets stakeholder expectations • Leave a landform that is stable and compatible with intended post-closure land use Provide the beneficial reuse of Santos GLNG infrastructure constructed to third parties (e.g. landholders or local authorities) where an appropriate agreement has been signed by both parties and regulatory authorities are satisfied.
Chemical and fuel management plan (CFMP)	The CFMP details the appropriate storage and handling practices of chemicals and fuels. The objectives of the plan are to: • Facilitate compliance with relevant legislation, regulations and approvals • Provide a framework for Santos GLNG to store and handle bulk chemicals and fuels in a way that minimises risk to the environment and human health • Assess the potential risk of a chemical or fuel prior to its use • Identify and implement appropriate mitigation measures.

5. METHODOLOGY

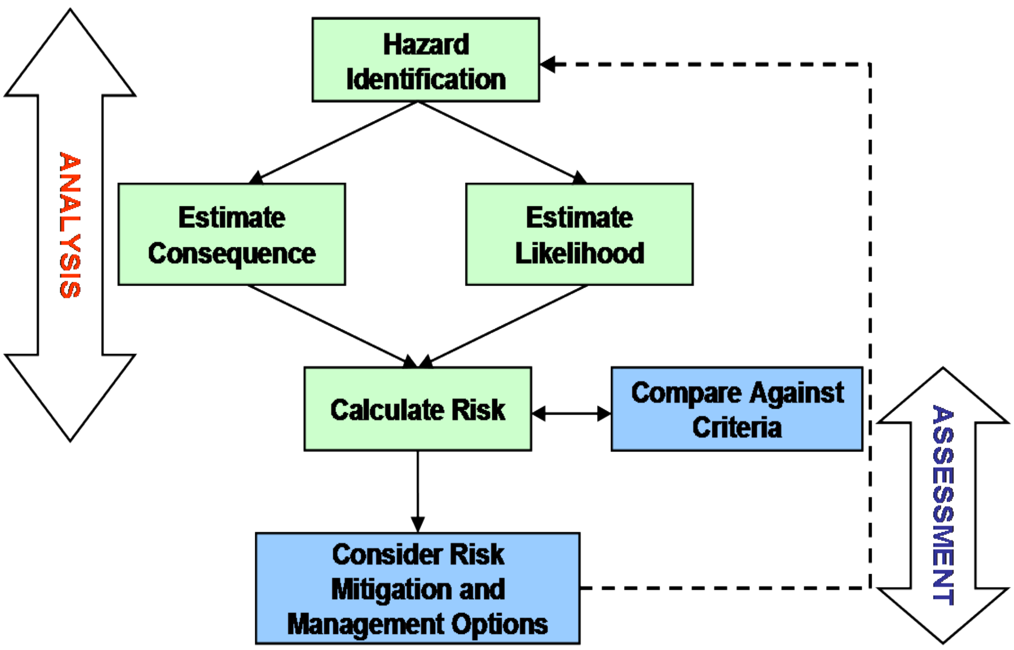
5.1. Overview

The potential direct and indirect impacts of the GFD Project on environmental values have been assessed using one of three impact assessment methods: significance assessment, risk assessment and compliance assessment; this PHA has used the risk assessment method.

The risk assessment methodology for the PHA was based on the NSW DoP guidelines, *Multi-Level Risk Assessment Guideline* (Ref. 14) and HIPAP No. 6, *Hazard Analysis* (Ref. 1). These are the most commonly applied guidelines for land use safety planning in Queensland in the absence of State specific guidelines. A PHA is usually required for an EIS for a potentially hazardous industrial development. The PHA is preliminary in the sense that detailed design information is usually not available at this stage. The PHA is part of the hazard and risk management process that continues throughout the GFD Project lifecycle. In order to undertake the assessment at this preliminary stage it is necessary to make a number of assumptions. A list of assumptions is included in APPENDIX E: Assumptions.

A semi-quantitative level of analysis and assessment was used for the PHA, which is consistent with a Level 2 risk assessment as described in the *Multi-Level Risk Assessment Guideline*. The basic methodology for this PHA is shown in Figure 5.1 (reproduced from HIPAP No. 6); further details of the key study stages are given below.

Figure 5.1: PHA methodology (reproduced from HIPAP No. 6) (Ref. 1)



5.2. Hazard identification

The first step in the hazard identification involved a preliminary screening of the hazardous materials associated with the GFD Project, to identify materials with the potential for significant injury, fatality or property damage in the absence of controls. The preliminary screening method used is described in the *Multi-Level Risk Assessment Guideline* (Ref. 14).

For those materials identified from the preliminary screening, hazardous incident scenarios were identified based on a review of hazard identification studies undertaken for the GLNG Project, review of past incidents involving natural gas and Sherpa's experience in undertaking safety-related studies for various industries. Potential impacts on GLNG Project infrastructure due to external natural hazards and adverse environmental conditions were also identified. Based on an assessment of whether the identified hazards could potentially have off-site impacts on people or property, a list of scenarios to be further assessed in this PHA was developed.

5.3. Consequence analysis

Consequence analysis was undertaken for scenarios with the potential for off-site impacts. The consequences of hazardous events considered in this PHA include the following:

- Fireball, in the event of immediate ignition following a pipeline rupture
- Jet fire, if a continuous natural gas release is ignited immediately
- Flash fire, in the event of delayed ignition of a natural gas release
- Bund fire, in the event of escalation of an external fire to diesel stored at the compression facilities or associated facilities (e.g. accommodation facilities).

The consequences of the scenarios identified were modelled using the proprietary consequence modelling package, *TNO Effects*, with the exception of fireballs, which were modelled using the approach given in the *TNO Yellow Book*. The consequence analysis results are presented in Section 7.

5.4. Likelihood estimation

In line with the methodology for a level 2 risk assessment, the likelihood of occurrence of hazardous events with consequences that extend beyond the infrastructure boundary or pipeline easement have been assessed. The likelihoods of these events were estimated using event tree analysis, taking into account the following:

- Historical leak frequencies from equipment and pipelines, combined with a high level parts count of equipment
- Ignition probability
- Release orientation.

Only the main process equipment was considered in the likelihood analysis. Detailed analysis will be undertaken once location and full parts count of equipment are available in later stages of field development.

The likelihoods estimated for the scenarios assessed in this study are presented in Section 8.

5.5. Risk assessment

Risk assessment involves combining the off-site scenario consequences and their associated likelihoods and comparing against relevant risk criteria. The risks of the hazardous events considered in this study were assessed as follows:

- Risks associated with the wells and compression facilities were assessed on a qualitative basis, using the Santos GLNG risk matrix.
- Risks associated with the gas gathering and transmission pipelines were initially assessed on a qualitative basis which was extended to a quantitative basis. The results are presented as risk transects, which show the risk as a function of the perpendicular distance from the gas gathering or gas transmission pipelines.

Risks are presented as residual risk based on the adoption of existing processes and controls in the approved management and regulatory framework for the GLNG Project. This recognises that this assessment will be supplemented in the future by further planning, risk assessment, engineering design and risk mitigation controls and measures to ensure that risks from the GFD Project are reduced to levels that ALARP.

The risk criteria used in the study and the risk results are presented in Section 9.

5.6. Risk mitigation

Based on the findings of the risk assessment additional risk mitigation measures were reviewed to ensure that the risks can be managed to a tolerable level. As detailed in EHSMS09, risks will be reduced to ALARP. ALARP demonstration is an ongoing process over the GFD Project life. The ALARP demonstration will take into account specific design and operational features that are developed over the life of the GFD Project.

6. HAZARD IDENTIFICATION

6.1. Overview

As the first stage in the assessment a hazard identification (HAZID) exercise was undertaken for the GFD Project. The HAZID aimed to identify hazards generated by the GFD Project and external hazards with the potential to impact the GFD Project infrastructure.

The HAZID comprised the following key steps:

- Preliminary screening to identify hazardous materials associated with the GFD Project with the potential for significant injury, fatality or property damage in the absence of controls. This step focused on materials including those classified as dangerous goods with the potential to lead to off-site impact.
- Review of past incidents involving those hazardous materials identified in the preliminary screening.
- Identification of other hazards on site with the potential to lead to harm to people or property. This step focused on physical situations rather than materials, for example electrical energy.
- Review of external natural hazards or environmental conditions and their potential impact on the GFD Project.
- Identification of hazardous incident scenarios, which have been recorded in a Hazard Identification Word Diagram format.
- Development of scenarios to carry forward for assessment.

6.2. Preliminary screening of hazardous materials

The first step in the HAZID involved identifying and screening of the hazardous materials associated with the GFD Project to document and exclude from further analysis in the PHA those which do not pose off-site risk. The preliminary screening methodology is detailed in the NSW DoP *Multi-Level Risk Assessment Guideline* (Ref. 14) and involves comparison of the quantities of hazardous materials associated with the GFD Project with thresholds quantities specified in *Applying SEPP 33* (Ref. 15). APPENDIX A: Quantities of hazardous materials of this report shows the hazardous materials associated with the GFD Project, their storage quantities and relevant threshold quantities. Materials that are classified as dangerous goods and exceed threshold quantities are carried forward for further analysis in the PHA. Based on this, the following hazardous materials have been identified for further analysis in this PHA:

- **Natural gas:** The quantities of natural gas at the wells and compression facilities are likely to exceed the threshold quantities for a flammable pressurised gas

- **Diesel:** Although diesel is a combustible liquid and excluded from screening if not stored with flammable liquids (Class 3), there is the potential for diesel to be involved in a fire due to escalation from an (external) fire. Given the likely quantities of diesel stored, escalation of a fire to diesel storage has been assessed in the PHA.

Further details on the hazardous properties of natural gas and diesel are given below in Section 6.2.1 and Section 6.2.2.

Risks from transportation of fuels and chemicals was not considered in the PHA as the transported DG are below the threshold quantities and are unlikely to exceed threshold movements. Transportation of DG below threshold quantities is unlikely to pose a significant off-site risk. Detailed analysis of transportation risk of fuels and chemicals are provided in the Cardno Traffic and Transport Assessment Technical Report (Ref. 3).

6.2.1. Natural gas

A representative composition of natural gas likely to be produced from the wells was provided by Santos GLNG and is shown in Table 6.1. Natural gas from coal seams contains mainly methane, which is flammable between 5–15 vol% and is a simple asphyxiant. On release, the gas tends to rise as it has a lower density than air at ambient conditions.

Table 6.1: Natural gas composition

Component	Composition (%)
Methane	97.1 – 97.5
Ethane	0 – 0.1
Butane	<0.001
Pentane	<0.001
Carbon dioxide	0.1
Nitrogen	2.3 – 2.6
Hydrogen sulphide	0

6.2.2. Diesel

Although diesel is a hazardous substance, it is not classified as a dangerous goods. Diesel is generally not a flammable material; it is a combustible liquid. Whilst it has the potential to be involved in a fire, it has a flash point above 61.5°C and a very low vapour pressure. The probability of diesel ignition is very low under normal circumstances; a strong ignition source (naked flame or similar) is required to ignite diesel.

6.3. Incident review

A high level review of available literature was undertaken to identify whether there had been reported incidents involving loss of containment of natural gas from pipelines and aboveground facilities. A number of incident databases were consulted, in particular the *eMars database* (EU) and the *Australian pipeline incident database*. As detailed in APPENDIX D: Likelihood analysis Methodology and Results of this report, the Australian Pipeline Industry Association (APIA) is currently developing an Australian pipeline incident database. The database covers the period between 1965 and 2010 and includes statistics relating to damage incidents, which covers loss of containment incidents, damage to the coating or pipe caused by mechanical equipment and other defect that requires either reduction in the maximum operating pressure or pipe repair.

Based on the incidents reviewed, the following observations were made:

- A number of incidents involving natural gas releases from pipelines have been recorded. Most of the natural gas leaks from aboveground facilities relate to gas holders or storage facilities.
- The majority of the leaks were not ignited and therefore did not result in fatality/injury.
- There has never been a death or injury recorded in connection with damage to a pipeline in Australia.

The review covered past incidents that have occurred in similar facilities and are not based on Santos GLNG incident records.

6.4. Physical hazards

Physical hazards were reviewed and included in the hazard identification word diagram. Examples of physical hazards relate to the working environment. They may be related to activities (for example a dropped object, vehicle movement or working at heights) or they may relate to stored energy (for example electrical energy).

6.5. External natural hazards

As part of the hazard identification process, the potential for external natural hazards to affect the GFD Project facilities was reviewed, and is summarised in Table 6.2. Potential impacts from natural emergency situations arising from external hazards listed in the table and counter disaster and rescue procedures in accordance with Disaster Management Act 2003 (Qld) were taken into account for the assessment.

Table 6.2: External natural hazards

Hazard	Assessment
Earthquake	According to the Global Seismic Hazard Assessment Program (GSHAP), the GFD Project area is classified as a low to moderate earthquake hazard. In the event of an earthquake, the worst case scenario is considered to be a release of natural gas from the GFD Project facilities (see APPENDIX B: Hazard Identification Word Diagram). Additionally, emergency response by local authorities may be limited given the widespread effects of an earthquake.
Landslide/ subsidence	Landslide or subsidence may result in structural failure of GFD Project facilities. In the event of a landslide/subsidence, the worst case scenario is considered to be a release of natural gas from the GFD Project facilities (see APPENDIX B: Hazard Identification Word Diagram).
Bushfire	The GFD Project area is surrounded by predominantly agricultural land, as well as various reserves, parks and State forests. Bush fires are therefore considered a credible threat to the GFD Project facilities. In the event of a bushfire, the worst case scenario is considered to be a release of natural gas from the GFD Project facilities (see APPENDIX B:Hazard Identification Word Diagram). Additionally, emergency response by local authorities may be limited given the potentially widespread effects of a bushfire.
External flooding	Several rivers run through or in the vicinity of the GFD Project. Flooding of the GFD Project facilities may occur in the event of a rise in the water level of these rivers. In the event of flooding, the worst case scenario is considered to be a release of natural gas from the GFD Project facilities (see APPENDIX B:Hazard Identification Word Diagram). Additionally, emergency response by local authorities may be limited given the potentially widespread effects of a significant flood event.
Cyclone	The majority of cyclones are limited to coastal areas though some have affected areas further inland. High winds associated with cyclones may result in structural failure of GFD Project facilities. In the event of a cyclone, the worst case scenario is considered to be a release of natural gas from the GFD Project facilities (see APPENDIX B: Hazard Identification Word Diagram). Additionally, emergency response by local authorities may be limited given the potentially widespread effects of a cyclone.
Storm surge	Storm surges accompany a tropical cyclone as it comes ashore. According to the BoM, the area of sea water flooding associated with storm surges 'may extend along the coast for over 100 kilometres, with water pushing several kilometres inland if the land is low lying'. Given the location of the GFD Project, storm surge is not considered a credible threat to the GFD Project facilities.
Lightning	Equipment complying with relevant Australian Standards will be installed to manage the risks associated with lightning.
Extreme temperatures	Equipment will be designed to manage the risks associated with extreme temperatures.
Climate change	Climate change is likely to result in more extreme impacts of the natural hazards considered above, e.g. larger and/or more frequent flood events, bushfires, etc.

