Appendix H

Hydrology and geomorphology

Santos Ltd

Narrabri Gas Project - Environmental Impact Statement
Hydrology and Geomorphology

December 2016

Table of contents

Table index

Figure index

Appendices

Glossary

Afflux	With reference to flooding, afflux refers to the predicted change, usually in flood levels, between two scenarios. It is frequently used to as a measure of the change in flood levels between an existing scenario and a proposed scenario.
Alluvium	Unconsolidated deposit of gravel, sand or mud formed by water flowing in identifiable channels. Commonly well sorted and stratified.
Australian Height Datum (AHD)	A common national plane of level approximately equivalent to the height above sea level.
Annual exceedance probability (AEP)	The annual exceedance probability is a measure of the frequency of a rainfall event. It is the probability that a given rainfall total accumulated over a given duration will be exceeded in one year. A 1 per cent event is a rainfall event with a 1 per cent chance of being exceeded in magnitude in a year. In accordance with current Australian Rainfall and Runoff recommendations (Institute of Engineers, Australia, 1987), annual exceedance probability terminology has been used in this document.
Average recurrence interval (ARI)	The average recurrence interval, like the annual exceedance probability, is also a measure of the frequency of a rainfall event. The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration. For example, a 100-year average recurrence interval event occurs or is exceeded on average once every 100 years. It is important to note that the ARI is an average period and it is implicit in the definition of the ARI that the periods between exceedances are generally random. Average recurrence intervals of greater than 10 years are closely approximated by the reciprocal of the annual exceedance probability. A 1 in 100-year average recurrence interval is therefore approximately equivalent to a 1 per cent annual exceedance probability event. ARI terminology is not used in this document but is included in the glossary for its common usage in matters related to flooding.
Catchment	The area drained by a stream or body of water or the area of land from which water is collected.
Consent	Approval to undertake a development received from the consent authority.
Datum	A level surface used as a reference in measuring elevations.
Discharge	Quantity of water per unit of time flowing in a stream, for example cubic meters per second or megalitres per day.
Ephemeral	Stream that is usually dry, but may contain water for rare or irregular periods, usually after significant rainfall.

Erosion	A natural process where wind or water detaches a soil particle and provides energy to move the particle.
Flood	For the purposes of this report, a flood is defined as the inundation of normally dry land by water which: escapes from, is released from, is unable to enter, or overflows from the normal confines of: a natural body of water or watercourse such as rivers, creeks or lakes, or an altered or modified body of water, including dams, canals, reservoirs and stormwater channels.
Flood liable land	Land which is within the extent of the probable maximum flood and therefore prone to flooding.
Floodplain	The area of land subject to inundation by floods up to and including the probable maximum flood event.
Floodway	The area of the floodplain where a significant portion of flow is conveyed during floods. Usually aligned with naturally defined channels.
Formation	A fundamental unit used in the classification of rock or soil sequences, generally comprising a body with distinctive physical and chemical features.
Geomorphology	Scientific study of landforms, their evolution and the processes that shape them. In this report, geomorphology relates to the form and structure of watercourses.
Groundwater	Subsurface water stored in pores of soil or rocks.
Hazard	The potential or capacity of a known or potential risk to cause adverse effects.
Headward erosion	The upstream lengthening and / or cutting of a valley or gully at its head, as the stream erodes away the rock and soil at its headwaters in the opposite direction that it flows.
Hydraulic conductivity	The rate at which water at the prevailing kinematic viscosity will move under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow, usually expressed in metres per day (this assumes medium in which the pores are completely filled with water).
Hydraulics	The physics of channel and floodplain flow relating to depth, velocity and turbulence.
Hydrograph	A graph which shows how a water level at a particular location changes with time.
Hydrology	The study of rainfall and surface water runoff processes.
Infiltration	The downward movement of water into soil and rock, which is largely governed by the structural condition of the soil, the nature of the soil surface (including presence of vegetation) and the antecedent moisture content of the soil.
Landform	A specific feature of the landscape or the general shape of the land.

Meteorology	The science concerned with the processes and phenomena of the atmosphere, especially as a means of forecasting the weather.
Monitoring well/bore	A hole sunk into the ground and completed for the abstraction or injection of water or for water observation purposes. Generally synonymous with bore.
Overbank	The portion of the flow that extends over the top of watercourse banks.
Overland flow path	The path that water can follow if it leaves the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Water travelling along overland flow paths, often referred to as 'overland flows', may re-enter the main channel or may be diverted to another watercourse.
Permeability	The capacity of porous medium for transmitting water.
Pluviograph	A rain gauge with the capability to record data in real time to observe rainfall over a short period of time.
Probable maximum flood (PMF)	The probable maximum flood is the maximum flood which can theoretically occur based on the worst combination of the probable maximum precipitation and flood-producing catchment conditions that is reasonably possible at a given location.
Probable maximum precipitation (PMP)	The probable maximum precipitation is the greatest amount of rainfall which can theoretically occur over a given duration (period of time) for a particular geographical location.
Reach	Defined section of a stream with uniform character and behaviour.
Recharge	Addition of water to the zone of saturation; also the amount of water added. An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area.
Riparian	Pertaining to, or situated on, the bank of a river or other water body.
Risk	The chance of something happening that will have an impact measured in terms of likelihood and consequence.
Risk assessment	Systematic process of evaluating potential risks of harmful effects on the environment from exposure to hazards associated with a particular product or activity.
River Styles® framework	A geomorphic approach for examining river character, behaviour, condition and recovery potential which it provides a template for river management.
Runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
Salinity	The total soluble mineral content of water or soil (dissolved solids); concentrations of total salts are expressed as milligrams per litre (equivalent to parts per million).

Secretary's environmental assessment requirements	Requirements for an environmental assessment issued by the Secretary of the NSW Department of Planning and Environment in accordance with the *Environment Planning and Assessment Act 1979*.
Sediment	Material of varying sizes that has been or is being moved from its site of origin by the action of wind, water or gravity.
SILO	An enhanced climate data bank based on historical climate data provided by the Bureau of Meteorology. Records are mainly based on observed data, with interpolation where there are data gaps.
Sinuosity	Extent of curvature or meandering of a stream. Highly sinuous streams meander over a low gradient and short distance. Low sinuosity streams are straighter and have a steeper gradient.
Stream order	Stream classification system, where order 1 is for headwater (new) streams at the top of a catchment. Order number increases downstream using a defined methodology relating to the branching of streams.
Surface water	Water that is derived from precipitation or pumped from underground and may be stored in dams, rivers, creeks and drainage lines.
Study area	The subject site and additional areas which are likely to be affected by the proposal, either directly or indirectly. The study area extends as far as is necessary to take all potential impacts into account.
Topography	Representation of the features and configuration of land surfaces.
Water quality	Chemical, physical and biological characteristics of water. Also the degree (or lack) of contamination.
Water sharing plan	A legal document prepared under the NSW *Water Management Act 2000* that establishes rules for sharing water between the environmental needs of the river or aquifer and water users and also different types of water use.
Water table	The surface of saturation in an unconfined aquifer, or the level at which pressure of the water is equal to atmosphere pressure

Abbreviations

AHD	Australian Height Datum
BOM	Bureau of Meteorology
EIS	Environmental Impact Statement
EP&A Act	*Environmental Planning and Assessment Act 1979*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
IESC	Independent Expert Scientific Committee
LGA	Local Government Area
MDB	Murray Darling Basin
MNES	Matters of national environmental significance
NSW	New South Wales
Santos	Santos NSW (Eastern) Pty Ltd
TJ	Terajoules
WAL	Water access licence
WM Act	*Water Management Act 2000*
WSP	Water sharing plan

1. Introduction

1.1 Overview

The Proponent is proposing to develop natural gas in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri (refer to Figure 1-1).

The Narrabri Gas Project (the project) seeks to develop and operate a gas production field, requiring the installation of gas wells, gas and water gathering systems, and supporting infrastructure. The natural gas produced would be treated at a central gas processing facility on a local rural property (Leewood), approximately 25 kilometres south-west of Narrabri. The gas would then be piped via a high-pressure gas transmission pipeline to market. This pipeline would be part of a separate approvals process and is therefore not part of this development proposal.

The primary objective of the project is to commercialise natural gas to be made available to the NSW gas market and to support the energy security needs of NSW. Production of natural gas under the project would deliver economic, environmental and social benefits to the Narrabri region and the broader NSW community. The key benefits of the project can be summarised as follows:

- Development of a new source of gas supply into NSW would lead to an improvement in energy security and independence to the State. This would give NSW gas markets greater choice when entering into gas purchase arrangements. Potential would also exist for improved competition on price. Improved competition on price would have flow on benefits for NSW's economic efficiency, productivity and prosperity.
- The provision of a reduced greenhouse gas emission fuel source for power generation in NSW as compared to traditional coal-fired power generation.
- Increased local production and regional economic development through employment and provision of services and infrastructure to the project.
- The establishment of a regional community benefit fund equivalent to five per cent of the royalty payment made to the NSW Government within the future production licence area. If matched by the NSW Government, the fund could reach $120 million over the next two decades.

1.2 Description of the project

The project would involve the construction and operation of a range of exploration and production activities and infrastructure including the continued use of some existing infrastructure. The key components of the project are presented in Table 1-1, and are shown on Figure 1-1.

Table 1-1 Key project components

Component	Infrastructure or activity
Major facilities	
Leewood	• a central gas processing facility for the compression, dehydration and treatment of gas • a central water management facility including storage and treatment of produced water and brine • optional power generation for the project • a safety flare • treated water management infrastructure to facilitate the transfer of treated water for irrigation, dust suppression, construction and drilling activities • other supporting infrastructure including storage and utility buildings, staff amenities, equipment shelters, car parking, and diesel and chemical storage • continued use of existing facilities such as the brine and produced water ponds • operation of the facility
Bibblewindi	• in-field compression facility • a safety flare • supporting infrastructure including storage and utility areas, treated water holding tank, and a communications tower • upgrades and expansion to the staff amenities and car parking • produced water, brine and construction water storage, including recommissioning of two existing ponds • continued use of existing facilities such as the 5ML water balance tank • operation of the expanded facility
Bibblewindi to Leewood infrastructure corridor	• widening of the existing corridor to allow for construction and operation of an additional buried medium pressure gas pipeline, a water pipeline, underground (up to 132 kV) power, and buried communications transmission lines
Leewood to Wilga Park underground power line	• installation and operation of an underground power line (up to 132 kV) within the existing gas pipeline corridor
Gas field	

Gas exploration, appraisal and production infrastructure	• seismic geophysical survey
	• installation of up to 850 new wells on a maximum of 425 well pads
	  – new well types would include exploration, appraisal and production wells
	  – includes well pad surface infrastructure
	• installation of water and gas gathering lines and supporting infrastructure
	• construction of new access tracks where required
	• water balance tanks
	• communications towers
	• conversion of existing exploration and appraisal wells to production

Component	Infrastructure or activity

Ancillary	• upgrades to intersections on the Newell Highway
	• expansion of worker accommodation at Westport
	• a treated water pipeline and diffuser from Leewood to Bohena Creek
	• treated water irrigation infrastructure including:
	  – pipeline(s) from Leewood to the irrigation area(s)
	  – treated water storage dam(s) offsite from Leewood
	• operation of the irrigation scheme

The project is expected to generate approximately 1,300 jobs during the construction phase and sustain around 200 jobs during the operational phase; the latter excluding an ongoing drilling workforce comprising approximately 100 jobs.

Subject to obtaining the required regulatory approvals, and a financial investment decision, construction of the project is expected to commence in early 2018, with first gas scheduled for 2019/2020. Progressive construction of the gas processing and water management facilities would take around three years and would be undertaken between approximately early/mid-2018 and early/mid-2021. The gas wells would be progressively drilled during the first 20 or so years of the project. For the purpose of impact assessment, a 25-year construction and operational period has been adopted.

1.3 Project location

The project would be located in north-western NSW, approximately 20 kilometres south-west of Narrabri, within the Narrabri local government area (LGA) (see Figure 1-1).

The project area covers about 950 square kilometres (95,000 hectares), and the project footprint would directly impact about one per cent of that area.