Hazard	Assessment
Wildlife	Personnel contact with dangerous animals (e.g. snakes, dingos and kangaroos) or disease vectors (e.g. mosquitoes and midges) may result in injury. This is considered in APPENDIX B: Hazard Identification Word Diagram.

6.6. Hazard identification table

Following application of the Constraints protocol, identification of hazardous incident scenarios for the GFD Project was undertaken based on a review of hazard identification studies undertaken for the GLNG Project (Refs. 16 and 17), review of past incidents involving natural gas (see Section 6.3) and Sherpa's experience in undertaking safety-related studies for various industries. A hazard identification word diagram is included in APPENDIX B: Hazard Identification Word Diagram of this report and shows each of the scenarios identified for the following phases of the GFD Project:

- Construction and commissioning (C)
- Operations (O)
- Decommissioning (D).

No additional hazards were identified for the rehabilitation phase.

Hazards to people and property that were identified include the following:

- Release of natural gas from the wells, gathering and transmission pipelines and gas compression facilities due to various causes, such as:
  - Equipment failure or loss of process control (from piping, valves, vessels, or compressors due to flange leaks, tapping point failures, etc.)
  - Corrosion (internal or external)
  - Mechanical failure (e.g. due to vehicle impact and material defects)
  - External events (e.g. third party damage, bushfire and flooding).
- Escalation of external fire to diesel storage tanks at the gas compression facilities.
- Hazardous work environment (e.g. falling equipment, live electrical equipment and working in confined spaces).
- Contact with dangerous animals (e.g. snakes) or disease vectors (e.g. mosquitoes).
- Workshop, warehouse or accommodation fire involving combustible material.
- Increase in road hazards on regional and local roads due to heavy vehicle movement.
- Catastrophic failure of water storage dam.

Potential causes and consequences for identified hazards are recorded in APPENDIX B Hazard Identification Word Diagram. Safeguards to mitigate the risks associated with the identified hazards are also included in APPENDIX B: Hazard Identification Word Diagram and discussed further in Section 10.

6.7. Scenarios assessed

Based on an assessment of whether identified hazards could potentially have off-site impacts, a list of scenario to be further assessed in this PHA was developed.

Table 6.3 gives a summary of the scenarios in different phases of the GFD Project which have been carried forward for assessment in this PHA.

Table 6.3: Summary of scenarios for assessment

Project component	ID	Hazardous scenario	Phase [(a), (b)]		
			C	O	D
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	√	√	√
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground)	√	√	√
	GGL-2	Release of natural gas from gas gathering line (underground)	√	√	√
	GGL-3	Damage to adjacent gas transmission pipeline during construction of gathering line	√		
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal compression facility	√	√	√
	NGC-2	Escalation of fire to diesel storage	√	√	√
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	√	√	√
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	√	√	√
	GTL-3	Damage to adjacent gas transmission pipeline during construction of transmission pipeline	√		
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at gas compression facility	√	√	√
	HGC-2	Escalation of fire to diesel storage	√	√	√
Water management facilities	WMF-1	Catastrophic failure of water storage dam	√	√	√

Notes:
(a) C: Construction and commissioning, O: Operation, D: Decommissioning
(b) √: indicates the project phase (C, O, D) for which the hazardous scenarios are applicable; blank indicates that the scenario is not applicable for that project phase

The potential consequences of the scenarios listed in Table 6.3 include the following:

- **Jet fire**, if a natural gas leak from a pressurised inventory is ignited immediately. The fire size is a function of the rate of flammable material released, which is in turn a function of pressure and release hole size. Fatality of 100% is assumed within the dimension of the jet fire, reducing with decreasing heat radiation levels away from the flame.
- In the event of immediate ignition following a pipeline rupture, it is considered a **fireball** may occur.
- **Flash fire**, if ignition is delayed. In the event that the natural gas release is not ignited immediately, a vapour cloud will form. If ignition subsequently occurs, the vapour cloud burns rapidly without a blast wave and will flash back to burn as a jet fire from the release point. With a flash fire, there is a high chance of fatality to anyone within the ignited vapour cloud (assumed 100% for the analysis), but due to the short duration of the flame, there is a low chance of significant impact outside the vapour cloud radius.
- **Vapour cloud explosion (VCE)**, if ignition of the vapour cloud occurs within a congested or confined plant area. The wells do not have significant congestion and most equipment at the nodal and hub gas compression facilities will be at grade and well-spaced, i.e. there will be no large areas of congestion or confinement associated with the GFD Project. VCEs are therefore not considered further in this study.
- Diesel fire, in the event of escalation of a fire to diesel stored at the compression facilities or associated facilities (e.g. accommodation facilities). This has been modelled as a **bund fire**, as detailed in Section 7.2.3.
- Catastrophic flooding in the event of catastrophic failure of a water storage structure (which may have a storage capacity of 30 – 350 megalitres (ML) or greater).

There are no significant escalation targets in the facilities (such as large LPG vessels or toxic inventories) whose failure would result in escalation of the event and off-site impact.

7. CONSEQUENCE ANALYSIS

7.1. Overview

Consequence analysis was undertaken for the hazardous events identified in APPENDIX B: Hazard Identification Word Diagram of this report and summarised in Table 6.3. The consequences of the hazardous events listed in Table 6.3 include the following:

- Fireball, in the event of immediate ignition following a pipeline rupture
- Jet fire, if a continuous natural gas release is ignited immediately
- Flash fire, in the event of delayed ignition of a natural gas release
- Bund fire, in the event of escalation of a fire to diesel stored at the compression facilities or associated facilities (e.g. accommodation facilities).

The consequences of the hazardous scenarios identified were modelled using the proprietary consequence modelling package, *TNO Effects* (Ref. 18), with the exception of fireballs, which were modelled using the approach given in the *TNO Yellow Book* (Ref. 19). Inputs for consequence analysis are summarised in Section 7.2. The consequence analysis results are reported in terms of distances to specified levels of harm. These levels correspond to the land use planning criteria for fatality, injury and property damage, which are presented in Section 7.3. Detailed consequence analysis results are provided in APPENDIX C: Consequence analysis Methodology and Results; a summary of the consequence results for each of the hazardous scenario assessed are shown in Section 7.4.

7.2. Modelling inputs

7.2.1. Process conditions

Table 7.1 summarises the process conditions used to model the scenarios identified in Section 6.7. These conditions are based on typical design parameters provided by and discussed with Santos GLNG. The values are representative of typical process conditions at the preliminary phase of the GFD Project. As required by EHSMS09, a series of Hazard Studies will be undertaken over the life of the facility and changes to process conditions will be captured during the project lifecycle.

Table 7.1: Process conditions selected for consequence analysis

Project component	ID	Hazardous scenario	Pressure [a] (kPag)	Temperature [a] (°C)
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	400	50
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground)	200	40
	GGL-2	Release of natural gas from gas gathering line (underground)	200	40
	GGL-3	Damage to adjacent gas transmission pipeline during construction of gathering line	15,000	50
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal gas compression facility	2,000	40
	NGC-2	Escalation of fire to diesel storage	Ambient	Ambient
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	2,000	40
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	15,000	50
	GTL-3	Damage to adjacent gas pipeline during construction of gas transmission pipeline	15,000	50
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub gas compression facility	15,000	50
	HGC-2	Escalation of fire to diesel storage	Ambient	Ambient
Note: (a) The process conditions shown are based on typical design parameters and are liable to change as design progresses.				

7.2.2. Release conditions

Loss of containment from the GFD Project components was modelled for a range of representative hole sizes. For wells and gas compression facilities, the hole sizes modelled were derived from the International Association of Oil and Gas Producers (OGP) process equipment hole size range (Ref. 20), as follows:

- 22 mm
- 85 mm

- 200 mm or full bore.

Although the OGP data contains smaller hole sizes, these are not considered to lead to off-site impacts and have therefore not been accounted for in this assessment. Releases from the wells and gas compression facilities were modelled using the initial release rate (i.e. without considering the effects of depressuring); release orientations considered are as follows:

- Releases from the compression facilities were modelled as horizontal
- Releases from the wells were modelled as vertical and horizontal.

Based on data from the European Gas Pipeline Incident Data Group (EGIG) (Ref. 21), the hole sizes assessed for pipeline releases were as follows:

- 10 mm
- 50 mm
- Rupture (double sided pipeline release).

Releases from aboveground transmission pipelines were modelled as horizontal while releases from buried pipelines were modelled as 45° and vertical releases (except for flash fires, which were modelled as horizontal due to limitations with the TNO Effects dispersion model). The 10 and 50 mm releases were modelled using initial release rates while the release rates for pipeline ruptures were taken at 30 seconds after rupture, consistent with the approach in Appendix Y of AS 2885.1 (see APPENDIX C:Consequence analysis Methodology and Results).

Further details on the basis for the release conditions modelled in this study are given in APPENDIX C: Consequence analysis Methodology and Results of this report.

7.2.3. Bund fire

In the event of escalation of a fire to diesel stored at the compression facilities or associated facilities, it is considered that the worst credible consequence would be catastrophic failure of the diesel storage tank, resulting in a release of the tank contents into the tank bund. A diesel storage fire has therefore been modelled as a bund fire, with the following parameters:

- The total inventory of diesel involved in the fire is 110,000 L (maximum total diesel tank storage volume at one location, from information provided by Santos GLNG), which may be stored in multiple tanks of typically 25,000 L capacity. The total inventory of 110,000 L was used as a conservative approach to model diesel fire consequences; this accounts for escalation of an external fire to affect multiple diesel storage tanks at one location.
- The bund height has been assumed to be 1.5 m, which is the maximum allowable height in AS 1940 (Ref. 22), unless means for safe entry and exit are provided.

- The bund is designed to contain 110% of the volume of the storage tank, as required by AS 1940.

This scenario will not be credible for sites with self bunded diesel tanks.

7.2.4. Other inputs

The dispersion of natural gas releases was modelled under the three weather conditions described in Section 3.5, since the consequences vary according to the prevailing wind and stability. Jet fires and fireballs were modelled only under the worst case, highest wind speed case, D5, since they are less influenced by the prevailing weather.

Other environmental conditions used in consequence modelling are summarised in Section 3.5.

7.3. Assessment criteria

To determine the impact of fires on people and property, it is necessary to relate their physical effects (e.g. heat radiation) to different levels of harm (i.e. probabilities of fatality). The consequence criteria (i.e. levels of harm) used in this study are shown in Table 7.2 and Table 7.3 for people and property respectively. These criteria are based on the levels given in HIPAP 4.

Table 7.2: Consequence criteria for people

Phenomenon	Level	Impact/comment
Fireball	1% fatality	Due to the short duration of a fireball, the probability of fatality is dependent on the thermal dose from the fireball, which is calculated based on the heat radiation, fireball size and duration.
	50% fatality	
	100% fatality	
Jet/pool fire	4.7 kW/m^2	Will cause pain in 15-20 seconds and injury after 30 seconds exposure, or 1% chance of fatality
	10 kW/m^2	50% chance of a fatality for extended exposure (over 60 s)
	23 kW/m^2	100% fatality for short exposure. Unprotected steel will reach thermal stress temperature which can cause failures. Property damage.
Flash fire	Within Lower Flammability Limit (LFL)	100% probability of fatality

Table 7.3: Consequence criteria for property

Phenomenon	Level	Impact/comment
Fireball	Within fireball diameter	It is assumed that equipment within the fireball diameter would be seriously damaged or fail.
Jet/pool fire	23 kW/m^2	Unprotected steel will reach thermal stress temperature which can cause failures. Property damage.
Flash fire	-	Due to the short duration of a flash fire, no property damage is expected from a flash fire. However, in the event of a jet fire following flash back from a flash fire, property damage may occur. In this event, damage to property within the 23 kW/m^2 heat radiation contour would be expected.

7.4. Results

Table 7.4 summarises the consequence distances for the hazardous scenarios assessed in this study; detailed results are contained in APPENDIX C: Consequence analysis Methodology and Results. With the exception of pipeline rupture, the modelled release rates are the initial release rates and do not account for pressure decay that would occur following detection, isolation and depressuring. Hence, this is a conservative assessment, with pressure decay being most rapid for large releases. Modelling of releases will be refined during the Hazard Study process detailed in EHSMS09.02.

The consequence results are only one input to the risk assessment. The likelihood of occurrence of the fires and the risk assessment is detailed in the following sections of the PHA. Modelling results for both heat radiation and LFL are based on receptors located at 1.5 m above ground level. Based on the results of the calculations, the following observations can be made:

- Fireballs are modelled as ignition of a gas cloud that has formed 10 seconds after a pipeline has been ruptured. The impact area (measured 1.5 m above ground level) for fireballs may extend up to 385 m for a full bore rupture from a high pressure gas transmission pipeline (GTL-2) or as a result of full bore rupture due to damage to an adjacent high pressure gas pipeline during construction of a transmission pipeline (GGL-3, GTL-3).
- For jet fires, the distances to the 4.7 kW/m^2 heat radiation level (corresponding to 1% fatality) ranges from 4 m for a 10 mm release from the aboveground gas gathering line (GGL-1) to approximately 330 m for a 200 mm release from equipment/piping at a hub compression facility (HGC-1). The distances to the 23 kW/m^2 heat radiation level (at which property damage is anticipated) are lower and extend to approximately 250 m for a 200 mm release from equipment/piping at a

hub compression facility (HGC-1). Distances are modelled horizontally from the release location with the receptor 1.5 m above ground level.

- Predicted jet fire distances are lowest for the gas gathering lines when compared to the other facilities, due to the low operating pressure and therefore release rate in the event of a leak.
- The impact area for flash fires may extend up to 300 m for a full bore rupture from a high pressure gas transmission pipeline (GTL-2). Since flash fires were modelled as originating from horizontal releases, the flammable cloud remains near ground level as the momentum effects dominate buoyancy effects.
- Flash fire impact areas are generally shorter in length and narrower, when compared to the jet fire impact areas. In the event of a flash back, the ensuing jet fire may therefore impact a larger area than the initial flash fire.

The impact area for fires involving diesel stored at the compression facilities may extend up to 25 m from the edge of the storage bund. The distances between the diesel storage areas at the compression facilities and the site boundary are not known at this stage of the GFD Project. It is recommended that siting of diesel storage areas at the compression facilities take into account the likely impact zone from a diesel bund fire. The distances to the site boundaries or pipeline right-of-way are shown in Table 7.4. The distances are based on preliminary site layouts and are used to identify incidents with the potential for off-site impact. Based on a comparison of these distances with the conservative consequence distances calculated, it can be concluded that:

- For wells, only the largest fires from 200 mm holes could be expected to extend beyond the well lease boundary; the impact area for smaller fires are up to 10 m long (based on a 22 mm release) and would only have localised impact.
- Similar to wells, only the largest fires from 200 mm holes in the nodal gas compression facilities would extend beyond the facility boundary.
- Fires associated with 85 mm and 200 mm holes in the hub gas compression facility have the potential to extend beyond the facility boundary.
- Most releases from the gas gathering and gas transmission pipelines have the potential to extend beyond the pipeline easement, as shown in Table 7.4.

Additionally, catastrophic failure of a water storage structure (WMF-1) will likely result in flooding of on-site and off-site facilities.

In line with the methodology for a level 2 risk assessment (as described in the *Multi-Level Risk Assessment Guideline* (Ref. 14)), the likelihood of occurrence of hazardous events with consequences that extend beyond the facility boundary or pipeline easement have been assessed, as detailed in Section 8.

Table 7.4: Consequence results summary

Project component	ID	Hazard	Hole size (mm)	Maximum distance (m) to [a]: 1% fatality (fireball)	4.7 kW/m^2 (jet/bund fire)	23 kW/m^2 (jet/bund fire)	LFL (flash fire)	Minimum distance to boundary or right-of-way (m)
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	22	N/A	10	8	5	44
			85	N/A	33	26	17	
			200	N/A	73	57	40	
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground)	10	N/A	4	3	2	3
			50	N/A	18	14	9	
			Rupture	86	N/A	N/A	94	
	GGL-2	Release of natural gas from gas gathering line (underground)	10	N/A	3	2	2	3
			50	N/A	13	5	9	
			Rupture	86	N/A	N/A	94	
	GGL-3	Damage to adjacent gas pipeline during construction of gathering line	10	N/A	16	8	12	6
			50	N/A	72	34	59	
			Rupture	385	N/A	N/A	288	
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal compression facility	22	N/A	19	15	10	70
			85	N/A	64	49	37	
			200	N/A	139	106	87	
	NGC-2	Escalation of fire to diesel storage	N/A	N/A	23	11	N/A	[b]
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	10	N/A	7	3	5	5
			50	N/A	30	13	22	
			Rupture	137	N/A	N/A	120	
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	10	N/A	16	8	12	5
			50	N/A	72	34	59	
			Rupture	385	N/A	N/A	288	

Project component	ID	Hazard	Hole size (mm)	Maximum distance (m) to [(a)]:				Minimum distance to boundary or right-of-way (m)
				1% fatality (fireball)	4.7 kW/m^2 (jet/bund fire)	23 kW/m^2 (jet/bund fire)	LFL (flash fire)	
	GTL-3	Damage to adjacent gas pipeline during construction of transmission pipeline	10	N/A	16	8	12	10
			50	N/A	72	34	59	
			Rupture	385	N/A	N/A	288	
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub compression facility	22	N/A	45	35	26	120
			85	N/A	151	115	80	
			200	N/A	327	248	240	
	HGC-2	Escalation of fire to diesel storage	N/A	N/A	23	11	N/A	[(b)]

Notes:

(a) N/A indicates that a particular consequence is not relevant (eg fireballs only occur in the event of immediate ignition following a pipeline rupture)

(b) The distances between the diesel storage areas at the compression facilities and the site boundary are not known at this stage of the GFD Project.

8. ESTIMATION OF LIKELIHOOD OF HAZARDOUS EVENTS

8.1. Overview

The likelihood of an event is the number of occurrences of the event over a specified time period, generally taken as one year. The likelihoods of the hazardous scenarios with off-site impact were estimated using event tree analysis, taking into account the following:

- Leak frequencies from equipment and pipelines
- Ignition probability
- Release orientation.

Detailed likelihood results are provided in APPENDIX D: Likelihood analysis Methodology and Results of this report; a summary of the likelihood results for hazardous scenarios with off-site impact is shown in Section 8.4.

8.2. Leak frequencies

Leak frequencies for the wells and gas compression facilities were estimated by combining generic leak frequency data and a high level parts count of equipment. For the purposes of this assessment, generic leak frequency data for the following equipment was used:

- Well (covering production and workover), from the Netherlands RIVM National Institute for Public Health and the Environment (Ref. 23)
- Pressure vessel, from the UK HSE (Ref. 24)
- Gas compressor, from the RIVM data
- Filter, from data compiled by OGP (Ref. 20).

At this stage of the GFD Project life, a full parts count of equipment (i.e. accounting for piping lengths and numbers of fittings, valves etc) could not be performed. Only the main process equipment was taken into account in the likelihood analysis. Detailed analysis will be undertaken once location and full parts count of equipment are available in later stages of field development.

Leak frequencies for the gas gathering and gas transmission pipelines were estimated using generic pipeline leak frequency data and application of modification factors based on material (such as HDPE). Generic pipeline leak frequencies were obtained from data compiled by the UK Onshore Pipeline Operators Association (UKOPA) (Ref. 25) and EGIG (Ref. 21).

Derivation of the leak frequencies for GFD Project components is shown in APPENDIX D: Likelihood analysis Methodology and Results.

The available pipeline leak and failure data was reviewed to take account of HDPE and GRE pipework proposed for some areas. For example failure modes associated with corrosion are not applicable for GRE piping. The failure modes were modified and a data set presented for non-steel pipes is presented in section D3 of APPENDIX D: Likelihood analysis Methodology and Results.

8.3. Ignition probability

Ignition probabilities for this study were derived based on the following sources:

- The *Ignition Probabilities (IP)* Research Report (Ref. 26) was used for ignition probabilities of releases from the wells and compression facilities. These probabilities are based on plant size, plant type and release rate.
- Ignition probabilities for pipelines were based on EGIG data (Ref. 21).

The ignition probabilities applied are described in APPENDIX D: Likelihood analysis Methodology and Results of this report.

8.4. Release orientation

As detailed in Section 7.2.2, release orientations considered in this study are as follows:

- Releases from the wells were modelled as vertical and horizontal. The RIVM data for wells provides different leak frequencies for vertical and horizontal releases
- Releases from the compression facilities were modelled as horizontal
- Releases from the aboveground gas gathering lines were modelled as horizontal
- Releases from the buried gas gathering lines and transmission pipelines were modelled as 45° and vertical releases, as follows:
  - For pipelines, the main cause of large holes is external interference, with damage to the top of the pipeline or a crater with gas ejected vertically. Therefore, it was assumed that 80% of puncture and rupture events are in the vertical direction, and 20% in a lateral direction (at 45° angle)
  - Since pinhole releases are typically due to corrosion, which could occur at point on the pipeline, it has been assumed that 50% of pinhole releases are in a vertical direction and 50% in a lateral direction.

8.5. Results

The likelihoods estimated for hazardous scenarios with off-site impact are shown in Table 8.1 for the wells and compression facilities, and Table 8.2 for the gas gathering lines and transmission pipelines.

Catastrophic failure of a water storage structure (WMF-1) is considered to be remote given the regulation of water storage structures required by the Queensland

Government Department of Natural Resources and Mines (2002): Queensland Dam Safety Management Guidelines. (Refs.27).

Table 8.1: Leak and outcome frequencies for wells and compression facilities

Project component	ID	Hazard	Hole size (mm)	Leak frequency (per year)	Outcome frequency (per year)	
					Jet fire	Flash fire
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	200	9.8E-4	2.5E-5	2.5E-5
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal compression facility	200	4.1E-5	4.0E-6	3.6E-6
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub compression facility	85	3.8E-3	4.8E-4	4.2E-4
			200	4.5E-5	1.5E-5	9.9E-6

Table 8.2: Leak and outcome frequencies for gas gathering lines and transmission pipelines

Project component	ID	Hazard	Hole size (mm)	Leak frequency (per km-year)	Outcome frequency [a] (per km-year)			
					Fireball	Jet fire (45°)	Jet fire (vertical)	Flash fire
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground)	10	5.6E-05	N/A	1.12E-06 [b]		1.1E-06
			50	2.3E-05	N/A	2.34E-07 [b]		2.3E-07
			Rupture	1.4E-05	2.3E-06	N/A	N/A	2.3E-06
	GGL-2	Release of natural gas from gas gathering line (underground)	10	2.2E-05	N/A	2.2E-07	2.2E-07	4.5E-07
			50	2.0E-05	N/A	4.0E-08	1.6E-07	2.0E-07
			Rupture	7.6E-06	1.3E-06	N/A	N/A	1.3E-06
	GGL-3	Damage to adjacent gas pipeline during construction of gathering line [c]	10	3.2E-05	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	1.3E-06	N/A	N/A	1.3E-06
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	10	3.2E-05	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	1.3E-06	N/A	N/A	1.3E-06
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	10	3.2E-05	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	1.3E-06	N/A	N/A	1.3E-06
	GTL-3	Damage to adjacent gas pipeline during construction of gas transmission pipeline [c]	10	3.2E-05	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	1.3E-06	N/A	N/A	1.3E-06

Notes:

(a) N/A indicates that a particular frequency has not been assessed (e.g. fireballs only occur in the event of immediate ignition following a pipeline rupture)

(b) Releases from the aboveground gas gathering line has been modelled as horizontal.

(c) Frequencies estimated for scenarios involving damage to adjacent gas pipeline(s) are only valid for the construction period of the GFD Project gas gathering or transmission pipelines.

9. RISK ASSESSMENT

9.1. Overview

Risk assessment involves combining the off-site scenario consequences and their associated likelihoods and comparing against criteria. The risks of the hazardous events considered in this study were assessed as follows:

- Risks associated with wells, gas compression facilities and pipelines were assessed on a qualitative basis, using the risk matrix given in Section 9.2.
- Risks associated with the gas gathering and gas transmission pipelines were further assessed on a quantitative basis and are presented as risk transects, which show the risk as a function of the perpendicular distance from the gas gathering or gas transmission pipelines.

The assessed risks were evaluated against the risk criteria used in the study, as detailed in Section 9.2. Risk results are presented in Sections 9.3 to 9.6.

9.2. Risk criteria

9.2.1. Risk matrix

For this study, risks associated with the wells and compression facilities were assessed using a risk matrix approach based on *AS/NZS 31000:2009 Risk Management – Principles and Guidelines* and the associated Handbook *Managing environment-related risk (HB203:2012, Ref. 13)*. The likelihood and consequence criteria used are shown in Table 9.1 and Table 9.2 respectively. The level of risk was determined by combining the likelihood and consequence criteria using the risk matrix shown in Table 9.3.

Table 9.1: Likelihood criteria

Likelihood category	Description
Almost certain Common	Will occur, or is of a continuous nature, or the likelihood is unknown. There is likely to be an event at least once a year or greater (up to 10 times per year). It often occurs in similar environments. The event is expected to occur in most circumstances.
Likely Has occurred in recent history	There is likely to be an event on average every one to five years. Likely to have been a similar incident occurring in similar environments. The event will probably occur in most circumstances.
Possible Could happen, has occurred in the past, but not common	The event could occur. There is likely to be an event on average every 5 to 20 years.
Unlikely Not likely or uncommon	The event could occur but is not expected. A rare occurrence (once per 100 years).
Remote Rare or practically impossible	The event may occur only in exceptional circumstances. Very rare occurrence (once per 1,000 years). Unlikely that it has occurred elsewhere; and, if it has occurred, it is regarded as extremely unique.

Table 9.2: Consequence criteria

Consequence category	Description	Impacts to People
Critical Severe, widespread long-term effect	Destruction of sensitive environmental features. Severe impact on ecosystem. Impacts are irreversible and/or widespread. Regulatory and high level government intervention/action. Community outrage expected. Prosecution likely. Financial loss in excess of $100 million.	Multiple fatalities
Major Wider spread, moderate to long-term effect	Long-term impact of regional significance on sensitive environmental features (e.g. wetlands). Likely to result in regulatory intervention/action. Environmental harm either temporary or permanent, requiring immediate attention. Community outrage possible. Prosecution possible. Financial loss from $50 million to $100 million.	Single fatality
Moderate Localised, short-term to moderate effect	Short term impact on sensitive environmental features. Triggers regulatory investigation. Significant changes that may be rehabilitated with difficulty. Repeated public concern. Financial loss from $5 million to $50 million.	Permanent disabling injury/injuries
Minor Localised short-term effect	Impact on fauna, flora and/or habitat but no negative effects on ecosystem. Easily rehabilitated. Requires immediate regulator notification. Financial loss from $500,000 million to $5 million.	Injury/injuries requiring medical treatment (lost time injury/injuries)
Negligible Minimal impact or no lasting effect	Negligible impact on fauna/flora, habitat, aquatic ecosystem or water resources. Impacts are local, temporary and reversible. Incident reporting according to routine protocols. Financial losses up to $500,000.	First aid treatment, or illness/injury not requiring treatment (no lost time injuries)

Table 9.3: Risk matrix

Consequence	Likelihood				
	Almost certain	**Likely**	**Possible**	**Unlikely**	**Remote**
Critical	Very High	Very High	High	High	Medium
Major	Very High	High	High	Medium	Medium
Moderate	High	Medium	Medium	Medium	Low
Minor	Medium	Medium	Low	Low	Very Low
Negligible	Medium	Low	Low	Very Low	Very Low

Consistent with the EHSMS09, the risk levels in the risk matrix can be categorised as follows:

“Very High” risks are intolerable and must not be accepted.

“High”, “Medium” and “Low” level risks are acceptable provided they have been reduced to as low as reasonably practicable (ALARP).

“Very Low” risks are deemed to be ALARP.

9.2.2. Quantitative risk criteria

For this study, risks associated with the gas gathering and gas transmission pipelines were assessed using the risk criteria provided in the NSW DoP publication HIPAP No. 4, *Risk Criteria for Land Use Safety Planning* (Ref. 2), which are reproduced in Table 9.4. These criteria are also applied to developments in Queensland where a PHA is required by the Department of Environment and Heritage Protection (EHP).