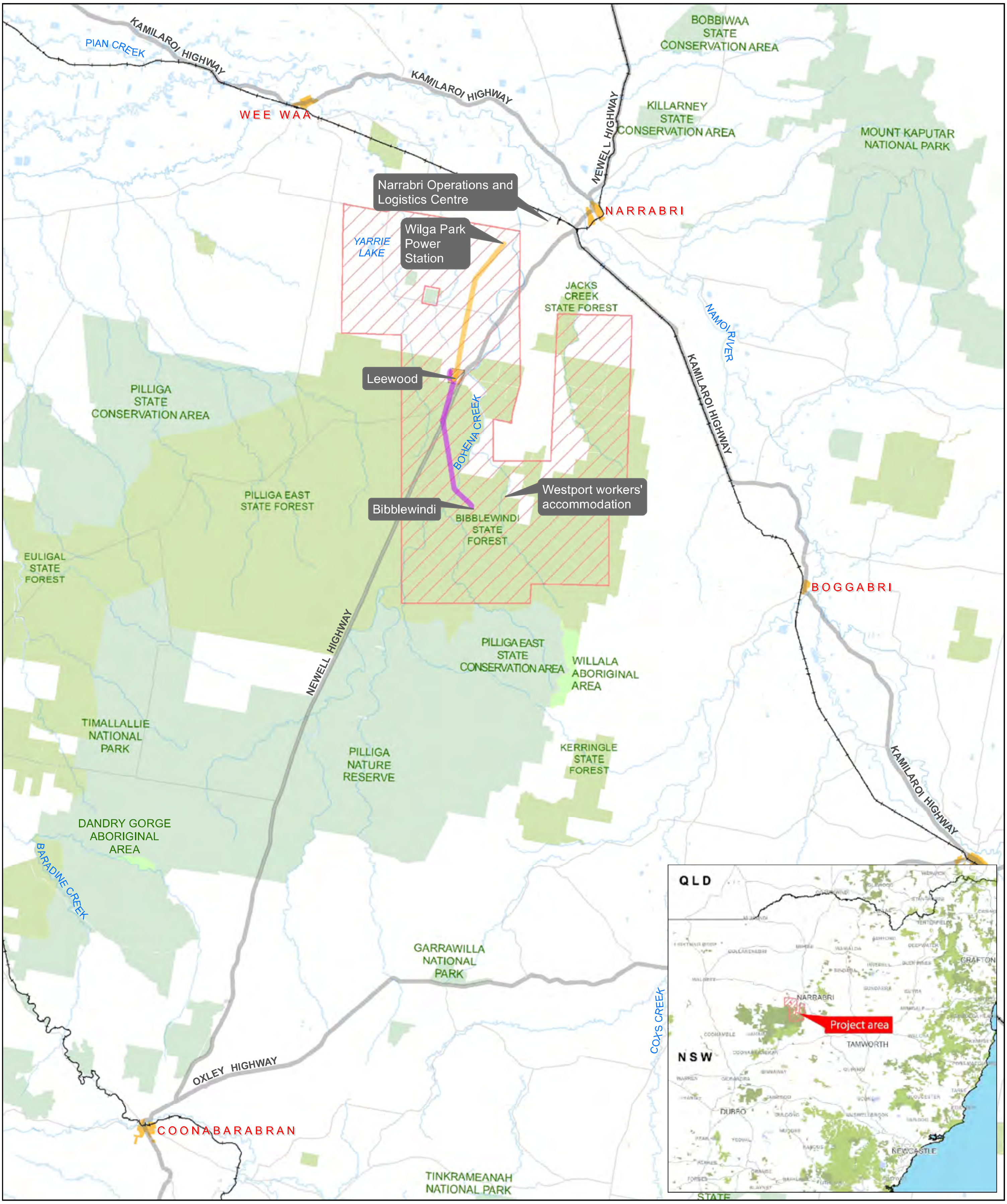
The project area contains a portion of the region known as 'the Pilliga', which is an agglomeration of forested area covering more than 500,000 hectares in north-western NSW around Coonabarabran, Baradine and Narrabri. Nearly half of the Pilliga is allocated to conservation, managed under the NSW *National Parks and Wildlife Act 1974*. The Pilliga has spiritual meaning and cultural significance for the Aboriginal people of the region.

Other parts of the Pilliga were dedicated as State forest, and set aside for the purpose of 'forestry, recreation and mineral extraction, with a strategic aim to "provide for exploration, mining, petroleum production and extractive industry" under the *Brigalow and Nandewar Community Conservation Area Act 2005*. The parts of the project area on state land are located within this section of the Pilliga.

The semi-arid climate of the region and general unsuitability of the soils for agriculture have combined to protect the Pilliga from widespread clearing. Commercial timber harvesting activities in the Pilliga were preceded by unsuccessful attempts in the mid-1800s to establish a wool production industry. Resource exploration has been occurring in the area since the 1960s; initially for oil, but more recently for coal and gas.

The ecology of the Pilliga has been fragmented and otherwise impacted by commercial timber harvesting and related activities over the last century through:

- the establishment of more than 5,000 kilometres of roads, tracks and trails
- the introduction of pest species
- the occurrence of drought and wildfire.



LEGEND

- Project area
- Leewood
- Urban
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	12 Mar 2015

Regional context and location of key infrastructure

Figure 1-1

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

The project area avoids the Pilliga National Park, Pilliga State Conservation Area, Pilliga Nature Reserve and Brigalow Park Nature Reserve. Brigalow State Conservation Area is within the project area but would be protected by a 50 metre surface exclusion zone.

Agriculture is a major land use within the Narrabri LGA; about half of the LGA is used for agriculture, split between cropping and grazing. Although the majority of the project area would be within State forests, much of the remaining area is situated on agricultural land that supports dry-land cropping and livestock. No agricultural land in the project area is mapped by the NSW Government to be biophysical strategic agricultural land (BSAL) and detailed soil analysis has established the absence of BSAL. This has been confirmed by the issuance of a BSAL Certificate for the project area by the NSW Government.

1.4 Planning framework and structure of this report

1.4.1 Planning framework

The project is permissible with development consent under the *State Environmental Planning Policy (Mining, Petroleum and Extractive Industries) 2007*, and is identified as 'State significant development' under section 89C(2) of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and the *State Environmental Planning Policy (State and Regional Development) 2011*.

The project is subject to the assessment and approval provisions of Division 4.1 of Part 4 of the EP&A Act. The Minister for Planning is the consent authority, who is able to delegate the consent authority function to the Planning Assessment Commission, the Secretary of the Department of Planning and Environment or to any other public authority.

The project is also a controlled action under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The project was declared to be a controlled action on 5 December 2014, to be assessed under the bilateral agreement between the Commonwealth and NSW Governments, and triggering the following controlling provisions:

- listed threatened species and ecological communities
- a water resource, in relation to coal seam gas development and large coal mining development
- Commonwealth land.

This Hydrology and Geomorphology Assessment identifies the potential environmental issues associated with construction and operation of the Narrabri Gas Project. The assessment also addresses the specific hydrology and geomorphology components of the Secretary's environmental assessment requirements for the project (refer to section 3.2.1). The assessment will be used to support the EIS for the project. The requirements addressed in this report include:

- An assessment of the likely impacts of the development on the quantity of the regions surface water resources.
- An assessment of the likely impacts of the development on watercourses, riparian land, and other water uses.
- An assessment of the likely flooding impacts of the development.

This assessment excludes hydrological and geomorphological impacts associated with the proposed managed release to Bohena Creek. Such impacts are addressed in *Narrabri Gas Project: Managed Release Study (Bohena Creek)* (refer to Appendix G1).

1.4.2 Structure of report

The report is structured as follows:

- **Chapter 1 – Introduction.** This chapter introduces the project and the proponent and describes the project area.
- **Chapter 2 – Methodology.** This chapter defines the study area assessed in this report and describes the steps undertaken in the assessment.
- **Chapter 3 – Legislative context.** This chapter outlines the relevant Commonwealth and State legislation relating to the assessment. Guidelines and assessment criteria (where applicable) relevant to the gasfield construction, operation and decommissioning are also identified.
- **Chapter 4 – Existing environment.** This chapter describes the existing environmental values of the study area relevant to hydrology and geomorphology; including results of desktop assessments and field investigations (where applicable).
- **Chapter 5 – Impact assessment.** This chapter examines the potential environmental impacts associated with the construction and operation of the project.
- **Chapter 6 – Risk assessment and mitigation.** This chapter contains a risk assessment and outlines the proposed mitigation strategies to be implemented during the life of the project to manage the potential environmental impacts and assesses the resulting residual impact.
- **Chapter 7 – Conclusion.** This chapter presents a conclusion to the report and presents the next steps in the advancement of the project.

2. Methodology

2.1 Study area

The study area for the Hydrology and Geomorphology Assessment consists of the project area plus the hydrological catchments upstream of the project area, as shown in Figure 2-1. Limited field survey relevant to the study was also carried out, with the extent of the survey indicated in Figure 2-2.

2.2 Data sources

The sources of data used in the Hydrology and Geomorphology Assessment are provided in Table 2-1.

Table 2-1 Data sources

Source	Item
Provided by Santos	Aerial imagery
	LiDAR data
NSW Land and Property Management Authority	Topographic data
Bureau of Meteorology	Climate data
Australian Rainfall and Runoff (Institution of Engineers, Australia, 1987)	Intensity-frequency-duration design rainfall data
	Various hydrological parameters
Former NSW Office of Water	Gauged water level and flow data

2.3 Related studies

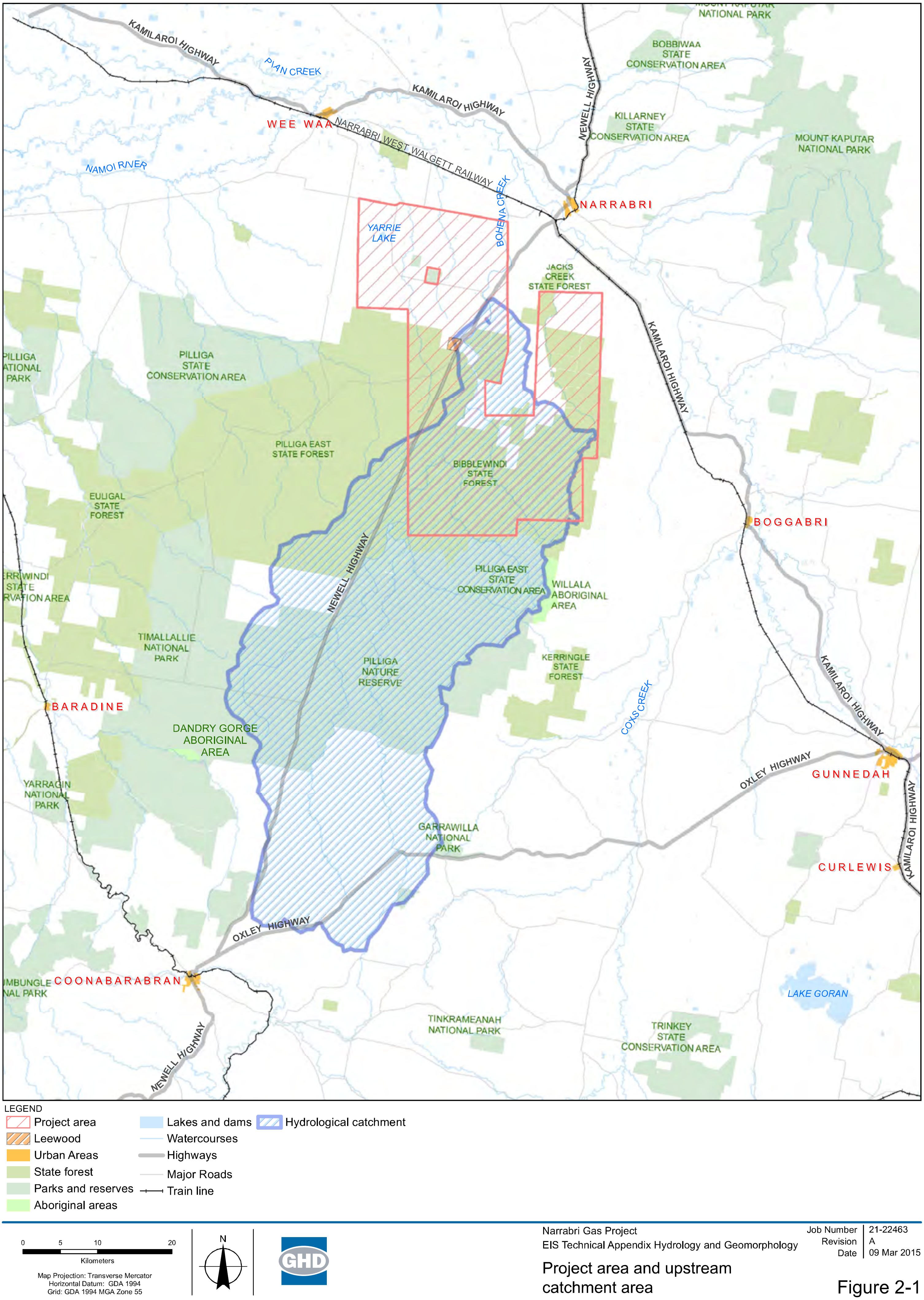
The following assessments of hydrology and geomorphology relating to the study area have been reviewed and used to inform the current assessment:

- Narrabri Gas Project: Managed Release Study (Bohena Creek) (refer Appendix G1) – An assessment of the potential impacts of the proposed surface water discharge from the Leewood Water Management Facility at a location on Bohena Creek (near the proposed management facility).