Table 9.4: HIPAP No. 4 land use planning criteria

Description and land use	Criteria (per year)
Individual fatality risk	
Hospitals, child-care facilities and old age housing (sensitive land uses).	5×10^{-7}
Residential developments and places of continuous occupancy such as hotels and tourist resorts (residential land use).	1×10^{-6}
Commercial developments, including offices, retail centres and entertainment centres (commercial land use).	5×10^{-6}
Sporting complexes and active open space areas.	1×10^{-5}
Target for lease/facility boundary.	5×10^{-5}
Injury risk – heat radiation not exceeding 4.7 kW/m^2	
Residential and sensitive use.	5×10^{-5}
Injury risk – explosion overpressure not exceeding 7 kPa	
Residential and sensitive use.	5×10^{-5}
Injury risk – toxic exposure	
Residential and sensitive use areas. Seriously injurious to sensitive members of the community following a relatively short period of exposure.	1×10^{-5}
Residential and sensitive use areas Irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community.	5×10^{-5}
Risk of property damage and accident propagation – 23 kW/m^2 heat flux	
Neighbouring potentially hazardous installations or at land zoned to accommodate such installations.	5×10^{-5}
Risk of property damage and accident propagation – 14 kPa explosion overpressure	
Neighbouring potentially hazardous installations, at land zoned to accommodate such installations or at nearest public buildings.	5×10^{-5}

The individual fatality risk criteria for land use safety planning are the peak individual risk, which is a conservative measure as it is based on 24 hour-per-day exposure with no allowance for the protection buildings may offer or for the potential to move away and escape from a developing incident.

In rural areas with isolated dwellings, land use planners usually apply the risk criteria for residential land use, particularly for new developments.

These risk tolerability criteria have been chosen by the NSW DoP so as not to impose a risk that is significant when compared to the background risk to which people are normally exposed.

9.3. Risks to people

9.3.1. Construction and commissioning

Construction of infrastructure will be relatively short-term in one area and will occur in different areas over different times. Construction and commissioning activities are unlikely to result in significant off-site impacts to people and should be adequately controlled by implementation of the Environment, Health and Safety Management System, as well as construction management plans and procedures.

Hazardous scenarios identified for the construction and commissioning phase involve damage to an adjacent gas pipeline during construction of the gas gathering or transmission pipelines. The risks to people from these scenarios are assessed in Table 9.5 to be Medium, i.e. the risks may be accepted as tolerable if they can be shown to be ALARP.

Other scenarios during the construction and commissioning phase are considered to be similar to those for the operations phase, the risks of which are assessed below.

9.3.2. Operations

Wells and compression facilities

Table 9.6 summarises the risks to people from wells and gas compression facilities during the operations phase. Potential impacts on resources (eg forests, water reserves, roads, rail level crossings, residential, work and recreational areas) from both natural and induced emergency situations, and counter disaster and rescue procedures in accordance with Disaster Management Act 2003 (Qld) (Ref. 28) were not considered to significantly increase the assessed risk (Table 9.6).

The risks of the identified hazardous scenarios were assessed to be Medium; i.e. the risks may be accepted as tolerable if they can be shown to be ALARP.

Table 9.5: Risk to people – construction and commissioning phase

Project component	ID	Hazard [(a)]	Risk assessment - People			Comments
			Consequence	Likelihood	Risk	
Gas gathering line	GGL-3	Damage to adjacent gas pipeline during construction of gathering line	Critical	Remote	Medium	It has been conservatively assumed that multiple off-easement fatalities may occur in the event of a fire following damage to an adjacent gas pipeline. The likelihood of damage to an adjacent gas pipeline during construction and commissioning resulting in off-easement fatalities/injuries is considered to be remote, as no fatalities/injuries have been recorded in connection with damage to a pipeline in Australia (see Section 6.3).
Gas transmission pipeline	GTL-3	Damage to adjacent gas pipeline during construction of transmission pipeline	Critical	Remote	Medium	It has been conservatively assumed that multiple off-easement fatalities may occur in the event of a fire following damage to an adjacent gas pipeline. The likelihood of damage to an adjacent gas pipeline during construction and commissioning resulting in off-easement fatalities/injuries is considered to be remote, as no fatalities/injuries have been recorded in connection with damage to a pipeline in Australia (see Section 6.3).

Note:

(a) This table summarises the risk to people of hazardous scenarios specific to the construction and commissioning phase. Other scenarios during the construction and commissioning phase are considered to be similar to those for the operations phase.

Table 9.6: Risk to people from wells and compression facilities – operations phase

Project component	ID	Hazard	Hole size (mm)	Outcome		Risk assessment - People			Comments
				Type	Frequency (per year)	Consequence	Likelihood	Risk	
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	200	Jet fire	2.5E-5	Critical	Remote	Medium	From Table 7.4, the jet fire fatality impact zone (4.7 kW/m^2) extends beyond the site boundary. It has been conservatively assumed that multiple off-site fatalities may occur in the event of a jet fire at a well.
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal compression facility	200	Jet fire	4.0E-6	Critical	Remote	Medium	From Table 7.4, the jet fire fatality impact zone (4.7 kW/m^2) extends beyond the site boundary. It has been conservatively assumed that multiple fatalities may occur in the event of a jet fire at a nodal gas compression facility.
			200	Flash fire	3.6E-6	Critical	Remote	Medium	From Table 7.4, the flash fire fatality impact zone (LFL) extends beyond the site boundary. It has been conservatively assumed that multiple fatalities may occur in the event of a flash fire at a nodal gas compression facility.
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub compression facility	85	Jet fire	4.8E-4	Critical	Remote	Medium	From Table 7.4, the jet fire fatality impact zone (4.7 kW/m^2) extends beyond the site boundary. It has been assumed that multiple fatalities may occur in the event of a jet fire at a hub gas compression facility.
			200	Jet fire	1.5E-5	Critical	Remote	Medium	From Table 7.4, the jet fire fatality impact zone (4.7 kW/m^2) extends beyond the site boundary. It has been assumed that multiple fatalities may occur in the event of a jet fire at a hub gas compression facility.
			200	Flash fire	9.9E-6	Critical	Remote	Medium	From Table 7.4, the flash fire fatality impact zone (LFL) extends beyond the site boundary. It has been conservatively assumed that multiple fatalities may occur in the event of a flash fire at a hub gas compression facility.

Gas gathering and gas transmission pipelines

The risk associated with the gas gathering and gas transmission pipelines is qualitatively assessed in Table 9.7.

Table 9.7: Risk to people – gas gathering and transmission pipelines

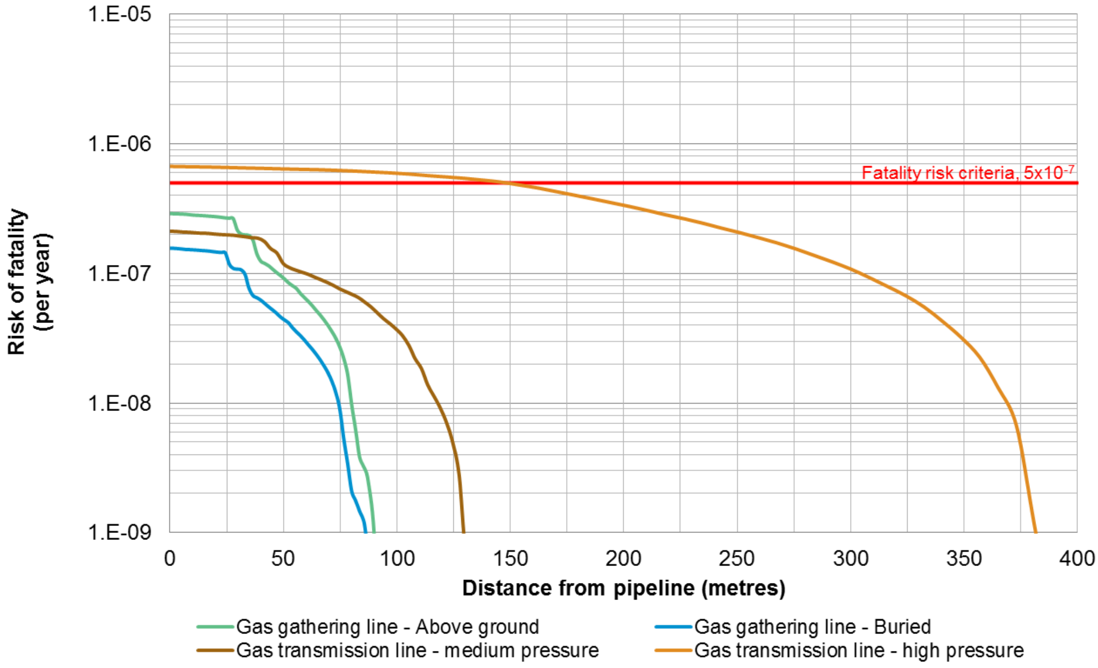
Project component	ID	Hazard	Risk assessment - People			Comments
			Consequence	**Likelihood**	**Risk**	
Gas gathering line	GGL-1&2	Release of Natural Gas from pipeline	Critical	Remote	Medium	It has been conservatively assumed that multiple fatalities may occur beyond the pipeline corridor in the event of a fire following a loss of containment from a gas gathering line. The likelihood (given controls) of fatalities is considered Remote.
Gas transmission pipeline	GTL-1&2	Release of Natural Gas from pipeline	Critical	Remote	Medium	It has been conservatively assumed that multiple fatalities may occur beyond the pipeline corridor in the event of a fire following a loss of containment from a gas gathering line. The likelihood of fatalities is considered Remote.

To further inform the PHA, risks to people from the gas gathering and gas transmission pipelines are shown as fatality and injury risk transects. Transects show the risk of fatality or injury as a function of the perpendicular distance from the gas gathering or gas transmission pipelines.

Fatality risk transects for the gas gathering and gas transmission pipelines are shown in Figure 9.1. The highest risk of fatality is estimated for the high pressure gas transmission pipeline as it has the highest operating pressure. The maximum fatality risk is approximately 7 x 10^{-7} per year immediately next to the high pressure gas transmission pipeline and remains in the order of 10^{-7} per year up to 300 m from the pipeline. Based on the quantitative risk criteria in Table 9.4, it can be seen that the high pressure gas transmission pipeline satisfies the individual fatality risk criteria, with the exception of the criterion relating to sensitive land use (5 x 10^{-7} per year). The risk to sensitive land uses can be mitigated by ensuring appropriate pipeline routing and maintaining separation distances.

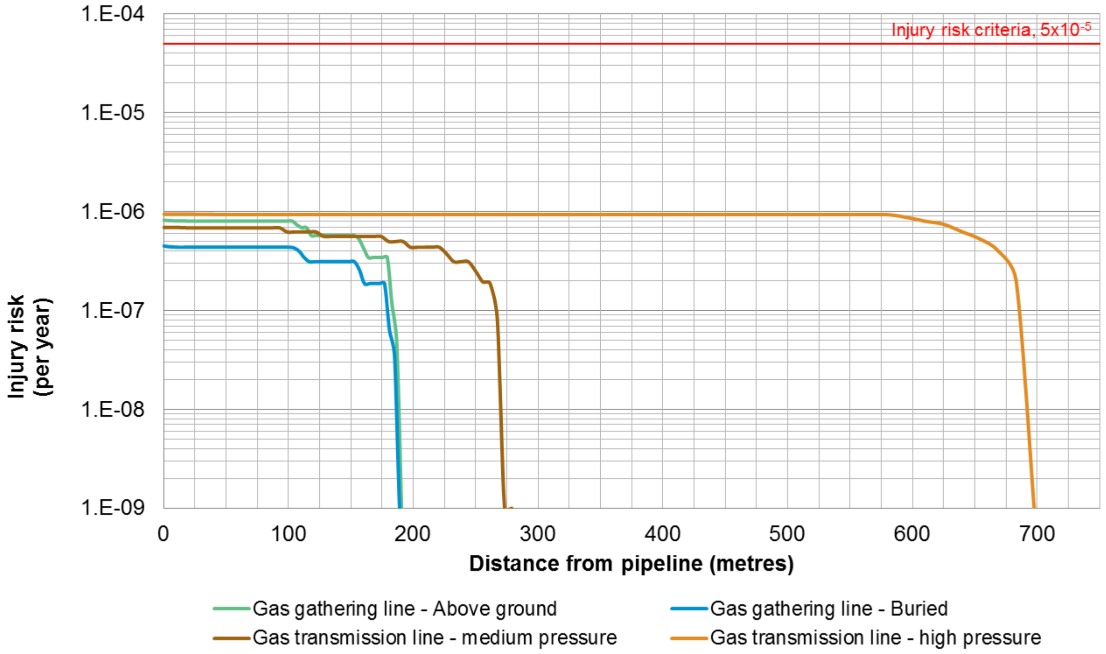
For the gas gathering lines and medium pressure gas transmission pipelines, the estimated risks of fatality are well below the land use planning risk criteria levels.

Figure 9.1: Fatality risk transects for gas gathering and gas transmission pipelines – operations



Injury risk transects for the gas gathering and gas transmission pipelines are shown in Figure 9.2. The highest estimated injury risk is approximately 1 x 10^{-6} per year immediately next to the high pressure gas transmission pipeline. Based on the quantitative risk criteria in Table 9.4, it can be seen that the injury risks associated with the gas gathering and gas transmission pipelines are well below the injury risk criterion for heat radiation of 5 x 10^{-5} per year.

Figure 9.2: Injury risk transects for gas gathering and gas transmission pipelines – operations



Water management facilities

The likelihood of catastrophic failure of a water storage structure (WMF-1) is considered to be remote given the regulation of water storage structures required by the Queensland Government Department of Natural Resources and Mines (2002): Queensland Dam Safety Management Guidelines.. The risk to people due to this scenario is therefore assessed to be medium; i.e. the risk may be accepted as tolerable if it can be shown to be ALARP.

9.3.3. Decommissioning

Decommissioning and rehabilitation will be ongoing during the life of the GFD Project, as old fields are depleted, and new ones are developed. As for construction and commissioning, decommissioning will be relatively short-term. Decommissioning activities are unlikely to result in significant off-site impacts to people and should be adequately controlled by implementation of the Environment, Health and Safety Management System, as well as decommissioning plans and procedures.