  Investigations were undertaken into:

  - ecological risk
  - toxicity
  - aquatic ecology and stygofauna
  - geomorphology
  - water quality.

The outcomes of the managed release assessment were used to support the project EIS.



Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 09 Mar 2015

Project area and upstream catchment area

Figure 2-1

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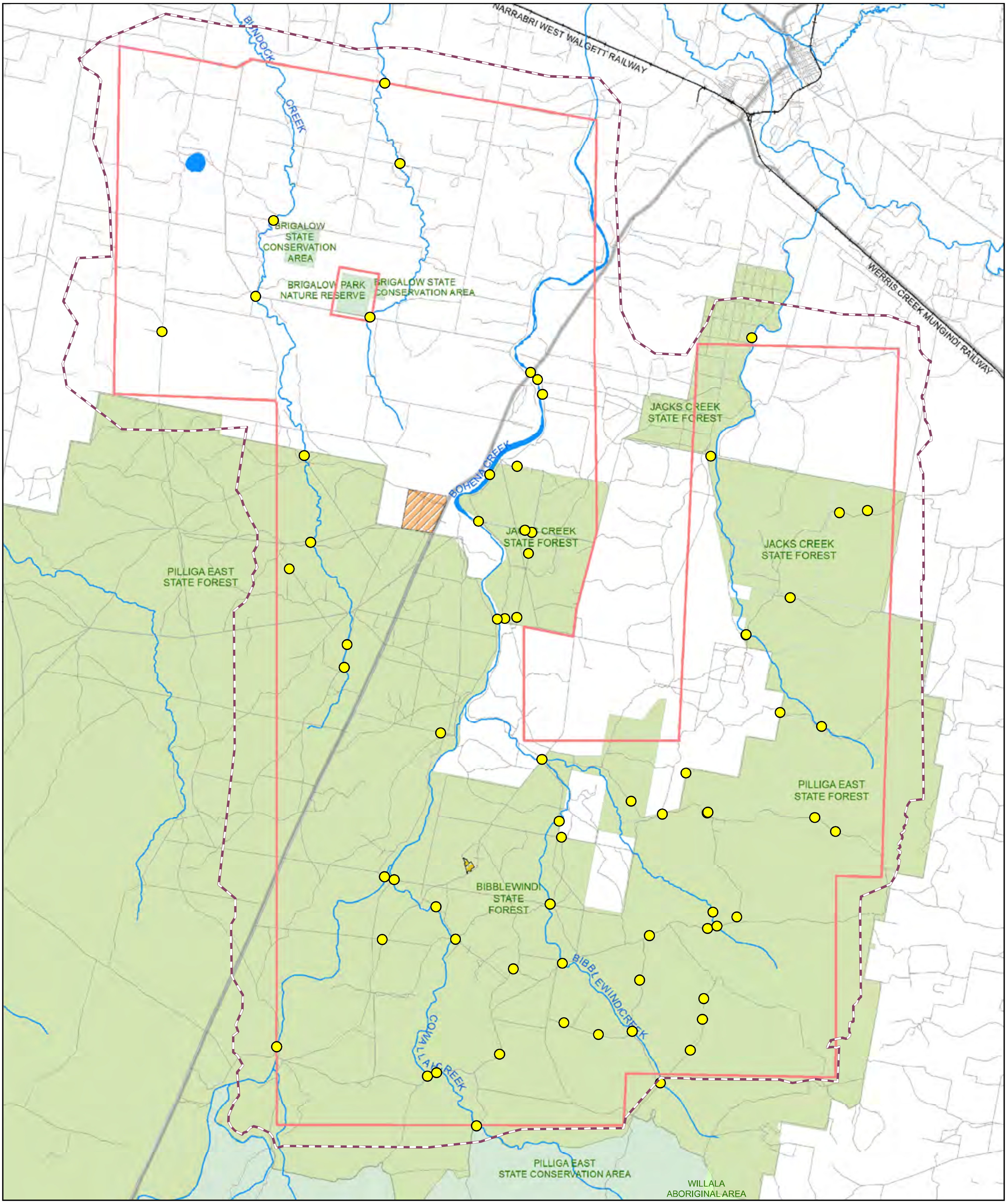
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Roads
- Train line
- Hydrology and Geomorphology field survey locations
- TUFLOW Model Extent

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 12 Dec 2016

Field Survey and Flood Model area

Figure 2-2

N:\AU\Sydney\Projects\21\22463\GIS\Maps\21_22463_KBM29_.mxd [KBM: 89]

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

2.4 Scope of work

The Hydrology and Geomorphology Assessment involved the following tasks:

- Desktop assessment of existing information and reports.
- Review of relevant statutory requirements.
- Characterisation of relevant existing environmental conditions.
- An assessment of catchment hydrology and hydraulics, which involved the following tasks:
  - Review of the current and historical flooding characteristics in the study area.
  - Conduct hydrological and hydraulic investigations of the existing flooding conditions and the future flooding conditions considering proposed structures in the study area.
  - Identify the flood levels, depths and velocities for the 10 per cent AEP flood event, 1 per cent AEP flood event and the Probable Maximum Flood (PMF) and potential impacts to local watercourses.
  - Assess flood hazard, floodplain hydraulic categorisation and flood planning levels for key infrastructure locations.
- An assessment of watercourse geomorphology, which involved the following tasks:
  - Site investigation and assessment of watercourse condition.
  - Interpretation of outputs from the catchment hydrology and hydraulics investigations.
  - Assessment of potential impacts on watercourse geomorphology.
- Develop measures to prevent, control, abate or mitigate the identified potential impacts of the project.

2.5 Catchment hydrology and hydraulics

2.5.1 Desktop assessment

A desktop assessment was undertaken of existing GIS data, aerial imagery and climatic data to develop an understanding of existing catchment conditions.

Further details of data sources used and desktop analysis undertaken are provided in The Narrabri Gas Project – Environmental Impact Statement Gas Field Flood Study (Refer to Appendix A of this report).

2.5.2 Hydraulic modelling

Hydrologic and hydraulic flood modelling was undertaken to define the existing site flood conditions.

This included development of a new hydraulic flood model for the entire project area. The methodology undertaken for the modelling is described in detail in Appendix A.

2.5.3 Impact Assessment

Impact assessment was undertaken based on:

- Review of existing flood conditions.
- Assessment of likely flooding impacts for the gas field based on typical infrastructure layout details provided in the Project Description (refer to EIS Chapter 6) and the Field Development Protocol (refer to Appendix C of the EIS).
- Where sufficient data was available, site specific assessment of flood impacts.

Assessment of impacts was undertaken for Leewood, Bibblewindi and Westport workers' accommodation where the majority of infrastructure is concentrated, and there is the greatest potential to impact surface water flow paths. The infrastructure design, along with the dispersed nature of gas field surface infrastructure and the relatively small area of each well pad (approximately one hectare during construction reducing to approximately 0.25 hectares for operation) reduces the likelihood of flooding impacts. Therefore, the potential for impacts to flooding was assessed in general terms.

Flood risk would continue to be an important input into the detailed design phase of the project.

2.6 Watercourse geomorphology

2.6.1 Desktop assessment

A desktop assessment of existing information (GIS data and aerial imagery) was undertaken to identify and preliminarily map in GIS the types (river style), geomorphic condition and stream order of watercourses in the study area. The assessment encompassed all mapped watercourses as defined by the 1:50,000 topographic stream layer as refined by EcoLogical Australia (refer Appendix G1).

Stream ordering followed the Strahler stream classification system where watercourses are given an 'order' according to the number of additional tributaries associated with each watercourse (Strahler, 1952). Figure 2-3 indicates the Strahler stream ordering process for a generic catchment. Numbering begins at the top of a catchment with headwater ('new') flow paths being assigned the number one.

Where two flow paths of order one join, the section downstream of the junction is referred to as a second order stream. Where two second order streams join, the watercourse downstream of the junction is referred to as a third order stream, and so on. Where a lower order stream (e.g. first order) joins a higher order stream (e.g. third order), the area downstream of the junction will retain the higher stream order.

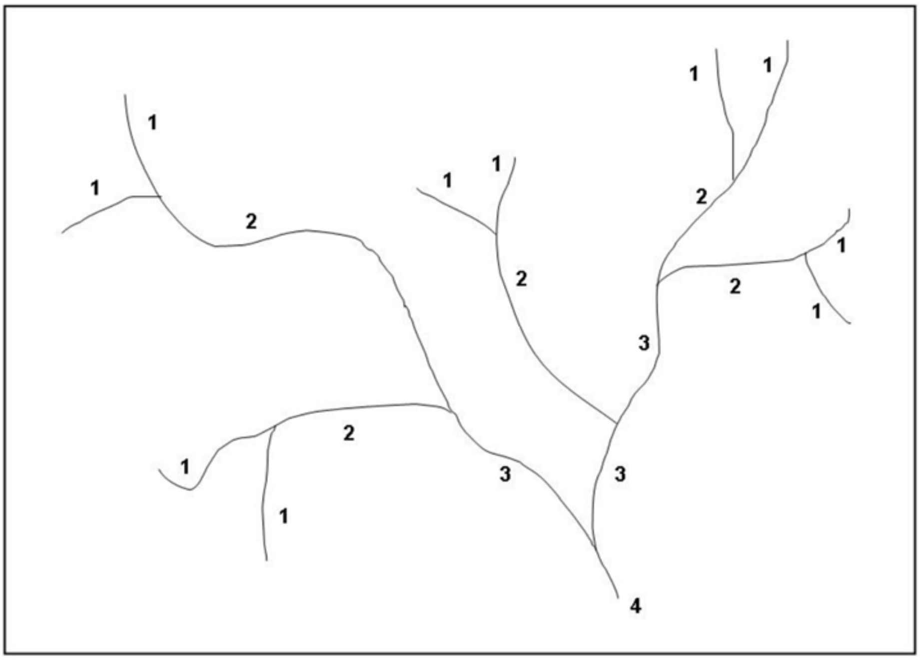


Figure 2-3 Stream order for a generic catchment

(using Strahler method, 1952)

2.6.2 Site investigation

A site investigation was undertaken between the 4th and 7th of February 2014 to identify the current physical characteristics of the watercourses of study area. Information recorded during the field investigation included:

- Geomorphic type and condition of watercourses.
- Nature, location and extent of existing watercourse instabilities.
- Nature and location of watercourse controls (e.g. bedrock, logs).
- Nature of channel and bedload materials.

General site data was recorded using a hand held Geographical Positioning System (GPS) device with other measurements being undertaken including valley widths and channel widths and depths during the site investigation.

2.6.3 Geomorphic condition assessment

The assessment of stream physical form and function is broadly based on the methods and principles of the River Styles® framework (Brierley and Fryirs, 2005).

Determination of stream types is largely based on the following parameters:

- Degree of valley confinement and bedrock influences.
- Presence and continuity of a channel.
- Channel planform (number of channels, sinuosity).
- Channel and floodplain geomorphic features.
- Nature of channel and floodplain sediments.

The assessment of geomorphic condition was based on Outhet and Cook (2004) who described a rapid method of condition assessment that frames geomorphic condition in the context of natural and human induced variability. The characteristics of each condition category are described in Table 2-2. These categories provide an indication of the degree of alteration a reach has experienced from its expected natural form.

Table 2-2 Geomorphic condition categories

Indicative geomorphic condition	Characteristics
Good	Geomorphic structure is largely unchanged from the pre-disturbance state such that only minor cases of localised instability occur. Relatively intact and effective vegetation coverage dominated by native species, giving resistance to natural disturbance and accelerated erosion. There is minimal alteration to catchment controls such as sediment supply and the hydrological regime allowing fast recovery from natural disturbance. There is also a high potential for ecological diversity.
Moderate	Geomorphic structure is moderately altered such that a reduced diversity of river features exists and floodplain connectivity is somewhat limited. Localised degradation of river character and behaviour, typically marked by modified patterns of geomorphic units. Patchy effective vegetation coverage allowing some localised accelerated erosion. The river has not fully adjusted to prevailing conditions and is experiencing ongoing changes.
Poor	Considerable geomorphic alteration to the functioning and structure of the system when compared with the pre-disturbance condition. Type, extent and rate of processes are radically altered. Floodplain connectivity may be significantly altered. Abnormal or accelerated geomorphic instability (reaches are prone to accelerated and / or inappropriate patterns or rates of planform change and / or bank and bed erosion). Excessively high volumes of sediment inputs which blanket the bed, reducing flow diversity. Absent or geomorphologically ineffective coverage by vegetation (allowing most locations to have accelerated rates of erosion).

2.7 Risk assessment

The identified risks and potential impacts to watercourse hydrology and geomorphology associated with the project were evaluated as part of an environmental risk assessment. The likelihood (the likely frequency of the potential event or action occurring) and consequence (resulting level of impact) of each identified risk was assessed using criteria determined in consultation with the proponent.