In preparation for decommissioning of GFD Project facilities such as gas compression facilities, gas transmission pipelines and water management facilities, process equipment and pipework must be purged of flammable gas and other hazardous materials such as acids and alkalis. The consequences of failing to properly prepare equipment for decommissioning and demolition are similar to those during operations when equipment is prepared for maintenance. The risks to people from wells, gas compression facilities and gas gathering lines and transmission pipelines lines during decommissioning are therefore considered to be similar to those for the operations phase.

As water storage dams have potential long-term use for water storage, they may be left intentionally following decommissioning of other infrastructure with the agreement of the landholder, or incompletely demolished leaving potential restrictions to flow of floodwaters. The potential impacts associated with these facilities are primarily due to remaining structures affecting flood flows in the area of concern, which would only occur if these structures were located in areas such as natural drainage paths for floodwater or in flood plains. The risk associated with this is considered to be adequately mitigated by appropriate siting of the water storage structure during design and construction and consultation with the landholder.

9.4. Risks to property

9.4.1. Construction and commissioning

Hazardous scenarios identified for the construction and commissioning phase involve damage to an adjacent gas pipeline during construction of the gas gathering or transmission pipelines. The risks to property from these scenarios are assessed in Table 9.8 to be low; i.e. the risks are considered to be 'tolerable' and existing controls will be maintained.

Other scenarios during the construction and commissioning phase are considered to be similar to those for the operations phase, the risks of which are assessed below.

9.4.2. Operations

Wells and compression facilities

Table 9.9 summarises the risks to property from the wells and gas compression facilities for the operations phase. Potential impacts on resources (e.g. forests, water reserves, roads, rail level crossings, residential, work and recreational areas) from both natural and induced emergency situations, and counter disaster and rescue procedures in accordance with Disaster Management Act 2003 (Qld) (Ref. 28) were not considered to significantly increase the assessed risk (Table 9.6).

Land use surrounding the GFD Project area is predominantly agricultural but also includes mine sites, various reserves, parks and State forests, as well as some towns. As the wells and compression facilities are generally located in isolated areas with no immediate surrounding buildings or occupied areas, there is minimal potential for off-site escalation, impact on forests or water resources or damage to infrastructure (e.g. local and State-controlled roads and rail level crossings) or third party property. Nevertheless, the assessment conservatively assumes that off-site impact on forests, water resources, infrastructure and third party property in the order of $5 million - $50 million may occur in the event of a fire at the well or compression facilities.

Based on this, the risks of the identified scenarios were assessed to be low; i.e. the risks are considered to be 'tolerable' and existing controls will be maintained.

Table 9.8: Risk to property – construction and commissioning phase

Project component	ID	Hazard [(a)]	Risk assessment - Property			Comments
			Consequence	Likelihood	Risk	
Gas gathering line	GGL-3	Damage to adjacent gas pipeline during construction of gathering line	Moderate	Remote	Low	It has been conservatively assumed that off-easement financial losses from $5 million - $50 million may occur in the event of a fire following damage to an adjacent gas pipeline. The likelihood of damage to an adjacent gas pipeline during construction and commissioning resulting in financial losses from $5 million - $50 million is considered to be remote.
Gas transmission pipeline	GTL-3	Damage to adjacent gas pipeline during construction of transmission pipeline	Moderate	Remote	Low	It has been conservatively assumed that off-easement financial losses from $5 million - $50 million may occur in the event of a fire following damage to an adjacent gas pipeline. The likelihood of damage to an adjacent gas pipeline during construction and commissioning resulting in financial losses from $5 million - $50 million is considered to be remote.

Note:

(a) This table summarises the risk to people of hazardous scenarios specific to the construction and commissioning phase. Other scenarios during the construction and commissioning phase are considered to be similar to those for the operations phase.

Table 9.9: Risks to property from wells and compression facilities – operations phase

Project component	ID	Hazard	Hole size (mm)	Outcome		Risk assessment - Property			Comments
				Type	Frequency (per year)	Consequence	Likelihood	Risk	
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	200	Jet fire	2.5E-5	Moderate	Remote	Low	From Table 7.4, the jet fire property impact zone (23 kW/m^2) extends beyond the site boundary. It has been conservatively assumed that off-site financial losses from $5 million - $50 million may occur in the event of a jet fire at a well.
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal gas compression facility	200	Jet fire	4.0E-6	Moderate	Remote	Low	From Table 7.4, the jet fire property impact zone (23 kW/m^2) extends beyond the site boundary. It has been conservatively assumed that off-site financial losses from $5 million - $50 million may occur in the event of a jet fire at a nodal gas compression facility.
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub gas compression facility	200	Jet fire	1.5E-5	Moderate	Remote	Low	From Table 7.4, the jet fire property impact zone (23 kW/m^2) extends beyond the site boundary. It has been conservatively assumed that off-site financial losses from $5 million - $50 million may occur in the event of a jet fire at a hub gas compression facility.

Gas gathering and gas transmission pipelines

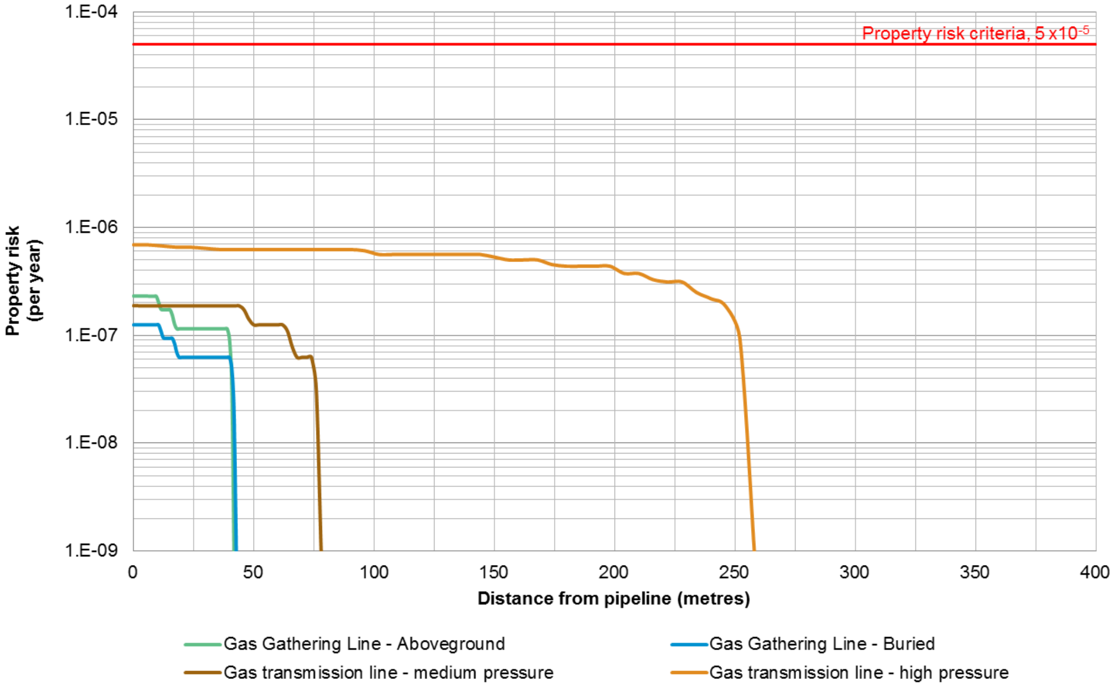
The risk associated with the gas gathering and gas transmission pipelines is qualitatively assessed in Table 3.1.

Table 9.10: Risk to property – gas gathering and transmission pipelines

Project component	ID	Hazard	Risk assessment - People			Comments
			Consequence	Likelihood	Risk	
Gas gathering line	GGL-1&2	Release of Natural Gas from pipeline	Moderate	Remote	Low	It has been conservatively assumed that financial losses from $5 million - $50 million may occur in the event of a fire following a loss of containment from a gas gathering line. The likelihood (given controls) of an event of fire following a loss of containment resulting in financial losses from $5 million - $50 million is considered to be remote.
Gas transmission pipeline	GTL-1&2	Release of Natural Gas from pipeline	Moderate	Remote	Low	It has been conservatively assumed that financial losses from $5 million - $50 million may occur in the event of a fire following a loss of containment from a gas transmission line. The likelihood (given controls) of an event of fire following a loss of containment resulting in financial losses from $5 million - $50 million is considered to be remote.

Property risk transects for the gas gathering and gas transmission pipelines are shown in Figure 9.3. The highest estimated property risk is approximately 7×10^{-7} per year immediately next to the high pressure gas transmission pipeline. Based on the quantitative risk criteria in Table 9.4, it can be seen that the property risks associated with the gas gathering and gas transmission pipelines are well below the criterion for risk of property damage and accident propagation of 5×10^{-5} per year.

Figure 9.3: Property risk transects for gas gathering and gas transmission pipelines – operations



Water management facilities

The likelihood of catastrophic failure of a water storage structure (WMF-1) is considered to be remote. In the event of catastrophic failure of a water storage dam, the impact to forests or water resources, infrastructure (e.g. local and State-controlled roads and rail level crossings) or third party property may be significant; a major consequence category has been assumed. The risk to property due to this scenario is therefore assessed to be medium; i.e. the risk may be accepted as tolerable if it can be shown to be ALARP.

9.4.3. Decommissioning

The risks to property from wells, gas compression facilities and gas gathering and transmission pipelines during decommissioning are considered to be similar to those for the operations phase.

As detailed in Section 9.3.3, the risk associated with water storage dams is considered to be adequately mitigated by appropriate siting of the water storage structure during design and construction and consultation with the landholder.

9.5. Cumulative impact assessment

The vicinity around the GFD Project area includes a variety of major developments currently being assessed or approved and being implemented, as summarised in

Section 3.2. These developments have the potential to act cumulatively with GFD Project impacts to people and property.

For example, the risk for an individual arising from the failure of a gas gathering line, a gas transmission pipeline or a gas compression facility, will increase in proportion to the number of such items of infrastructure that exist in the areas where he or she lives and works. A person located within the impact distance from more than one piece of infrastructure, such as transmission pipelines that share a similar alignment, or gas processing facilities located close to each other, will experience increased risk approximately in proportion to the number of infrastructure items involved. The construction of other projects will also create risks that will be cumulative for the population overall, and will increase the risk of incidents in the region that might adversely impact people and property.

Based on the major developments detailed in Section 3.2, components of the following developments have been identified to be within the GFD Project tenures:

- Nathan Dam and Pipelines: The Nathan water pipeline travels through part of the Scotia gas field. However, it has been announced that this project has been shelved.
- QCLNG: The QCLNG pipeline travels through part of the Scotia gas field. It should be constructed and operational prior to development of the Scotia gas field. Given the generally low risks associated with gas pipelines (see Sections 9.3 and 9.4), it is considered that the cumulative risks of the QCLNG pipeline and GFD Project will be unlikely to exceed the risk criteria given in Section 9.2.

The other developments in the region are generally located one kilometre or more from the GFD Project. At this distance, no cumulative risk impacts to people and property can be expected. Natural and induced emergency situations; and counter disaster and rescue procedures also have the potential to impact on resources such as forests, water reserves, roads, rail level crossings, residential, work and recreational areas. One potential cumulative impact may arise if two projects both had emergency situations at the same time. In this event, the limited emergency services available in the region may be stretched. However, Santos GLNG will have its own emergency response facilities available to respond to their situations. Therefore, the significance of the overall cumulative impact on risk levels for the GFD Project is considered to be low.

9.6. Public liability

During phases of the GFD Project up to and including decommissioning and rehabilitation, no public liability will attach to the State for:

- Private infrastructure built as part of the GFD Project
- Visitors on public land who may be affected by action of the GFD Project unless:

- Explicitly agreed otherwise with the State
- Damage and injury occurs as a result of negligence by an agent of the State.

It should be noted that the wells and gas compression facilities will be secured areas and land access procedures will be in place.

Following successful decommissioning of the GFD Project, which occurs progressively over the life of the GFD Project, and completion of rehabilitation that may be required in accordance with the GFD Project approvals, the GFD Project will no longer have responsibility for infrastructure that remains, or for person entering upon former project areas.

10. RISK MITIGATION

10.1. Overview

The risk assessment results presented in Section 9 are the residual risks associated with the proposed infrastructure. The residual risk is the risk taking into account the risk mitigation controls proposed by the GFD Project.

The risk assessment demonstrates that the residual risks associated with the majority of the proposed infrastructure are either a medium risk or are below risk acceptance criteria. The one exception is the risk to sensitive land uses as a result of a release and fire from the high pressure gas transmission pipeline. Whilst this was qualitatively assessed as a medium risk, the quantitative risk assessment indicates that the risk criteria for sensitive land uses extends off site.

Risks that are medium or below the risk acceptance criteria are acceptable provided that they are managed to a level that is as low as reasonably practicable (ALARP). Risks will be managed to ALARP over the life of the GFD Project through the application of the Environment Health and Safety Management System including the development of a Significant Hazard Risk Register (SHRR).

10.2. Additional risk mitigation

The risk posed by the high pressure gas transmission pipelines exceeds the risk acceptance criteria for sensitive land uses up to 300 m from the pipeline. The risk to sensitive land uses can be mitigated by ensuring appropriate pipeline routing and maintaining separation distances.

Following the adoption of appropriate pipeline routing and separation distances the risk acceptance criteria will be met.

10.3. Significant hazard and risk register

Hazards and risks associated with the GFD Project will be monitored and reviewed through a SHRR. The SHRR consolidates the output from relevant EHS and process safety risk assessment processes and is used to:

- Identify the major EHS hazards to be included in EHS inductions.
- Prioritise resources for the auditing/monitoring of key hazard and risk management measures.
- Assist with the development of site EHS inspection, monitoring and audit programs.
- Assist with the development of annual EHS and process safety Improvement Plans.
- Document the ALARP demonstration.

The SHRR will updated when new significant hazards/incidents are identified or the residual risk of a significant hazard/incident is altered (e.g. design detail provides additional information or the effective implementation of a new risk reduction control is completed). At a minimum, the SHRR is required to be reviewed every five years to validate that the content reflects the current risk profile of the site.

10.4. Conclusion

Based on the proposed controls and the implementation of separation distances between the high pressure pipeline and sensitive land uses, the risks levels are acceptable. Ongoing management of the risk and demonstration of ALARP will be achieved by the GFD Project through the implementation of EHSMS09 and supporting processes.

11. STUDY FINDINGS

11.1. Findings

The hazard assessment identified that three types of infrastructure facilities associated with the proposed development could result in scenarios with the potential for off-site impact. These included:

- Wells
- Compression facilities
- Transmission pipelines.