The assessment of environmental risks was based on the likelihood and consequence criteria provided in Table 2-3 and Table 2-4 respectively. Likelihood criteria range on a scale from ‘almost certain’ (once a year or greater) to ‘rare’ (once per thousand years). Consequence criteria range on a scale from ‘critical’ (severe, widespread long-term effect) to ‘negligible’ (minimal impact or no lasting effect), dependent on the size of the impact, the spatial area affected and the expected recovery time of the environment as well as community and regulatory considerations.

Table 2-3 Likelihood criteria

Likelihood level	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 ten 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 five to twenty years.
Unlikely Not likely or uncommon	The event could occur but is not expected. A rare occurrence (once per one hundred years).
Rare Remote or practically impossible	The event may occur only in exceptional circumstances. Very rare occurrence (once per one thousand years). Unlikely that it has occurred elsewhere; if it has occurred, it is regarded as extremely unique.

Table 2-4 Consequence criteria

Consequence category	Description
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.
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.
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.
Minor Localised short-term effect	Impact of fauna, flora and/or habitat but no negative effects on ecosystem. Easily rehabilitated.
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.

The level of risk for each impact to watercourse hydrology and geomorphology was assessed using the risk matrix presented in Table 2-5. Each risk was assigned a primary (or unmitigated) risk rating, ranging from 'very high' to 'very low', based on likelihood and consequences of impacts occurring.

Table 2-5 Risk matrix

Likelihood Consequence	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

Following the identification of appropriate management or mitigation measures, the potential impact of each primary risk was re-assessed to determine a residual risk rating. This enabled the effectiveness of the proposed mitigation measures in reducing predicted potential impacts to be assessed.

3. Legislative context

3.1 Commonwealth legislation

3.1.1 Environment Protection and Biodiversity Conservation Act 1999

The purpose of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is to ensure that actions likely to cause a significant impact on matters of national environmental significance (MNES) undergo an assessment and approval process. The EPBC Act identifies a water resource, in relation to coal seam gas development and large coal mining development, as a MNES. An action, including a project, development, undertaking or activity, which 'has, will have or is likely to have, a significant impact on a matter of national environmental significance' deemed by the Australian Government's Minister for the Environment and Energy to be a 'controlled action' is required to undergo federal assessment.

The Independent Expert Scientific Committee (IESC) is a statutory body under the EPBC Act that provides scientific advice on the impact that coal seam gas and large coal mining development may have on water resources to federal and state government regulators. As detailed by IESC (2014), the committee requires a baseline description of water resources and an assessment of the potential impacts on water resources associated with the project. The Hydrology and Geomorphology Assessment was undertaken based on the requirements for assessment by the IESC under the EPBC Act.

3.1.2 Water Act 2007

The Murray Darling Basin Authority is an independent statutory body that operates under the Commonwealth *Water Act 2007* to manage the water resources of the Murray Darling Basin (MDB), in which the project is located, in an integrated and sustainable manner. The Murray Darling Basin Plan came into effect in 2012 and provides a coordinated approach to water use within the MDB. The plan aims to achieve a balance between environmental, economic and social considerations and limits water use to environmentally sustainable levels for both surface water and groundwater resources.

3.2 State legislation

3.2.1 Environmental Planning and Assessment Act 1979

The EP&A Act, which is administered by the NSW Department of Planning and Environment, is the core legislation relating to planning and development activities in NSW and provides the statutory framework under which development proposals are assessed. The objective of this Hydrology and Geomorphology Assessment is to address the relevant components of the Secretary's environmental assessment requirements and other State and local government submissions, which are presented in Table 3-1.

Table 3-1 Impact assessment requirements

<table>
<tr><th>Element</th><th>Where addressed in this report</th></tr>
<tr><td colspan="2">Secretary's environmental assessment requirements</td></tr>
<tr><td>An assessment of the likely impacts of the development on the quantity and quality of the region's surface and groundwater resources.</td><td>Section 5</td></tr>
<tr><td>An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure and other water users.</td><td>Section 5</td></tr>
<tr><td>An assessment of the likely flooding impacts of the development.</td><td>Section 5</td></tr>
<tr><td colspan="2">NSW Environment Protection Agency</td></tr>
<tr><td>Outline site layout, demonstrating efforts to avoid proximity to water resources (especially for activities with significant potential impacts e.g. effluent ponds) and showing potential areas of modification of contours, drainage, etc.</td><td>Chapter 6 and Chapter 8 EIS; and EIS Appendix C</td></tr>
<tr><td>Provide an overview of the affected environment to place the proposal in its local and regional environmental context including:
d) geomorphology (rates of landform change and current erosion and deposition processes)</td><td>Section 4</td></tr>
<tr><td>Identify potential impacts associated with geomorphological activities with potential to increase surface water and sediment runoff or to reduce surface runoff and sediment transport. Also consider possible impacts such as bed lowering, bank lowering, instream siltation, floodplain erosion and floodplain siltation.</td><td>Section 5</td></tr>
<tr><td>Describe hydrological impact mitigation measures including:
a) site selection (avoiding sites prone to flooding and waterlogging, actively eroding or affected by deposition)
b) minimising runoff
c) minimising reductions or modifications to flow regimes
d) avoiding modifications to groundwater.</td><td>Section 6</td></tr>
<tr><td>Describe geomorphological impact mitigation measures including:
a) site selection
b) erosion and sediment controls
c) minimising instream works
d) treating existing accelerated erosion and deposition
e) monitoring program.</td><td>Section 6</td></tr>
<tr><td colspan="2">(then) NSW Office of Water</td></tr>
<tr><td>Assessment of impacts on surface and groundwater sources (both quality and quantity), related infrastructure, watercourses, riparian land and groundwater dependent ecosystems and measures proposed to reduce and mitigate these impacts.</td><td>Section 5</td></tr>
<tr><td>Detailed surface water and groundwater modelling to assess impacts of the project, in accordance with standards outlined in relevant National and State Guidelines. The EIS should also describe the plan for ongoing validation calibration and development of the model.</td><td>Section 2</td></tr>
<tr><td>The EIS should take into account the objects and regulatory requirements of the Water Act 2007 and Water Management Act 2000 (WMA 2000) as applicable. Proposals and management plans should be consistent with the Objects (s.3) and Water Management Prinsiples (s.5) of the WMA 2000.</td><td>Section 4, 5 6</td></tr>
</table>

Element	Where addressed in this report
The EIS should address the potential impacts of the project on all watercourses likely to be affected by the project, existing riparian vegetation and the rehabilitation of riparian land. It is recommended the EIS provides details on all watercourses potentially affected by the proposal including: • A detailed description of all potential impacts on the watercourses / riparian land. • A description of the design features and measures to be incorporated to mitigate potential impacts. • Geomorphic and hydrological assessment of watercourses including details of stream order (Strahler system), river style and energy regimes both in channel and on adjacent floodplains.	Sections 4, 5 and 6
Narrabri Shire Council	
The need to address surface water contamination, disturbance to watercourse beds/banks and modification to local watercourse or flood prone lands is noted. The Council raises the need for robust work that addresses the local characteristics and longer term management strategy outcomes.	Sections 4, 5 and 6
The EIS should discuss: • An assessment of local flood risks, including appropriate mitigation measures to ensure no well pad, holding ponds and other infrastructure and emergency access are inundated by flood waters or water from meteoric rain events. This assessment is to take in all water courses, floodways and floodplains within and adjacent to the project area.	Sections 5 and 6
NSW Office of Environment and Heritage	
The EIS must map the following features relevant to flooding as described in the Floodplain Development Manual 2005 (NSW Government 2005) including: a. Flood prone land b. Flood planning area, the area below the flood planning level c. Hydraulic categorisation	Section 4, 5
The EIS must describe flood assessment and modelling undertaken in determining the design flood levels for events, including a minimum of the 1 in 10 year, 1 in 100 year and the probable maximum flood, or an equivalent extreme event	Appendix A of this report
The modelling in the EIS must consider and document a. The impact on existing flood behaviour for a full range of flood events including up to the probable maximum flood b. Impacts of the development on flood behaviour resulting in detrimental changes in potential flood affectation of other developments or land. This may include redirection of flow, flow velocities, flood levels, hazards and hydraulic categories. c. Relevant provision of the NSW Floodplain Development Manual 2005	Sections 4 and 5

Element	Where addressed in this report
The EIS must assess the impacts on the proposed Narrabri Gas Project on flood behaviour, including a. Whether there will be detrimental increases in potential flood affectation of other properties, assets and infrastructure b. Consistency with Council floodplain risk management plans c. Compatibility with the flood hazard of the land d. Compatibility with the hydraulic functions of flow conveyance in floodways and storage in flood storage areas of the land e. Whether there will be adverse effect to beneficial inundation of the floodplain environment on or adjacent to or downstream of the site. f. Whether there will be direct or indirect increase in erosion, siltation, destruction of the riparian vegetation or a reduction in the stability of river banks or watercourses. g. Any impacts the development may have upon existing community emergency management arrangements for flooding h. Whether the proposal incorporates specific measures to manage risk to life from flood. i. Emergency management, evacuation and access, and contingency measures for the development considering the full range of flood risk j. Any impacts the development may have on the social and economic costs to the community as a consequence of flooding.	Sections 4 and 5 and Appendix A

3.2.2 Water Act 1912

The *Water Act 1912* is administered by the New South Wales Government Department of Primary Industries Water (DPI Water) and has historically been the primary legislation managing water resources in NSW. The *Water Act 1912* governs access, trading and allocation of licences associated with both surface water and groundwater sources and is currently being progressively phased out and replaced by water sharing plans (WSPs) under the *Water Management Act 2000* (WM Act). Once a WSP commences, existing licences under the *Water Act 1912* are converted to water access licences (WALs) and to water supply works and use approvals under the WM Act. The elements to which the *Water Act 1912* applies include extraction of water from a river, extraction of water from groundwater sources, aquifer interference (less than 3 megalitres per year) and diversion works of surface water runoff for capture (of a capacity less than basic landholder rights).

The surface water and groundwater systems associated with the project are currently regulated by WSPs under the WM Act, discussed further in section 3.2.3.

3.2.3 Water Management Act 2000

The WM Act, also administered DPI Water, is progressively being implemented throughout NSW to manage water resources, superseding the *Water Act 1912*. The aim of the WM Act is to ensure that water resources are conserved and properly managed for sustainable use benefiting both present and future generations. It is also intended to provide formal means for the protection and enhancement of the environmental qualities of watercourses and their in-stream uses as well as to provide for protection of catchment conditions. Fresh water sources throughout NSW are managed by WSPs under the WM Act. Key rules within WSPs specify when licence holders can access water and how water can be traded.

Water sharing plans

The project is located within the area covered by the WSP for the Namoi Unregulated and Alluvial Water Sources, which commenced in October 2012. The WSP regulates the unregulated rivers and creeks and alluvial groundwater within the Namoi River catchment. The WSP covers 22 unregulated surface water sources, which are grouped into one extraction management unit, and four alluvial groundwater sources. The study area is covered by four water sources, which are the Bohena Creek, Brigalow Creek, Bundock Creek and Eulah Creek water sources.

Groundwater sources associated with the project are regulated by the following five WSPs:

- Upper and Lower Namoi Groundwater Sources.
- NSW Murray-Darling Basin Fractured Rock Groundwater Sources.
- NSW Murray-Darling Basin Porous Rock Groundwater Sources.
- NSW Great Artesian Basin Groundwater Sources.
- NSW Great Artesian Basin Shallow Groundwater Sources.

Relevant aspects of the WSPs for groundwater sources are addressed in the *Groundwater Impact Assessment* (refer Appendix F).

Controlled Activity Approvals

Works proposed within the defined riparian zone of a watercourse are to be carried out in accordance with the WM Act. Section 91 of the WM Act details the requirements for controlled activity approval to carry out work on waterfront land, which includes the bed of a river, lake or estuary and land within 40 metres of its high water mark. Notably, Section 89J of the EP&A Act specifies that controlled activity approvals are not required for projects that are defined as State significant developments. Accordingly, controlled activity approval is not required for the project. However, it remains an offence to harm waterfront land when carrying out an exempt controlled activity. The NOW would be consulted in relation to the proposed construction and operation activities within the existing riparian corridors, which would provide a means of determining the suitability of engineering controls and general mitigation measures.

3.3 NSW Flood Prone Land Policy

A key guideline relevant to the assessment is the New South Wales *Floodplain Development Manual* (former Department of Infrastructure, Planning and Natural Resources, 2005). The Floodplain Development Manual concerns the management of flood-prone land within NSW. It provides guidelines in relation to the management of flood liable lands, including any development that has the potential to influence flooding, particularly in relation to increasing the flood risk to people and infrastructure.

4. Existing environment

4.1 Topography

The study area is located in the Namoi River catchment in the central north of NSW within the Murray Darling Basin (MDB). The study area is characterised by gentle north to north-west slopes. The flat, open terrain of the Namoi River floodplains is located north and west of the study area, with steep and undulating topography to the east and south. The topography in the region is dominated by Mount Kaputar to the north-east and the Warrumbungle Ranges to the south. Site elevation varies from approximately 200 metres Australian Height Datum (AHD) in the north of the study area to approximately 500 metres AHD in the south-east.

4.2 Land use

Land use in the region includes agriculture, rural residential development, native vegetation, irrigated agriculture (primarily cotton), intensive animal husbandry and extractive industries. The northern portion of the study area consists primarily of agricultural land supporting dry-land cropping and pastoral (livestock) activities. The central and southern portions of the study area consist of woodland vegetation associated with the Pilliga East State Forest, Bibblewindi State Forest and Jacks Creek State Forest.

Towns located downstream of the study area include Narrabri and Wee Waa.

4.3 Climate

4.3.1 Rainfall

Daily rainfall data was obtained as SILO patched point data from the Queensland Climate Change Centre of Excellence. SILO patched point data is based on historical data from a particular Bureau of Meteorology (BOM) station, with missing data 'patched in' by interpolating with data from nearby stations. SILO data was obtained for the Narrabri Bowling Club Station (station number 54120). That station was chosen based on the length and quality of the data record and proximity to the site. Pluviograph rainfall data recorded at three hour intervals (obtained from the BOM) were used as an input to the flooding assessment (refer to Appendix A).

The period of rainfall data used for this assessment extended from January 1900 to December 2013 and is summarised as annual totals in Figure 4-1. The statistics for the rainfall data set are:

- Minimum annual rainfall – 269 millimetres in 1994.
- Average annual rainfall – 639 millimetres.
- Median annual rainfall – 638 millimetres.
- Maximum annual rainfall – 1,232 millimetres in 1950.

The monthly rainfall statistics were also determined for the period of record for the Narrabri Bowling Club Station and selected statistics are provided in Figure 4-2. The average monthly rainfall was observed to vary from a low of approximately 36 millimetres in April to a high of approximately 81 millimetres in January. Figure 4-2 denotes a significant variation in the maximum recorded monthly rainfall with the lowest maximum monthly rainfall value being approximately 145 millimetres in September 1998 and the highest maximum monthly rainfall value being approximately 330 millimetres in February 1928.

The minimum monthly rainfall values recorded were 0 millimetres for all months, with the exception of December which had a minimum monthly rainfall value of 1 millimetre.

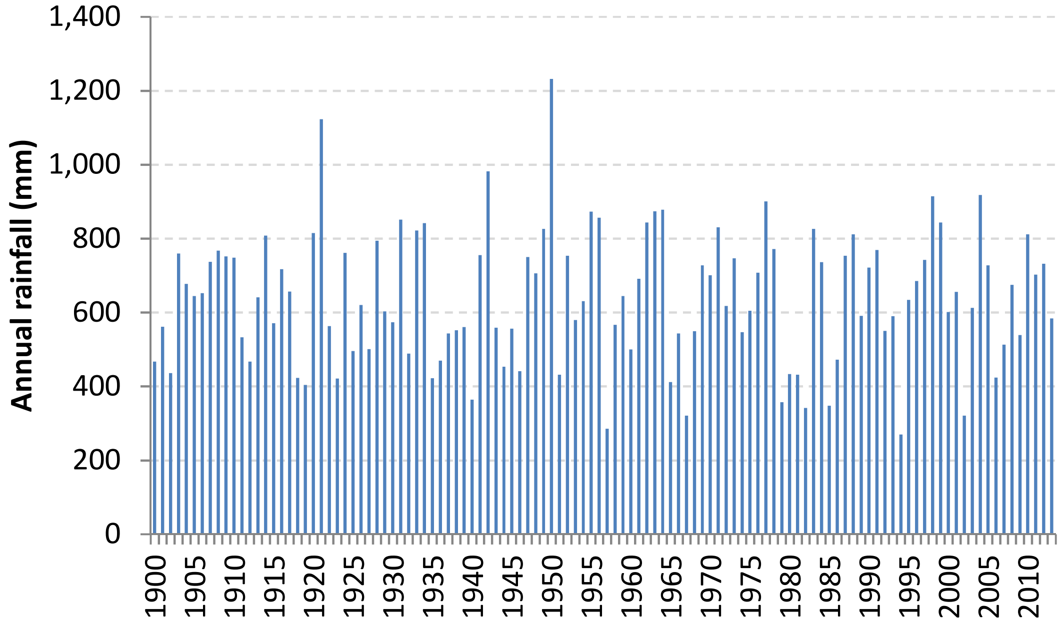


Figure 4-1 Annual rainfall recorded at Narrabri Bowling Club Station

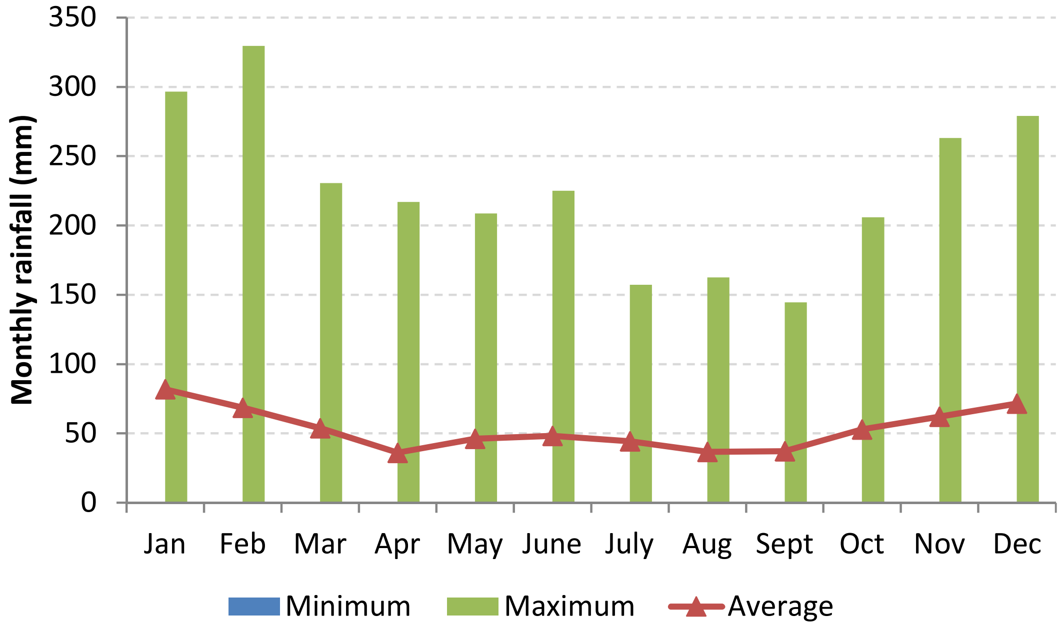


Figure 4-2 Monthly rainfall statistics for Narrabri Bowling Club Station

4.3.2 Evaporation

Information at the closest BOM station which records evaporation, Tamworth Airport (station number 55054), was reviewed and average monthly evaporation rates were determined. The average daily evaporation rates are presented in Figure 4-3.

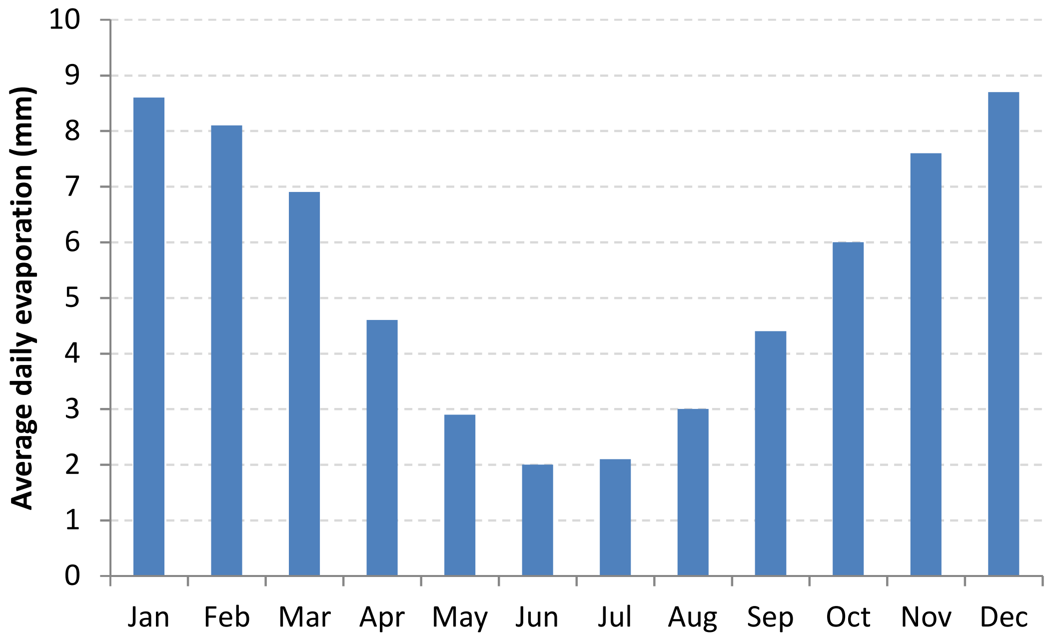


Figure 4-3 Average daily evaporation recorded at Tamworth Airport Station

The average annual evaporation total was approximately 1,969 millimetres, compared to the annual average rainfall of 639 millimetres. This gives an annual deficit (difference between annual evaporation and rainfall) of approximately 1,330 millimetres.

4.4 Surface water sources

4.4.1 Regional

As discussed in section 4.1, the study area is located in the Namoi catchment in the central north of NSW within the MDB. The catchment covers an area of approximately 42,000 square kilometres and represents approximately four per cent of the MDB. The headwaters of the Namoi River are located on the western slopes of the Great Dividing Range north of Tamworth and flows north-west for approximately 350 kilometres until it joins the Barwon River near Walgett. Major tributaries of the Namoi River include the Peel, Manilla and Mooki rivers. The Namoi River is a perennial system, with highly variable flows. Many of the tributaries of the Namoi River are intermittent or ephemeral with flow observed following significant rainfall events (Schlumberger, 2012).

The Namoi River catchment is divided from the Gwydir catchment to the north by the Nandewar Range and Mount Kaputar, the Macleay, Manning and Hunter catchments to the east by the Great Dividing Range and the Macquarie/Castlereagh catchments to the south by the Liverpool Ranges and Warrumbungle Ranges.

4.4.2 Local

Drainage within the study area can be categorised into three main areas as described below.

Bohena Creek and tributaries

Bohena Creek is the main watercourse system flowing through the study area. Bohena Creek flows in a northerly direction from the footslopes of the Warrumbungle Ranges to the Namoi River, approximately 10 kilometres downstream of Narrabri. Bohena Creek has catchment areas of approximately 1,400 square kilometres and 2,100 square kilometres at the upstream and downstream boundaries of the study area respectively.

Named tributaries of Bohena Creek within the study area are:

- Box Flat Creek.
- Duck Creek.
- Sandy Creek.
- Cowallah Creek and its tributary Mount Pleasant Creek.
- Bibblewindi Creek and its tributaries Pine, Yellow Springs and Spring creeks.
- Dead Bullock Creek.
- Sawpit Creek.
- Killen Creek.

Western Drainage

Watercourse in the western drainage area typically flow north through the study area before trending more westerly. Downstream of the study area, these watercourses flow into the Namoi River either directly or via the following creeks:

- Oakyhole Creek which flows to Brigalow Creek.
- Bundock Creek and its tributary Reedy Gully which flow to Wee Waa Gully.
- Mollee Creek which flows to Bundock Creek.
- Pig Creek which flows directly into the Namoi River.

Eastern Drainage

Watercourses in the eastern drainage area typically flow north through the study area, with some drainage to the east. Downstream of the study area, these watercourses flow into the Namoi River either directly or via the following creeks:

- Jacks Creek and its tributary Tupiari Creek which flows directly into the Namoi River.
- Sandy Creek which flows directly into the Namoi River.
- Pine Creek which flows directly into the Namoi River.
- Kurrajong Creek which flows to Tulla Mullen Creek prior to joining the Namoi River.
- Sandy Creek which flows to Tulla Mullen Creek prior to joining the Namoi River.

4.5 Gas field Catchment hydrology and hydraulics

A flood study of the gas field site has been carried out and is documented in the report *The Narrabri Gas Project – Environmental Impact Statement Gas Field Flood Study* (refer Appendix A).

The flood study included development of hydrological and hydraulic models used to assess a one per cent AEP flood extent, 10 per cent AEP event and probable maximum flood (PMF) event.

The results of the study informed the assessment of existing flooding conditions.

4.5.1 Summary of hydraulic and hydrologic models set up

Model configuration

A two-dimensional (2D) hydrodynamic rainfall-on-grid flood model was developed for the project area using TUFLOW software.