The likelihood of a loss of containment and subsequent harm has been assessed in the PHA to determine the risk associated by the facility. The main findings are summarised for each type of facility.

Risk rankings are based on the risk matrix in Section 9.2.1. The risk rankings are the residual risk considering that the existing processes and controls adopted in the approved management and regulatory framework for the Santos GLNG Project have been adopted by the GFD Project.

11.1.1. Wells

A loss of containment from a well is assessed as having a medium residual risk level. The medium risk is based on an assessment that the consequence of a release from a well site has the potential to impact beyond the site boundary, but the likelihood is sufficiently low based on the proposed controls to present a medium risk.

Medium risks levels are acceptable provided they can be demonstrated to be ALARP.

Risks will be managed to ALARP throughout the GFD Project's lifecycle using existing controls as documented in EHSMS09 and supporting process (e.g. planning and engineering design).

11.1.2. Gas compression facility

A loss of containment from a gas compression facility is assessed as having a medium residual risk level. The medium risk is based on an assessment that the consequence of a release from a gas compression facility has the potential to impact beyond the site boundary, but the likelihood is sufficiently low based on the proposed controls to present a medium risk.

Medium risk levels are acceptable provided they can be demonstrated to be ALARP.

Risks will be managed to ALARP throughout the GFD Project's lifecycle using existing controls as documented in EHSMS09 and supporting process (e.g. planning and engineering design).

11.1.3. Gas transmission pipelines

A loss of containment form a gas pipeline (gathering or transmission) is assessed as having a medium residual risk level. The medium risk level is based on an assessment that the consequence of a release has the potential to extend beyond the immediate vicinity of the pipeline, but the likelihood is sufficiently low based on the proposed controls to present a medium risk.

The pipeline risk assessment is informed by an assessment against criterion relating to sensitive land use. The risks associated with the proposed pipelines are below the risk acceptance criteria with the exception of the risk to sensitive land uses from the HP gas transmission pipeline. The risk contour for sensitive land uses extends 300 m from the pipeline.

Sensitive land uses include hospitals, child care facilities and old age housing. Given the rural nature of the infrastructure locations, the likelihood of the pipelines passing such facilities is low.

The risk to sensitive land uses can be mitigated by ensuring appropriate pipeline routing and maintaining separation distances.

11.2. Conclusions

A PHA of the proposed infrastructure for the GFD Project has been conducted. The PHA has been conducted early in the GFD Project as an input to the EIS. As such the PHA is based on selecting a set of representative facilities and operating conditions. The assessment takes account of the hazard and risk management framework adopted by Santos for the GLNG Project. Key aspects of the framework are detailed in Section 4. Based on the outcomes of the PHA conducted for the GFD Project, it is concluded that:

- Existing mitigation and controls are sufficient to manage risk to people and property associated with the wells and compression facilities. The existing controls include further risk assessments, planning, engineering design, material selection, security and signage.
- Based on the proposed controls and appropriate route selection and separation distances between the high pressure pipeline and sensitive land uses the risks levels from the pipelines can be managed.
- Ongoing management of the risk and demonstration of ALARP will be achieved by the GFD Project through the implementation of EHSMS09 and supporting processes including:
  - the development of the GFD Project Significant Hazards Risk Register (SHRR)
  - update of the SHRR as the GFD Project matures
  - implementation of Integrity Management Plans to assure the asset integrity and risk controls remain effective over the life of the GFD Project.

APPENDIX A. QUANTITIES OF HAZARDOUS MATERIALS

APPENDIX B. HAZARD IDENTIFICATION WORD DIAGRAM

The hazard identification word diagram is given in this Appendix and shows each of the scenarios identified for the following phases of the GFD Project. The highlighted rows indicate the scenarios that were further assessed in the PHA.

APPENDIX C. CONSEQUENCE ANALYSIS METHODOLOGY AND RESULTS

C1. Overview

This appendix documents the consequence analysis methodology and results for the various GFD Project components. In particular, further details are provided on the following:

- Selection of representative hole sizes
- Release rates modelled
- Release orientation modelled.

C2. Representative hole sizes

Loss of containment from the GFD Project components was modelled for a range of representative hole sizes. The leak scenarios and representative hole sizes selected for the analysis are summarised in Table C.1. The hole sizes used for modelling leaks are based on the leak frequency databases used in this study (see APPENDIX D of this report), as follows:

- Hole sizes for wells and gas compression facilities were obtained from the OGP data (Ref. 20). The modelled hole sizes are geometric averages of hole size ranges in the database. The following hole sizes have been excluded:
  - Hole sizes less than 22 mm have not been modelled as these releases are unlikely to lead to off-site impact.
  - Scenarios with hole sizes more than 200 mm were not modelled as the pressure will generally fall rapidly due to depressurisation effects in the equipment thus limiting the impact of exposure.
- The study uses three main leak scenarios by hole sizes from the EGIG database for the gas gathering and gas transmission pipelines, as follows (Ref. 21):
  - Pinhole leaks were modelled at a representative size of 10 mm.
  - Puncture leaks were leaks ranging from 20 mm to 80 mm. For this study, puncture leaks were modelled as 50 mm.
  - Ruptures are full bore releases, which were modelled as double sided pipeline releases.

Table C.1: Release scenarios and hole sizes

GFD Project component	Release scenario	Representative hole size
Well Nodal gas compression facility Hub gas compression facility	Equipment leaks including valves, flanges, compressors, instrument tappings and vessel leak.	22 mm
		85 mm
		200 mm
Gas gathering line gas transmission pipeline	Small pipework release, due to corrosion or defects	10 mm
	Medium size release (e.g. punctures)	50 mm
	Maximum hole size (i.e. pipeline rupture)	Pipeline diameter (double sided pipeline release)

C3. Release rates

For the wells and gas compression facilities, release rates and consequences were modelled assuming continuous releases at the initial (equipment) pressure. Depressuring or shutdown effects were not taken into account.

For the gas gathering lines and gas transmission pipelines, releases were modelled as follows:

- Releases from 10 mm and 50 mm holes were modelled as continuous releases at the pipeline pressure (i.e. no depressuring of the pipeline).
- For pipeline rupture, the following approach was used:
  - In the event of immediate ignition, it is considered that a fireball would occur. The amount of fuel for the fireball was estimated by assuming that ignition would occur within 10 seconds of the release.
  - If unignited, the flammable vapour cloud would take time to reach its full extent. As it develops, the release rate will decrease due to pressure drop along the pipeline. For the pipeline rupture scenario, the pipeline blowdown rate after 30 seconds of rupture was used. This is consistent with the approach in Appendix Y of AS 2885.1 for its radiation contour calculation. The rate from full bore ruptures was doubled to account for release from both sides of the pipeline. This would happen where a guillotine rupture occurs, and represents the worst case release. Other failure modes included in rupture are the pipeline opening up along a seam which may give a smaller release rate than guillotine rupture failure mode. The double sided release is consistent with the recommended methods by TNO (Ref. 29) and IGEM (Ref. 30).

The effect of block valve stations and similar emergency actions was not included as they generally would either not be initiated or would not be effective within the first 30 seconds to 60 seconds of a release.

C4. Release orientation

Release orientations considered in this study are as follows:

- Releases from the wells were modelled as vertical and horizontal.
- Releases from the gas compression facilities were modelled as horizontal. Horizontal releases result in the furthest impact distances and would give the worst case results for releases from the equipment.
- Releases from the aboveground gas gathering lines were modelled as horizontal.
- The angle of release from the buried gas gathering lines and gas transmission pipelines was specified as follows:
  - Vertical where the release is 90° to the horizontal plane. Releases due to third party impact will tend to occur on the top of the pipeline.
  - Horizontal releases will tend to scour the ground around the pipeline resulting in a crater which will deflect the jet upwards. The release is modelled as a jet flame at 45° to the horizontal plane.

C5. Results

The consequences of the hazardous events assessed in this study include the following:

- Fireball, in the event of immediate ignition following a pipeline rupture
- Jet fire, if a continuous natural gas release is ignited immediately
- Flash fire, in the event of delayed ignition of a natural gas release
- Bund fire, in the event of escalation of a fire to diesel stored at the compression facilities or associated facilities (eg accommodation facilities).

The consequences of the hazardous scenarios identified were modelled using the proprietary consequence modelling package, *TNO Effects* (Ref. 18), with the exception of fireballs, which were modelled using the approach given in the *TNO Yellow Book* (Ref. 19). The results of the analysis are shown in Table C.2 to Table C.5.

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Table C.2: Consequence analysis results for fireballs

GFD Project component	ID	Hazard	Fuel mass (tonne)	Fireball radius (m)	Distance (m) to following fatality probabilities [a]:		
					1%	50%	100%
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground)	2.8	43	86	Within fireball	-
	GGL-2	Release of natural gas from gas gathering line (underground)	2.8	43	86	Within fireball	-
	GGL-3	Damage to adjacent gas transmission pipeline gas during construction of gathering line	43.6	104	385	231	152
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	6.2	55	137	58	-
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	43.6	104	385	231	152
	GTL-3	Damage to adjacent gas pipeline during construction of transmission pipeline	43.6	104	385	231	152

Note:

(a) '-' indicates that the particular fatality probability level is not predicted to occur at receiver level.

Table C.3: Consequence analysis results for jet fires

GFD Project component	ID	Hazard	Release orientation	Hole size (mm)	Release rate (kg/s)	Flame length (m)	Flame width (m)	Distance (m) to following heat radiation levels [(a)]:		
								4.7 kW/m^2	10 kW/m^2	23 kW/m^2
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	Horizontal	22	0.2	6.2	1.8	10	8.6	7.7
				85	3.2	26	6	33	29	26
				200	17.8	56	13	73	64	57
			Vertical	22	0.2	4.0	1.2	5	2.7	-
				85	3.2	13	3.9	17	10	-
				200	17.8	28	8.4	39	22	-
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground)	Horizontal	10	0.03	2.7	0.8	4.1	3.6	3.4
				50	0.74	11	3.4	18	16	14
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
	GGL-2	Release of natural gas from gas gathering line (underground)	Vertical	10	0.03	1.7	0.5	2.1	1.1	0.46
				50	0.74	7.2	2.2	9.2	5.1	-
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
			45°	10	0.03	2.2	0.66	3.1	2.4	1.6
				50	0.74	9.2	2.8	13	9.9	5.1
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
	GGL-3	Damage to adjacent gas pipeline during construction of gas gathering line	Vertical	10	1.5	8.6	2.5	11	6.3	-
				50	36.3	36	10	51	30	-
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
			45°	10	1.5	11	3.1	16	12	7.6
				50	36.3	45	13	72	53	34
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal gas compression facility	Horizontal	22	1.0	12	3.4	19	17	15
				85	14.2	38	11	64	56	49
				200	78.2	81	24	139	121	106

GFD Project component	ID	Hazard	Release orientation	Hole size (mm)	Release rate (kg/s)	Flame length (m)	Flame width (m)	Distance (m) to following heat radiation levels [(a)]:		
								4.7 kW/m^2	10 kW/m^2	23 kW/m^2
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	Vertical	10	0.22	3.7	1.1	4.7	2.5	-
				50	5.1	16	4.5	21	12	-
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
			45°	10	0.22	4.8	1.4	6.9	5.2	3.1
				50	5.1	20	5.7	30	22	13
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	Vertical	10	1.5	8.6	2.5	11	6.3	-
				50	36.3	36	10	51	30	-
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
			45°	10	1.5	11	3.1	16	12	7.6
				50	36.3	45	13	72	53	34
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
	GTL-3	Damage to adjacent gas pipeline during construction of gas transmission pipeline	Vertical	10	1.5	8.6	2.5	11	6.3	-
				50	36.3	36	10	51	30	-
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
			45°	10	1.5	11	3.1	16	12	7.6
				50	36.3	45	13	72	53	34
				Rupture	N/A	N/A	N/A	N/A	N/A	N/A
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub gas compression facility	Horizontal	22	7.4	26.9	7.7	45	39	35
				85	100.6	86.9	25	151	131	115
				200	547.3	183.1	53	327	282	248

Note:
(a) '-' indicates that the particular fatality probability level is not predicted to occur at receiver level.

Table C.4: Consequence analysis results for flash fires

GFD Project component	ID	Hazard	Hole size (mm)	Release rate (kg/s)	Distance (m) to LFL:	
					Length	Width
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	22	0.23	4.5	0.5
			85	3.20	17	1.8
			200	17.80	40	4.2
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground)	10	0.03	1.7	0.2
			50	0.74	8.5	1.0
			Rupture	160	94	15
	GGL-2	Release of natural gas from gas gathering line (underground)	10	0.03	1.7	0.2
			50	0.74	8.5	1.0
			Rupture	160	94	15
	GGL-3	Damage to adjacent gas pipeline during construction of gathering line	10	1.5	12	1.2
			50	36.3	59	6.4
			Rupture	1800	288	40
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal gas compression facility	22	1.0	10	1.2
			85	14.2	37	4.0
			200	78.2	87	9.6
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	10	0.22	4.6	0.6
			50	5.1	22	2.4
			Rupture	258	120	29
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	10	1.5	12	1.2
			50	36.3	59	6.4
			Rupture	1800	288	40
	GTL-3	Damage to adjacent gas pipeline during construction of gas transmission pipeline	10	1.5	12	1.2
			50	36.3	59	6.4
			Rupture	1800	288	40

GFD Project component	ID	Hazard	Hole size (mm)	Release rate (kg/s)	Distance (m) to LFL:	
					Length	Width
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub gas compression facility	22	7.4	26	2.8
			85	100.6	80	11
			200	547.3	240	26

Table C.5: Consequence analysis results for bund fires

GFD Project component	ID	Hazard	Wind speed (m/s)	Fire diameter (m)	Flame length (m)	Distance (m) to following heat radiation levels:		
						4.7 kW/m^2	10 kW/m^2	23 kW/m^2
Nodal gas compression facility	NGC-2	Escalation of fire to diesel storage	2	10	14	23	16	9
			5	10	12	23	18	11
Hub gas compression facility	HGC-2	Escalation of fire to diesel storage	2	10	14	23	16	9
			5	10	12	23	18	11

APPENDIX D. LIKELIHOOD ANALYSIS METHODOLOGY AND RESULTS

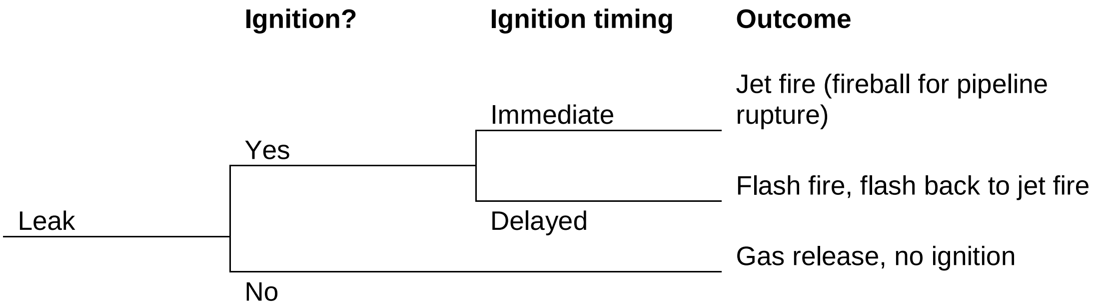
D1. Overview

This appendix documents the likelihood analysis methodology and results for the various GFD Project components. The likelihood of an event is the number of occurrences of the event over a specified time period, generally taken as one year. The likelihoods of the hazardous scenarios with off-site impact were estimated using event tree analysis, taking into account the following:

- Leak frequencies from equipment and pipelines
- Ignition probability
- Release orientation.