The model also includes a component of standalone hydrological assessment to estimate flows from the catchment upstream of the project area that was not included in the direct rainfall calculations. A RAFTS model was developed for the upstream flow estimates. Figure 4-4 shows:

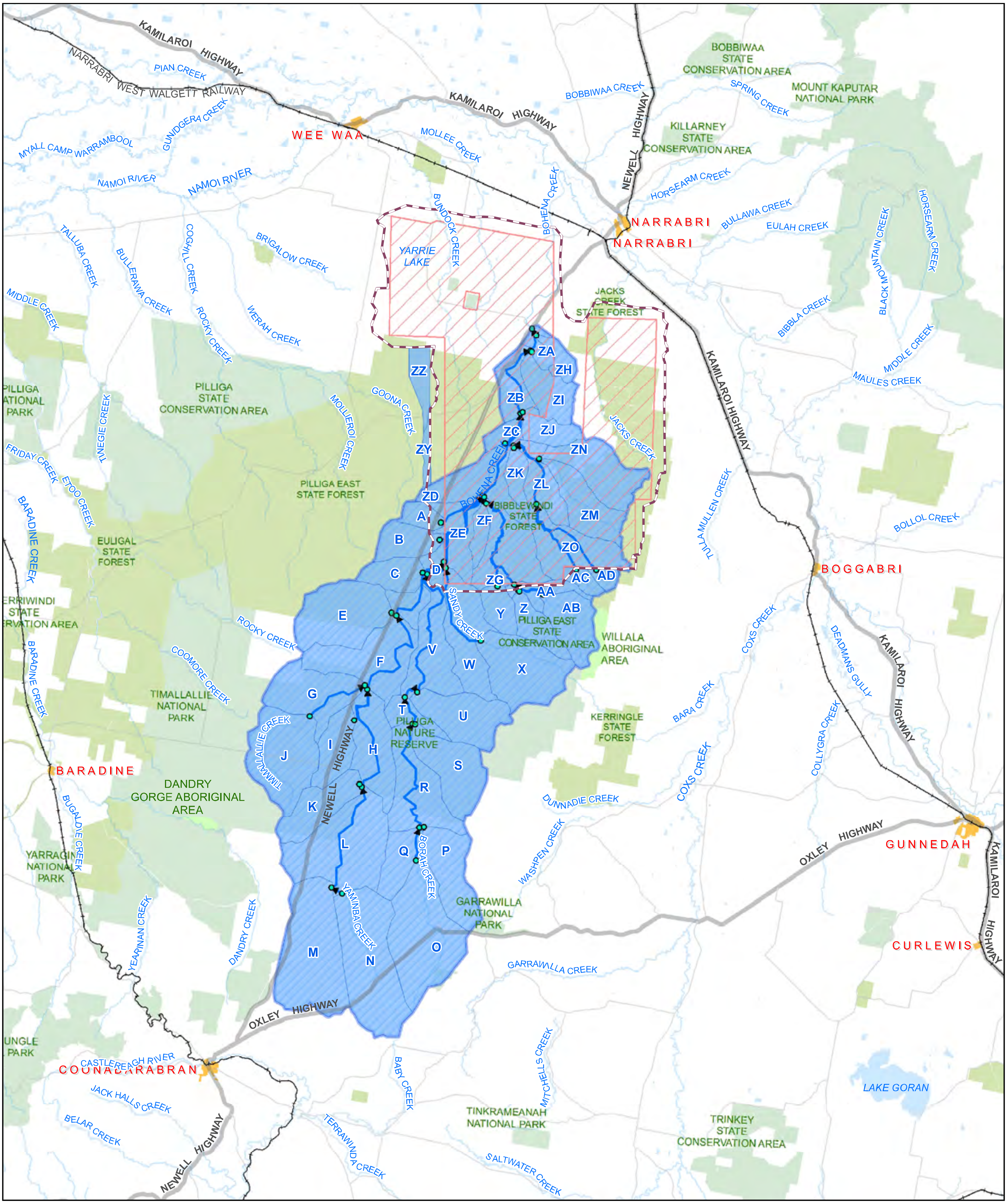
- The hydraulic model extent.
- The project area.
- The hydrological subcatchment boundaries upstream of the project area.

The hydrological model was calibrated to available data for the 1998 rainfall event.

The hydraulic model was simulated for a range of storm durations between 10 minutes and 24 hours so as to capture the peak flood extent. The hydrological model was checked for storm durations up to 36 hours so as to confirm the critical duration for Bohena Creek.

Estimates for Probable Maximum Precipitation (PMP) events were made using the Generalised Short Duration Method (GSDM), and Generalised Tropical Storm Method Revised (GTSMR) techniques developed by the Commonwealth Bureau of Meteorology (BOM).

Details of the model development and methodology are included in Appendix A.



LEGEND

- Project area
- Urban Areas
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Hydrological catchment
- Sub-catchment Outlets
- Model streams
- Model sub-catchments
- TUFLOW Model Extent

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 05 Dec 2016

XP-RAFTS Model Sub-catchment map

Figure 4-4

N:\AU\Sydney\Projects\21\22463\GIS\Maps\21_22463_KBM29_.mxd [KBM: 90]

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

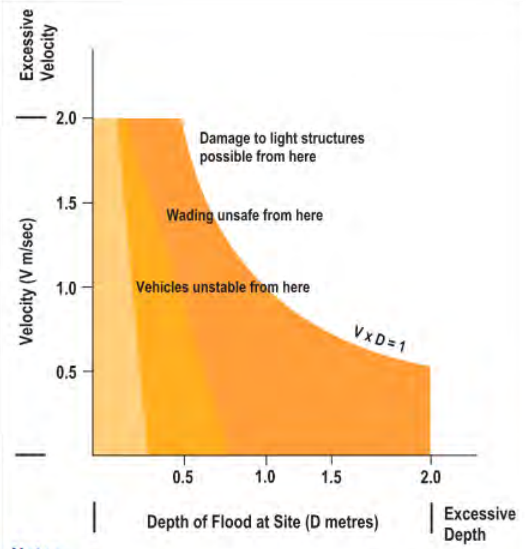
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

Approach to definition of flood hazard

Flood hazard is one measure of the potential for flooding to impact on people and properties. Increases in flood hazard as a result of development can influence evacuation during times of flooding and the safety of people in flood affected areas.

The floodplain can be categorised into areas considered to be of low, medium or high hazard. Preliminary categorisation of the floodplain takes into account a combination of flood depth and velocity to assign the level of hazard.

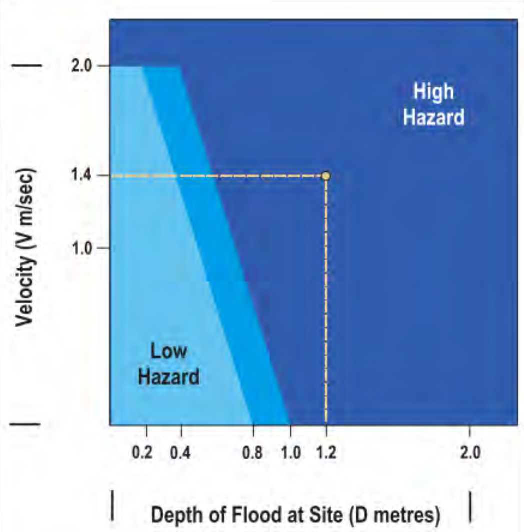
Figure 4-5 provides an initial guideline on the definition of low hazard and high hazard as well as a transition zone in between that could be defined as either low or high hazard, depending on factors other than velocity-depth product alone.



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.



Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

Figure 4-5 Floodplain hazard classification

The provisional hazard categories may be amended on further consideration of criteria other than velocity and depth, including factors such as the rate of rise of floodwaters, vulnerability of development, and duration of inundation.

Provisional categorisation of flood hazard in this study has been carried out in accordance with the above figures.

The results of the hazard analysis are discussed in the following section of this report (Section 4.5.2).

Analysis of hydraulic categories

Hydraulic categorisation refers to the delineation of the floodplain into areas dependent on their importance for floodplain function and reflects the potential for the impact of development on flood behaviour.

The Floodplain Development Manual defines three categories of flood prone land which are:

- **Floodways** – those areas of the floodplain where a significant volume of water flows during floods. They tend to be areas of natural channel and overland flow paths. Floodways are identified as those areas which, if blocked, would result in a significant increase in flood levels or a significant redistribution of flood flows.
- **Flood storage** – storage areas are areas of the floodplain which temporarily store flood flows during flood events. They are defined in the Manual as those areas which, if filled, would cause flood levels or peak discharge to increase substantially.
- **Flood fringe** – the flood fringe is the remaining area of flood liable land that is not classified as floodway or flood storage.

Hydraulic categorisation is used in floodplain management to identify those areas of the floodplain which are suitable for development and those which are not, as well as identifying the level of risk associated with flooding of existing development.

The results of the hydraulic category analysis are discussed in the following section of this report (section 4.5.2).

4.5.2 Baseline flooding

Flood extents, depths and velocities

The hydraulic modelling was used to estimate the flood extents across the entire project area with no project infrastructure in place.

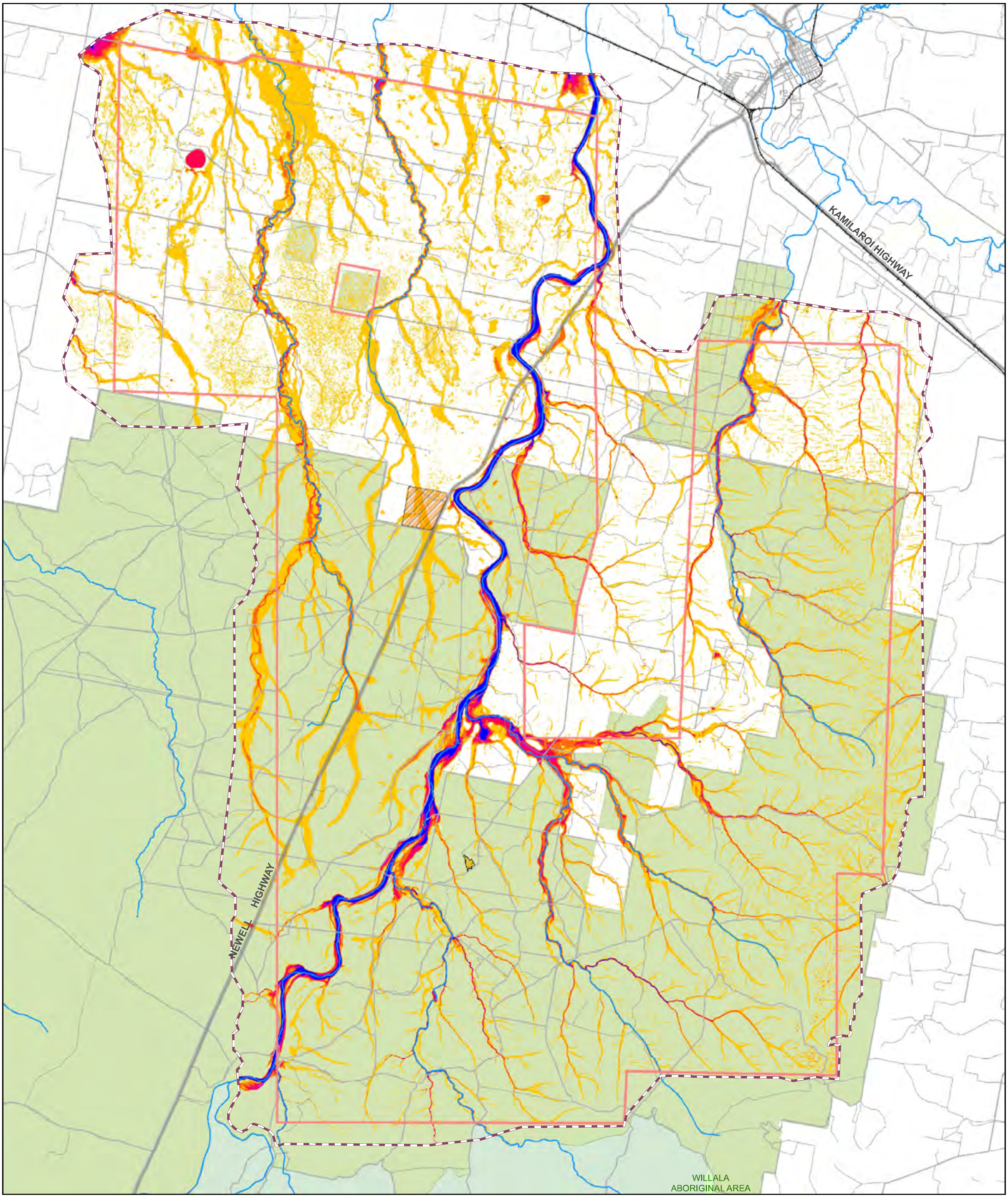
Flood extents are used for the purposes of planning infrastructure placement and identifying potential for impact to people, infrastructure and the environment through changes to the hydrologic regime.