Figure D.1 shows the event tree used in this study to show the progression of an event following a leak of natural gas.

Figure D.1: Event tree for loss of containment



D2. Wells and compression facilities

D2.1. Leak frequencies

Leak frequencies from the wells and gas compression facilities were estimated by combining generic leak frequency data and a high level parts count of equipment. Generic leak frequency data used in this assessment is summarised in Table D.1. At this stage of the GFD Project life, a full parts count of equipment (i.e. accounting for piping lengths and numbers of fittings, valves, etc.) could not be performed; only the main process equipment have been taken into account in the likelihood analysis.

Table D.1: Leak frequency data for wells and compression facilities

Equipment	Leak frequency			Unit	Comments
	22 mm	85 mm	200 mm		
Well (production, vertical release)	6.8E-05	-	7.8E-05	per well-year	RVIM data at 95% confidence level. Leak from tubing assumed to be equivalent to a 22 mm hole; tubing full release assumed to be equivalent to a 200 mm hole.
Well (production, horizontal release)	1.6E-05	-	-	per well-year	RVIM data at 95% confidence level. Leak from tubing assumed to be equivalent to a 22 mm hole.
Well (workover, vertical release)	1.0E-04	-	1.7E-04	per well-year	RVIM data (per workover) at 95% confidence level. Leak from tubing assumed to be equivalent to a 22 mm hole; tubing full release assumed to be equivalent to a 200 mm hole. Project information provided suggests well workover required once every 3 years.
Well (workover, horizontal release)	3.0E-05	-	-	per well-year	RVIM data (per workover) at 95% confidence level. Leak from tubing assumed to be equivalent to a 22 mm hole. Project information provided suggests well workover required once every 3 years.
Pressure vessel (storage & process)	5.0E-06	5.0E-06	4.0E-06	per vessel-year	UK HSE FR 1.1.3 - Pressure vessels (general vessels - data based on chlorine vessels). Hole sizes in data approximated to next largest hole size used in this study.
Gas compressor	3.7E-05	-	2.4E-07	per compressor-year	RVIM data at 95% confidence level. Leak assumed to be equivalent to a 22 mm hole; full bore rupture assumed to be equivalent to a 200 mm hole.
Filter	1.9E-04	3.5E-05	2.0E-05	per filter-year	OGP

D2.2. Ignition probability

The *IP Research Report* (Ref. 26) was used for ignition probabilities of releases from the wells and gas compression facilities. These probabilities are based on plant size, plant type and release rate. The following two ignition models from the report were used:

- No. 5, small plant gas or LPG (LPG) (Gas or LPG release from small onshore plant): Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from small onshore plants (plant area up to 1,200 m^2, site area up to 35,000 m^2).

- No. 8, large plant gas LPG (Gas or LPG release from large onshore plant): Releases of flammable gases, vapour or liquids significantly above their normal boiling point from large onshore outdoor plants (plant area above 1,200 m^2, site area above 35,000 m^2).

The selection of ignition model for each facility was based on the approximate site area; Table D.2 shows the ignition model that was used for the wells and compression facilities.

Table D.2: Ignition model used

Project component	Approximate site area	Ignition model	Hole size (mm)	Ignition probability
Well	13,700 m^2	5 Small Plant Gas LPG	22	7.04E-4
			85	7.34E-3
			200	2.59E-2
Nodal gas compression facility	40,000 m^2	8 Large Plant Gas LPG	22	7.04E-4
			85	7.34E-3
			200	2.59E-2
Hub gas compression facility	220,000 m^2	8 Large Plant Gas LPG	22	9.25E-3
			85	1.26E-1
			200	3.25E-1

The *IP Research Report* provides some data and discussion on ignition timing. Although it suggests ignition timing may not always be a reliable indicator of the outcome, the usual approach in a QRA is to use ignition timing as per Figure D.1. The IP Research Report indicates that the proportion of immediate ignition is 30% to 50%, with the remainder delayed – independent of release rate. For this study a split of 50/50 immediate to delayed was adopted for releases, since in order to reach the large dispersion distances, a significant delay in ignition is required.

D2.3. Release orientation

Releases from the wells were modelled as vertical and horizontal. The RIVM data for wells provides different leak frequencies for vertical and horizontal releases.

Releases from the compression facilities were modelled as horizontal.

D3. Gas gathering and gas transmission pipelines

D3.1. Leak frequencies for buried steel pipelines

The most applicable historical leak frequency data would be for pipelines in the same service, in similar locations and constructed to the same design standards. Such data, i.e. for Australian gas transmission pipelines in rural Queensland, does not exist or is statistically insignificant.

To derive leak frequencies for the gas gathering lines and transmission pipelines, UKOPA and EGIG data have been reviewed against leak data for Australian pipelines. Justification for use of the UKOPA/EGIG data includes:

- The pipeline population and exposure are more significant compared to Australian data and that the incident rates derived are more statistically significant
- The data is freely published and can be directly referenced
- It provides useful breakdowns by event size and cause of loss of containment
- Regulators and reviewers will have access to the same databases and would also expect to see conservative selection of data.

Australian data

The collection and publishing of incident data for Australian pipelines over time has not been as thorough and consistent compared to European data sources. However, the pipeline industry in Australia has more recently been spending considerable effort to improve the data collection and analysis of data.

The APIA is currently developing an Australian pipeline incident database. An APIA conference paper (Ref. 31) summarises the most recent results of the data collection process. This paper covers the period between 1965 and 2010. The current pipeline population included in the database is about 33,000 km of pipeline with a total exposure of about 0.8 million km-years[3].

The data presentation includes statistics relating to damage incidents, where damage incident is defined as:

- Loss of containment (not including minor leaks at flanges)
- Damage to the coating or pipe caused by mechanical equipment.
- Other defect (e.g. corrosion) which requires either maximum allowable operating pressure (MAOP) reduction or pipe repair (e.g. reinforcing sleeves, clock spring or cut-out and replacement).

The paper notes that there has never been a death or injury recorded in connection with damage to a pipeline in Australia.

The paper showed that for the overall period between 1965 and 2010, the damage incident rate was about 0.18 damage incidents per 1,000 km-yr. For the last report period (2004 – 2010), the damage incident rate was 0.09 per 1000 km-yr. An analysis of incidents since 2001 by location class, also gives a damage incident rate of 0.12 per

[3] Pipeline exposure indicates the total length of pipeline in the population sample as well as the number of years of experience for the sample. It is usually calculated by multiplying the average length of pipeline, L, in the sample for each period (eg 1965-1969) by the interval (five years). This is accumulated over the total time period in the population (eg every 5 year period from 1965-2010) to give the total pipeline exposure in km-years.

1,000 km-yr. Of the 34 damage incidents over this period, 7 resulted in loss of containment (i.e. about 20%). Therefore, the paper then estimates that the incident rate for loss of containment incidents is about 0.025 per 1,000 km-yr.

The data for the period 1965-2010 shows that the majority of damage incidents were due to external interference (118 out of a total of 137, or 86%).

European data (EGIG)

EGIG regularly publishes data on gas pipeline incident data. The latest report is the 8th Report (Ref. 21), which covers gas pipeline data from the period 1970–2010. EGIG is a consortium of fifteen major European gas pipeline operators. The pipeline population included in the database covers about 130,000 km of pipelines with a total exposure of about 3.2 million km-years.

The analysis undertaken showed that the overall incident frequency was 0.35 incidents per year per 1,000 km of pipeline length. This was for the whole period between 1970 and 2010. This gives a conservative figure as the data shows that the incident frequency is reducing over time. For example, the same data for the 5 year period between 2006 and 2010 gives an incident rate of 0.16 per 1,000 km-yr. The reduction in incident rate is attributed to improved maintenance and corrosion controls.

External interference events, which represent the most severe events, have gradually reduced in their relative frequency to other causes of loss of containment. Historically over the entire period, 48% of events have been due to external interference.

UK data (UKOPA)

UKOPA also collects pipeline incident data and regularly publishes results. UKOPA is a consortium of UK onshore pipeline operators, which was established to discuss strategic issues relating to the safe operations and maintenance of pipelines.

The UKOPA database covers UK onshore pipelines, including liquid and gas hydrocarbons in addition to natural gas. The majority of the pipeline population carries natural gas (about 20,000 km of a total of 22,000 km of pipeline). The most recent report covers the period between 1962 and 2010 (Ref. 25).

The pipeline population included in the database covers about 22,000 km of pipelines with a total exposure of about 0.79 million km-years.

Incident rates over different reporting periods are:

- 0.234 per 1,000 km-yr for 1962-2010
- 0.060 per 1,000 km-yr for 2001-2010
- 0.093 per 1,000 km-yr for 2006-2010.

Overall about 22% of incidents over the period 1962–2010 were identified to be due to external interference. However, the first 10 year period (1962–1972) was dominated by incidents resulting from pipe defects, mainly from weld defects. Since about 1972, the incident rate for external interference is similar to the rate due external corrosion.

A product loss incident is defined as 'an unintentional loss of product from the pipeline, within the public domain and outside the fences of installations, excluding associated equipment (e.g. valves, compressors) or parts other than the pipeline itself'.

Data comparison

Table D.3 summarises the incident frequency rates from the main sources discussed in the sections above. The overall incident frequency rates from the EGIG database and for the UKOPA database are similar for the entire record periods and for the most recent reporting period. Both the EGIG and UKOPA databases show a reducing failure rate over time. The EGIG data indicate about 50% of the causes of incidents are due to external interference compared to about 20% for the UKOPA data. No reason is proposed for this discrepancy.

The Australian data indicates that the incident rate is significantly lower than for European pipelines (about a factor of 6 for the most recent reporting periods) and for UK pipelines (about a factor of 4). The reasons for this difference cannot be easily determined without further detailed analysis of collected data. It may be considered that the reason is that the pipeline population and total exposure is small by comparison with European pipelines.

The Australian data indicates that the majority of the pipeline population is in remote rural locations (about 28,000 km out of 32,000). The majority of damage incidents (24 out of 34 in the period since 2001) occurred in R1 (remote rural) locations. For the same period, the majority of incidents (including near misses) occurred in T1 (suburban) locations. The damage incident rate for T1 locations was also estimated to be about four times the incident rate for R1 locations. The location of loss of containment incidents is not given.

The EGIG database does not indicate the location class, so no similar comparison can be made. The UKOPA data shows a similar pattern to that for the Australian database, i.e. a majority of pipelines in rural locations and an incident rate in suburban locations about four times that in rural locations.

Table D.3: Comparison of base leak frequency data for pipelines

Data source	Most recent period		Total period	
	Frequency (per 1,000 km-yr)	Years	Frequency (per 1,000 km-yr)	Years
EGIG	0.16	2006-2010	0.35	1970-2010
UKOPA	0.093	2006-2010	0.234	1962-2010
	0.060	2001-2010		
Australian	0.025	2001-2010	Calculation not reported for loss of containment incident frequency over whole period. Overall damage incident frequency calculated to be about 0.18 from Ref. 31.	1965-2010

Leak frequencies used

Since it is known that pipeline leak frequencies have reduced and are still reducing with time, data from older periods should not be applied to modern pipelines. The UKOPA pipeline leak frequency data for the past 10 years (2001–2010) has been used in this study for the following reasons:

- The 10 year period of data provided a suitable trade-off between length of time and reflecting the potential leak frequencies of modern pipelines
- The data provided a conservative figure based on Australian pipeline experience.

The overall leak frequency of 0.060 per 1,000 km-yr is conservative compared to Australian pipeline experience with its historical frequency of 0.025 per 1000 km-yr.

The hole size distribution from EGIG was used since it is more reflective of the proportion of external interference causes for Australian pipelines. External interference tends to give larger hole sizes than other causes. The hole size distributions in EGIG and UKOPA are only provided for the full data set from the 60's to present.

However, the hole size distribution from EGIG was used because a higher percentage of leaks from this database were from larger hole sizes. This recognises the high percentage (65%) of leaks in Australian pipelines due to external interference. External interference tends to give larger hole sizes than other causes. UKOPA has a noticeably smaller proportion of releases due to external interference than both EGIG and Australian data and hence its hole size distribution is not considered appropriate.

The leak frequencies for buried steel pipelines used in this study are summarised in Table D.4; these were used for the medium and high pressure gas transmission pipelines.

Table D.4: Leak frequencies for buried steel pipelines

Cause	Pipeline leak frequency by hole size (per 1,000 km-yr)			
	Pinhole (d <10 mm)	Puncture (10< d <50 mm)	Rupture (d >50 mm)	Total (by cause)
External interference	0.008	0.015	0.006	0.029
Corrosion	0.01	0.00035	0	0.01
Construction defect/ material failure	0.007	0.002	0.00068	0.01
Hot tap error	0.0031	0.00131	0	0.004
Ground movement	0.0007	0.0009	0.0013	0.003
Other/unknown	0.0036	0.00038	0	0.004
Total	**0.032**	**0.020**	**0.0080**	**0.06**

D3.2. Leak frequencies for buried non-steel pipelines

The predominant failure modes for steel pipelines (in decreasing order of prevalence) are (Ref. 21):

- External interference (e.g. excavation works)
- Construction/material problems
- Corrosion
- Design flaws
- Ground movement
- Hot tap errors.

By comparison, the predominant failure mode for non-steel (for example polyethylene, HDEP or GRE) pipework has also been external impact, usually due to excavation works. However, it has been shown that polyethylene piping has a larger resistance to external force than steel pipe and impact tends to result in smaller puncture sizes (Ref. 32). Visco-elastic materials such as polyethylene deform under load, allowing stresses to relax and stresses to be shed.

Construction and material problems in plastic piping tend to lead to brittle-like failures, which are the second most frequent failure mode in polyethylene pipeline systems; although, mainly in older-generation piping which tended to fail prematurely due to brittle cracking. Brittle-like cracking has been linked to stress intensification generated by external forces acting on the pipe (Ref. 33). Examples of conditions that can generate stress intensification include differential earth settlement (particularly at connections with more rigidly anchored fittings), excessive bending (as a result of installation configurations, especially at fittings), and point contact with rocks or other objects. Limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees was deemed to be a major contributor to minimising stress intensification.

Corrosion is not an issue for polyethylene piping, as it is for steel pipe.

The performance of polyethylene during ground-movement situations (earthquake) was demonstrated during the 1995 earthquake in Kobe, Japan, following which Osaka Gas found failures in steel/iron pipework but none in polyethylene systems.

Hot tapping is an inherently hazardous process and errors are mainly a function of human error (poor workmanship); both steel and polyethylene piping is susceptible to hot tap error leading to pipe failures.

Based on the preceding discussion, it is considered that the performance (integrity) of polyethylene pipe is as good as, if not better than, steel for the pipe size and rating indicated above. Therefore, it is proposed that the derived leak frequencies for steel pipelines is representative of, if not conservative for, polyethylene piping with a modification to eliminate corrosion failures. High-density polyethylene has been used in the assessment based on the available data sources. It is considered representative of polyethylene piping that may be used by the GFD Project.

The resulting leak frequencies for buried high density polyethylene pipelines used in this study are shown in Table D.5; these were used for the buried gas gathering lines.

Table D.5: Leak frequencies for buried non-steel pipelines

Cause	**Pipeline base frequency by cause and hole size (per 1,000 km-yr)**			
	Pinhole (d <10 mm)	**Puncture (10< d <50 mm)**	**Rupture (d >50 mm)**	**Total (by cause)**
External interference	0.0080	0.015	0.0056	0.029
Corrosion	0	0	0	0
Construction defect/ material failure	0.0070	0.0020	0.00068	0.010
Hot tap error	0.0031	0.0013	0	0.0044
Ground movement	0.00069	0.00092	0.0013	0.0029
Other/unknown	0.0036	0.00038	0	0.0040
Total	**0.022**	**0.020**	**0.0076**	**0.050**

D3.3. Leak frequencies for aboveground non-steel pipelines

For the aboveground high density polyethylene gas gathering lines, data for aboveground steel pipelines from the UK HSE (Ref. 24) was used as it is considered that the failure modes for aboveground pipelines are different to those for buried pipelines. The leak frequencies used in this study for the aboveground polyethylene gas gathering lines are shown in Table D.6, which were derived from the UK HSE data based on the following assumptions:

- Corrosion and external interference can be discounted as causes for aboveground PE pipeline failure
- The hole size distribution from the EGIG data is applicable.

Table D.6: Leak frequencies for aboveground polyethylene pipelines

Cause	Pipeline base frequency by cause and hole size (per 1,000 km-yr)			
	Pinhole (d <10 mm)	Puncture (10< d <50 mm)	Rupture (d >50 mm)	Total (by cause)
External interference	0.0000	0.0000	0.0000	0.0000
Corrosion	0.0000	0.0000	0.0000	0.0000
Construction defect/ material failure	0.0258	0.0108	0.0064	0.0430
Hot tap error	0.0118	0.0050	0.0030	0.0198
Ground movement	0.0077	0.0032	0.0019	0.0128
Other/unknown	0.0106	0.0044	0.0026	0.0176
Total	**0.056**	**0.023**	**0.014**	**0.093**

D3.4. Ignition probability

The UKOPA data does not include ignition probabilities. For this study, the probability of ignition following loss of containment from a pipeline is based on data in the EGIG report (Ref. 21), which is shown in Table D.7.

Table D.7: Probability of ignition for pipelines

Size of Leak	Ignition probability (%)
Pinhole-crack (10 mm)	4
Puncture (50 mm)	2
Rupture	
Overall	13
Diameter < 406 mm (16”)	10
Diameter ≥ 406 mm (16”)	33

As for releases from the wells and compression facilities, a split of 50/50 immediate to delayed ignition was adopted for releases from the gas gathering and transmission pipelines.

D3.5. Release orientation

Releases from the aboveground gas gathering lines were modelled as horizontal.

Releases from the buried gas gathering and transmission pipelines were modelled as 45° and vertical releases, as follows:

- For gas transmission pipelines, the main cause of large holes is external interference, with damage to the top of the pipeline or a crater with gas ejected vertically. Therefore, it was assumed that 80% of puncture and rupture events are in the vertical direction, and 20% in a lateral direction (at 45° angle).
- Since pinhole releases are typically due to corrosion, which could occur at point on the pipeline, it has been assumed that 50% of pinhole releases are in a vertical direction and 50% in a lateral direction.

D4. Results

The likelihoods estimated for hazardous scenarios with off-site impact are shown in Table D.8 for the wells and compression facilities, and Table D.9 for the gas gathering lines and transmission pipelines.

Table D.8: Leak and outcome frequencies for wells and gas compression facilities

GFD Project component	ID	Hazard	Hole size (mm)	Leak frequency (per year)	Ignition probability		Outcome frequency (per year)	
					Immediate	Delayed	Jet fire	Flash fire
Well	PDW-1	Release of natural gas from well head or equipment/piping at well lease	200	9.8E-4	0.026	0.026	2.5E-5	2.5E-5
Nodal gas compression facility	NGC-1	Release of natural gas from equipment/piping at nodal gas compression facility	200	4.1E-5	0.098	0.098	4.0E-6	3.6E-6
Hub gas compression facility	HGC-1	Release of natural gas from equipment/piping at hub gas compression facility	200	4.5E-5	0.33	0.33	1.5E-5	9.9E-6

Table D.9: Leak and outcome frequencies for gas gathering and gas transmission pipelines

GFD Project component	ID	Hazard	Hole size (mm)	Leak frequency (per km-year)	Ignition probability		Outcome frequency (per km-year)			
					Immediate	Delayed	Fireball	Jet fire (45°)	Jet fire (vertical)	Flash fire
Gas gathering line	GGL-1	Release of natural gas from gas gathering line (aboveground HDPE)	10	5.6E-05	0.02	0.02	N/A	1.12E-06 [(a)]		1.1E-06
			50	2.3E-05	0.01	0.01	N/A	2.34E-07 [(a)]		2.3E-07
			Rupture	1.4E-05	0.17	0.17	2.3E-06	N/A	N/A	2.3E-06
	GGL-2	Release of natural gas from gas gathering line (underground HDPE)	10	2.2E-05	0.02	0.02	N/A	2.2E-07	2.2E-07	4.5E-07
			50	2.0E-05	0.01	0.01	N/A	4.0E-08	1.6E-07	2.0E-07
			Rupture	7.6E-06	0.17	0.17	1.3E-06	N/A	N/A	1.3E-06
	GGL-3	Damage to adjacent gas pipeline during construction of gas gathering line	10	3.2E-05	0.02	0.02	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	0.01	0.01	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	0.17	0.17	1.3E-06	N/A	N/A	1.3E-06
Gas transmission pipeline	GTL-1	Release of natural gas from medium pressure gas transmission pipeline (underground steel)	10	3.2E-05	0.02	0.02	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	0.01	0.01	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	0.17	0.17	1.3E-06	N/A	N/A	1.3E-06
	GTL-2	Release of natural gas from high pressure gas transmission pipeline (underground steel)	10	3.2E-05	0.02	0.02	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	0.01	0.01	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	0.17	0.17	1.3E-06	N/A	N/A	1.3E-06
	GTL-3	Damage to adjacent gas pipeline during construction of gas transmission pipeline	10	3.2E-05	0.02	0.02	N/A	3.2E-07	3.2E-07	6.4E-07
			50	2.0E-05	0.01	0.01	N/A	4.1E-08	1.6E-07	2.1E-07
			Rupture	7.6E-06	0.17	0.17	1.3E-06	N/A	N/A	1.3E-06

Note:
(a) Releases from the aboveground gas gathering line has been modelled as horizontal.

APPENDIX E. ASSUMPTIONS

Project No. 20707
Project URS Santos Gas Field Development Project EIS
Title Summary of Assumptions

Component	No	Assumption/Data used	Reference/Justification
Consequence analysis	1	Process conditions/modelling inputs as listed in Table 7.1 of the report	As discussed with Santos GLNG
	2	Hole sizes for wellhead and compression facilities - 22 mm, 85 mm, 200 mm or full bore	OGP (Oil and Gas Producers)
	3	Hole sizes for pipeline releases - 10 mm, 50 mm, rupture (double sided release)	EGIG (European Gas Pipeline Incident Data Group)
	4	Bund height of 1.5 m for bund fire analysis	As per AS1940, maximum allowable height is 1.5 m, unless means for safe and rapid entry and exit are provided.
	5	Consequence criteria for people and property - as given in Tables 7.2 and 7.3 of the report	NSW HIPAP 4
	6	Pipeline release orientation for punctures and ruptures: 80% of puncture and rupture events - vertical direction 20% - lateral direction (45 degree angle)	Main cause of large holes is external interference (damage to top of pipeline, crater with gas ejected vertically)
	7	Pipeline release orientation for pinhole releases: 50% of pinhole release - vertical direction 50% of pinhole release - lateral direction (45 degree angle)	Pinhole releases typically occur due to corrosion and therefore could occur at any point on the pipeline circumference.
	8	Orientation of releases from compression facilities has been assumed to be horizontal.	This gives the most conservative consequence distances.
	9	Releases from the wellheads were modelled for both horizontal and vertical orientations.	Ref. 24 (RIVM National Institute for Public Health and the Environment) provides frequencies of both horizontal and vertical releases from wellheads.
	10	Release rates assumed to be constant at the initial pressure for equipment; and 10mm and 50mm pipeline releases.	No credit was taken for automatic isolation and depressuring of facilities. A conservative assumption that will have limited impact on the immediate fatality effects of the releases.
	11	For pipeline rupture scenarios the release rate after 30 seconds is assumed.	Appendix Y of AS2885.1
Frequency analysis	12	Leak from wellhead tubing assumed to be equivalent to a 22 mm hole; tubing full release assumed to be equivalent to a 200 mm hole.	Ref. 24 (RIVM National Institute for Public Health and the Environment) provides frequencies of tubing leak and tubing full release. Typical hole sizes have been assumed for these
	13	Leak frequency data used for buried steel pipelines - As given in Table D.4 of the report.	Leak frequency data - UKOPA Hole size distribution - EGIG
	14	Leak frequency data used for buried polyethylene pipelines - As given in Table D.5 of the report.	Derived from frequencies for steel pipelines with modification to eliminate corrosion failure mode. Leak frequency data - UKOPA Hole size distribution - EGIG
	15	Leak frequency data used for aboveground polyethylene pipelines - As given in Table D.6 of the report.	UK HSE
	16	Ignition probabilities for pipelines - given in Table D.7 of the report	EGIG (European Gas Pipeline Incident Data Group)
	17	Ignition probabilities for wellheads and compression facilities - given in Table D.2 of the report	Ignition Probabilities IP Research Report (Ref. 27 of the report)
	18	The likelihood of damage to an adjacent gas pipeline during construction and commissioning resulting in off-site fatalities/injuries is considered to be remote.	No fatalities/injuries have been recorded in connection with damage to a pipeline in Australia (Ref. Australian pipeline incident database)
Risk ranking	19	Multiple off-site fatalities may occur in the event of a fire following damage to adjacent gas pipeline	Conservative approach - corresponds to highest consequence category ('Critical')
	20	Multiple off-site fatalities may occur in the event of a jet fire at a production well or compression facilities	Conservative approach - corresponds to highest consequence category ('Critical')
	21	Multiple off-site fatalities may occur in the event of a flash fire at a production well or compression facilities	Conservative approach - corresponds to highest consequence category ('Critical')
	22	Off-site impact on forests, water resources, infrastructure and third party property in the order of $5 million - $50 million, in the event of fire at production well or compression facilities	Conservative approach - corresponds to consequence category ('Major')
Risk assessment - minimum distance to boundary or right-of-way	23	Production well - 44 m Minimum distance measured from wellhead to boundary.	RFI1.05 Infrastructure Description - Well pad plot plans 6312 Fairview Wellpad, Dwg No 6316-50-5000, Rev 0.
	24	Gas gathering lines - 3 m Pipeline Right of Way is 6 m, 3 m on either side of gathering line.	RFI 1.15 Santos GLNG Environmental Protocol Table 3
	25	Damage to adjacent gas pipeline during construction of gathering line - 6 m Minimum distance to right of way = 3 m (from above) + 3 m for right of way of adjacent gas pipeline	RFI 1.15 Santos GLNG Environmental Protocol Table 2
	26	Nodal gas compression facility - 70 m Given: Typical nodal 200m x 200m Assumed: Layout drawn to scale (1 row is roughly equivalent to 10 m) Minimum distance of nodal compressor from boundary is approximately 7 rows = 70 m	RFI1.03 GFD-FDP Construction Plan and Transport Inputs spread sheet (Typical Facilities - NODAL)
	27	Gas transmission line - 5 m Pipeline Right of Way is 6 m + provision of 5 m spacing from the edge of trench to allow for stockpiling of of construction waste. Minimum distance to pipeline right of way is therefore 11/2, which is approximately 5 m.	RFI 1.15 Santos GLNG Environmental Protocol Tables 2 & 3
	28	Damage to adjacent gas pipeline during construction of transmission line - 10 m Minimum distance to right of way = 5 m (from above) + 4.5 m for adjacent gas pipeline located in separate trench, which is approximately 10 m.	RFI 1.15 Santos GLNG Environmental Protocol Table 2
	29	Hub gas compression facility - 120 m Given: Typical hub 400m x 500m Assumed: Layout drawn to scale (1 row is roughly equivalent to 10 m) Minimum distance of hub compressor from boundary is approximately 12 rows = 120 m	RFI1.03 GFD-FDP Construction Plan and Transport Inputs spread sheet (Typical Facilities - HUB)

APPENDIX F. REFERENCES

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