The peak flood depth and velocity results for all events assessed are shown in Figure 4-6 to Figure 4-11.

Though much of the project area is traversed by ephemeral streams, the results show an extensive network of flow paths in rare flood event such as a one per cent AEP event.

The deepest flooding and highest flow velocities occur along Bohena Creek as the major watercourse in the project area. In the south and east of the project area, flow paths are largely confined to relatively narrow corridors of channels and overbank areas. In the flat terrain of the north and west where channels are less defined, large shallow areas of flooding are predicted.

The PMF map (Figure 4-8) shows the extent of flood prone land based on the analysis described in the flood study appendix. In the PMF, much of the flat, low lying areas in the north west of the site are predicted to be substantially inundated by flood waters.



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood depth (m)

- 0.00 - 0.50
- 0.5 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- >2

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

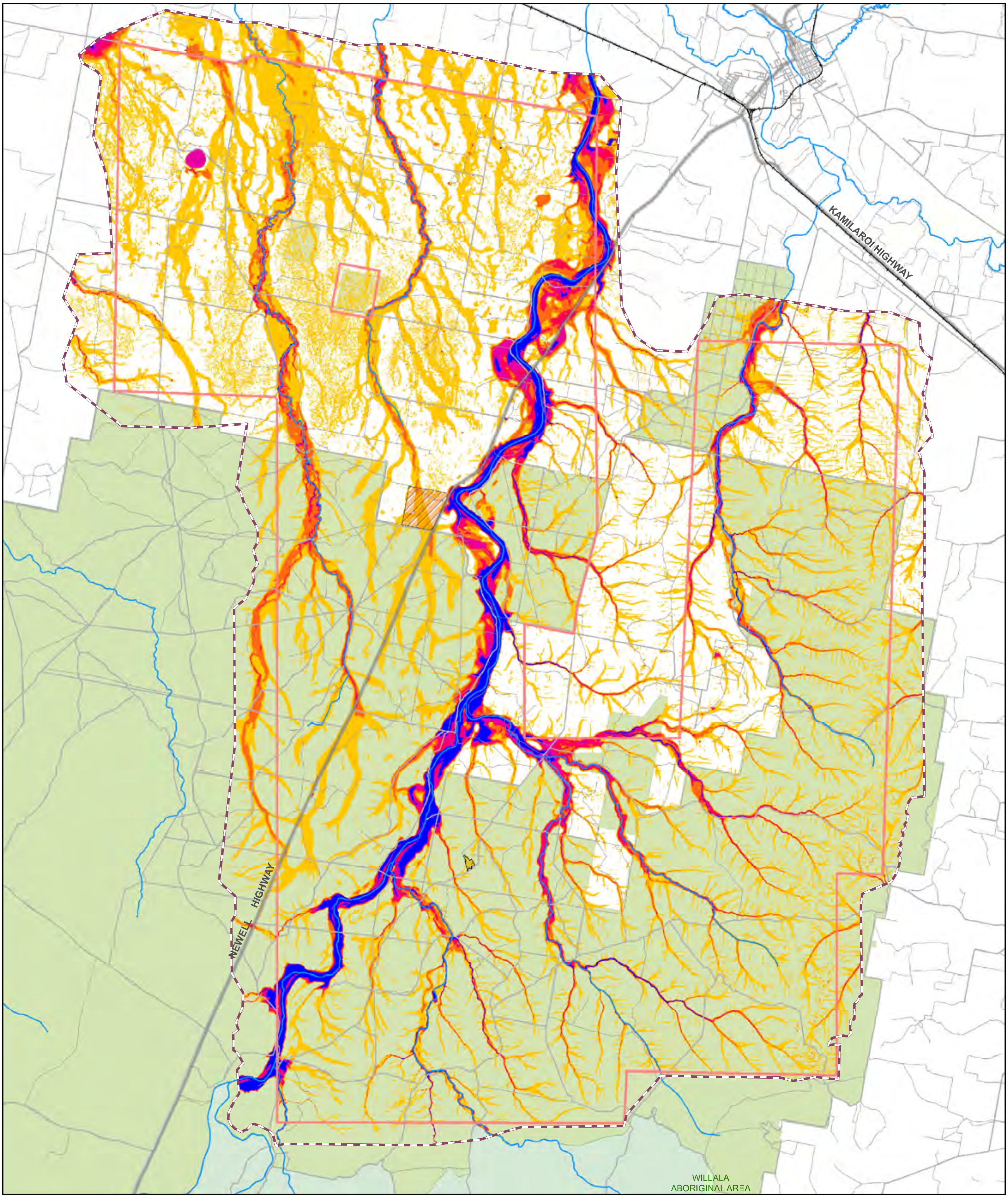
GHD

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

10% AEP Flood Depth Baseline Conditions

Figure 4-6



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood depth (m)

- 0.00 - 0.50
- 0.5 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- >2

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 10 Dec 2016

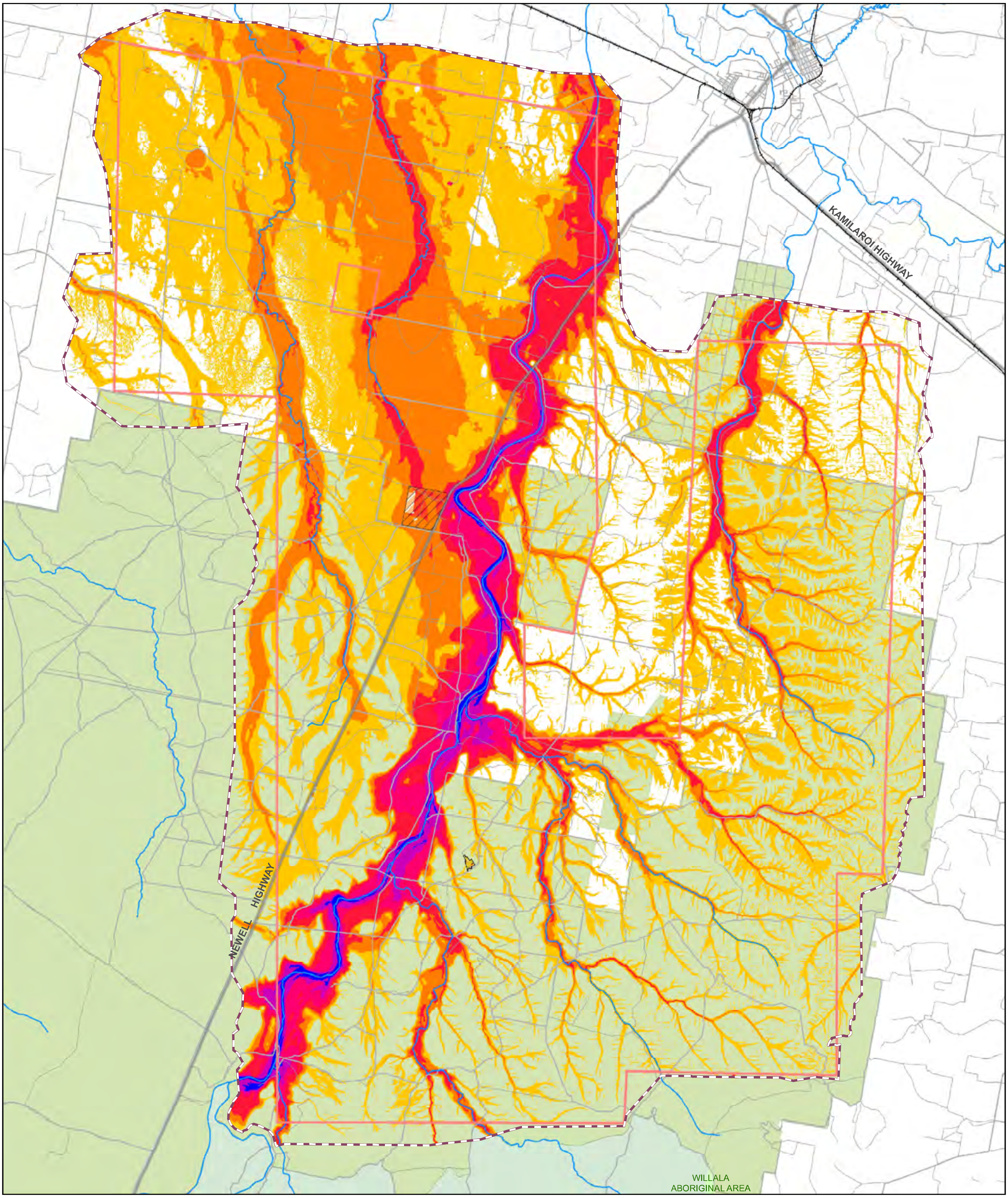
1% AEP Flood Depth Baseline Conditions

Figure 4-7

G:\21\22463\GIS\Maps\SMA_HYDRO.mxd

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood depth (m)

- 0 - 1
- 1 - 2.5
- 2.5 - 5
- 5 - 7.5
- 7.5 - 10
- 10+

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

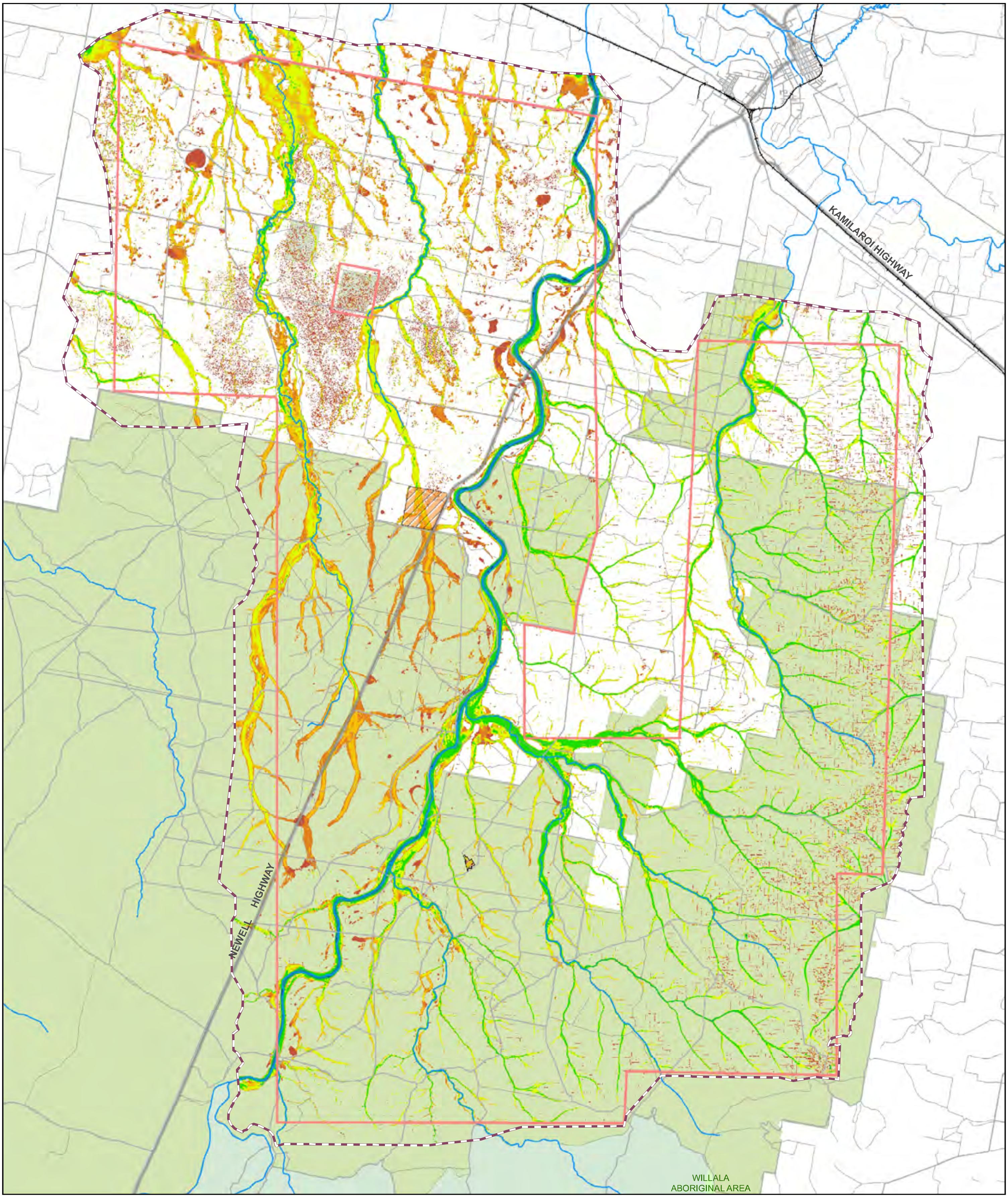
PMF Flood Depth Baseline Conditions

Figure 4-8

G:\21\22463\GIS\Maps\SMA_HYDRO.mxd

Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood velocity (m/s)

- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- >3

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

10% AEP Flood Velocity Baseline Conditions

Figure 4-9

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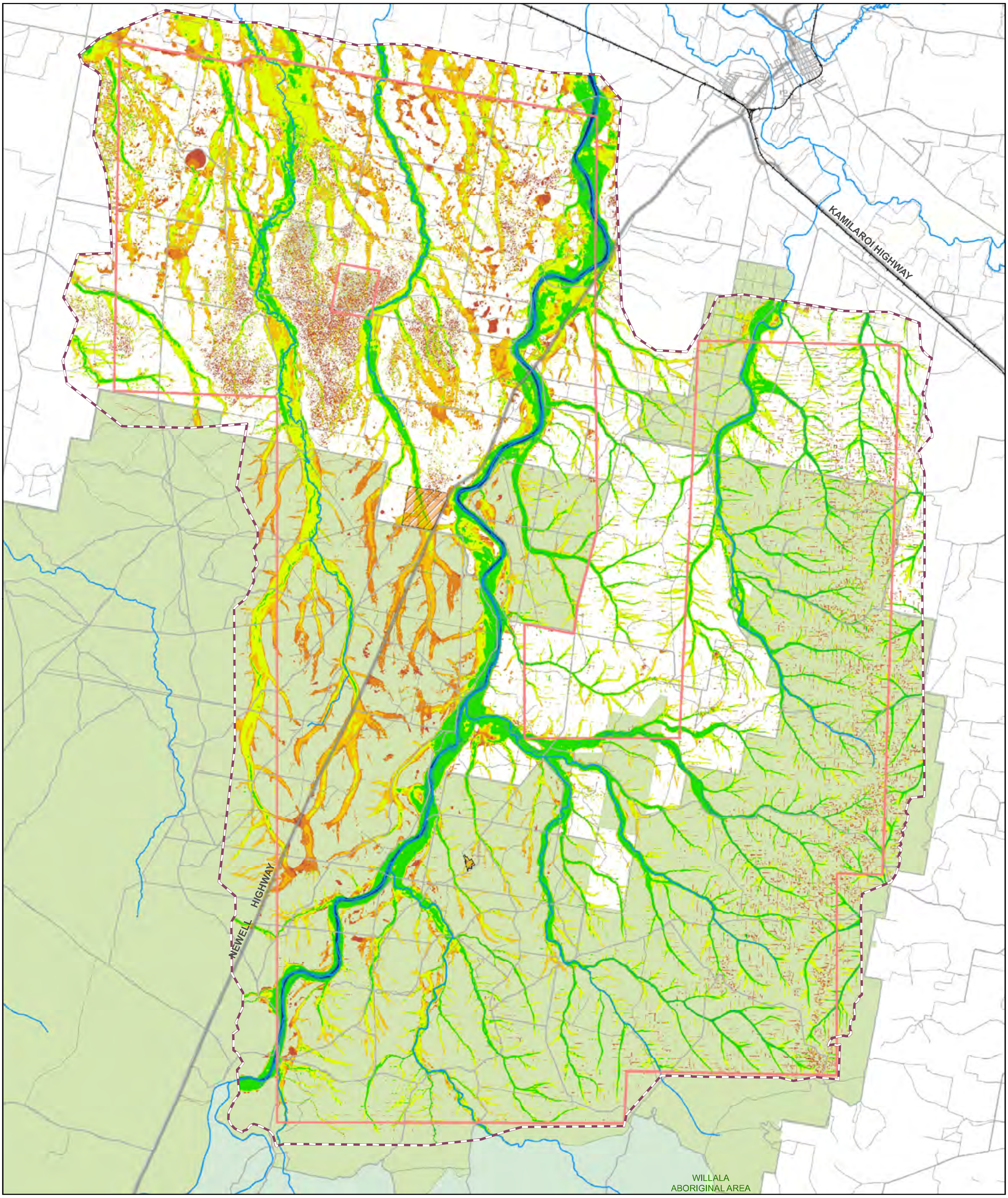
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood velocity (m/s)

- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- >3

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

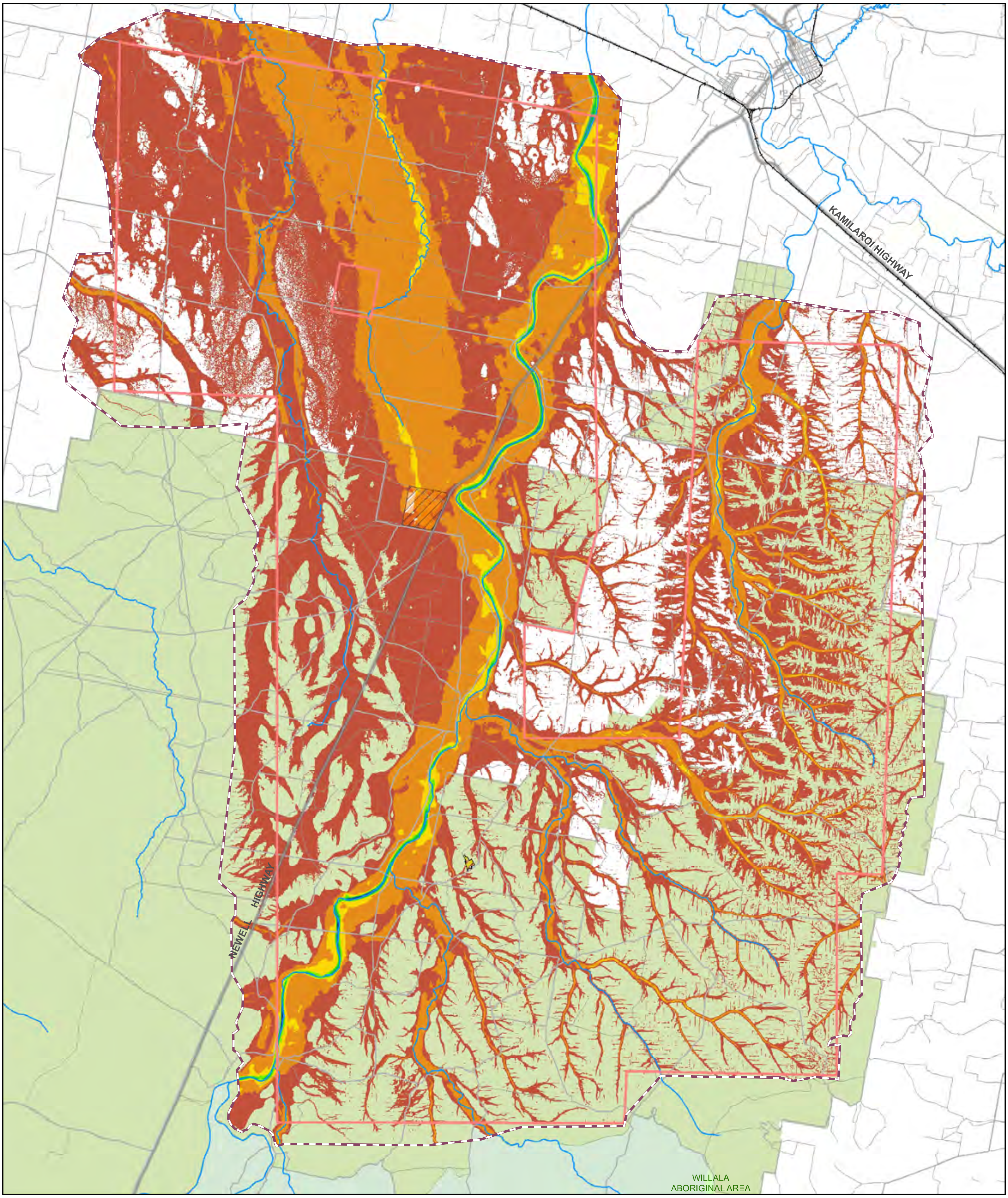
1% AEP Flood Velocity
Baseline Conditions

Figure 4-10

G:\21\22463\GIS\Maps\SMA_HYDRO.mxd

Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood velocity (m/s)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6+

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

PMF Flood Velocity
Baseline Conditions

Figure 4-11

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Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy

Flood hazard

A series of maps showing the provisional flood hazard with no project infrastructure in place is presented in Figure 4-12 to Figure 4-14.

These maps were prepared using the maximum velocity-depth product and categorising flood hazard according to Figure 4-13 (extracted from Appendix L of the NSW Floodplain Development Manual).

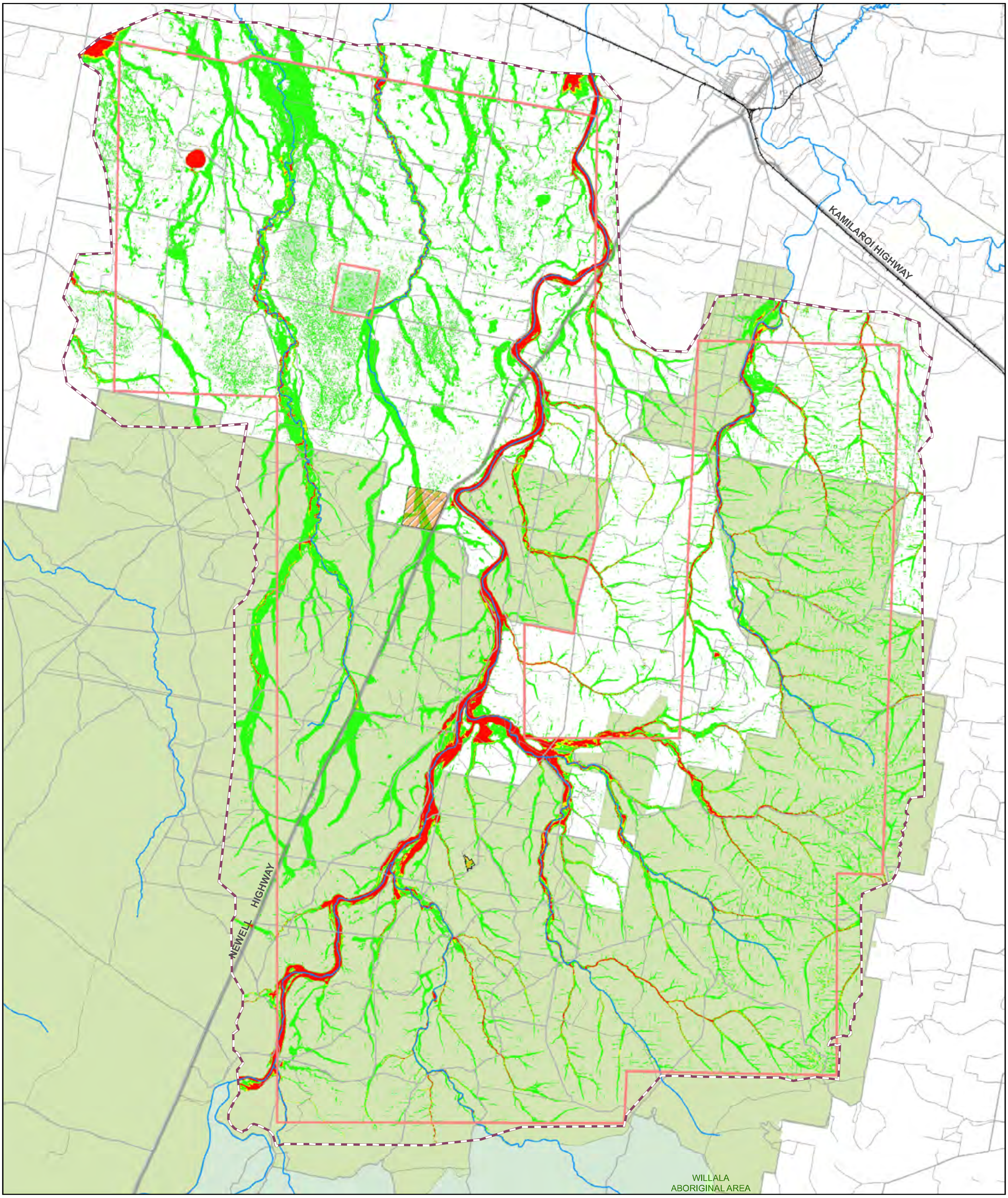
The results show that areas beyond the main channel of the named watercourses are generally classified as low hazard in a 10 per cent AEP and one per cent AEP event when considering flood depth and velocity. In the PMF for the baseline conditions, the high hazard area is more extensive, encompassing large parts of the north west of the project area, where the flow paths of Bohena Creek, Mollee Creek and Bundock Creek would converge.

The NSW Government's Floodplain Development Manual defines the hazard categories as exhibiting the following characteristics:

High Hazard - possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and

Low Hazard - should it be necessary, truck could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The implications of the flood hazard categorisations are discussed in greater detail in Chapter 5.



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Hazard risk

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

10% AEP Hazard Categories Baseline Conditions

Figure 4-12

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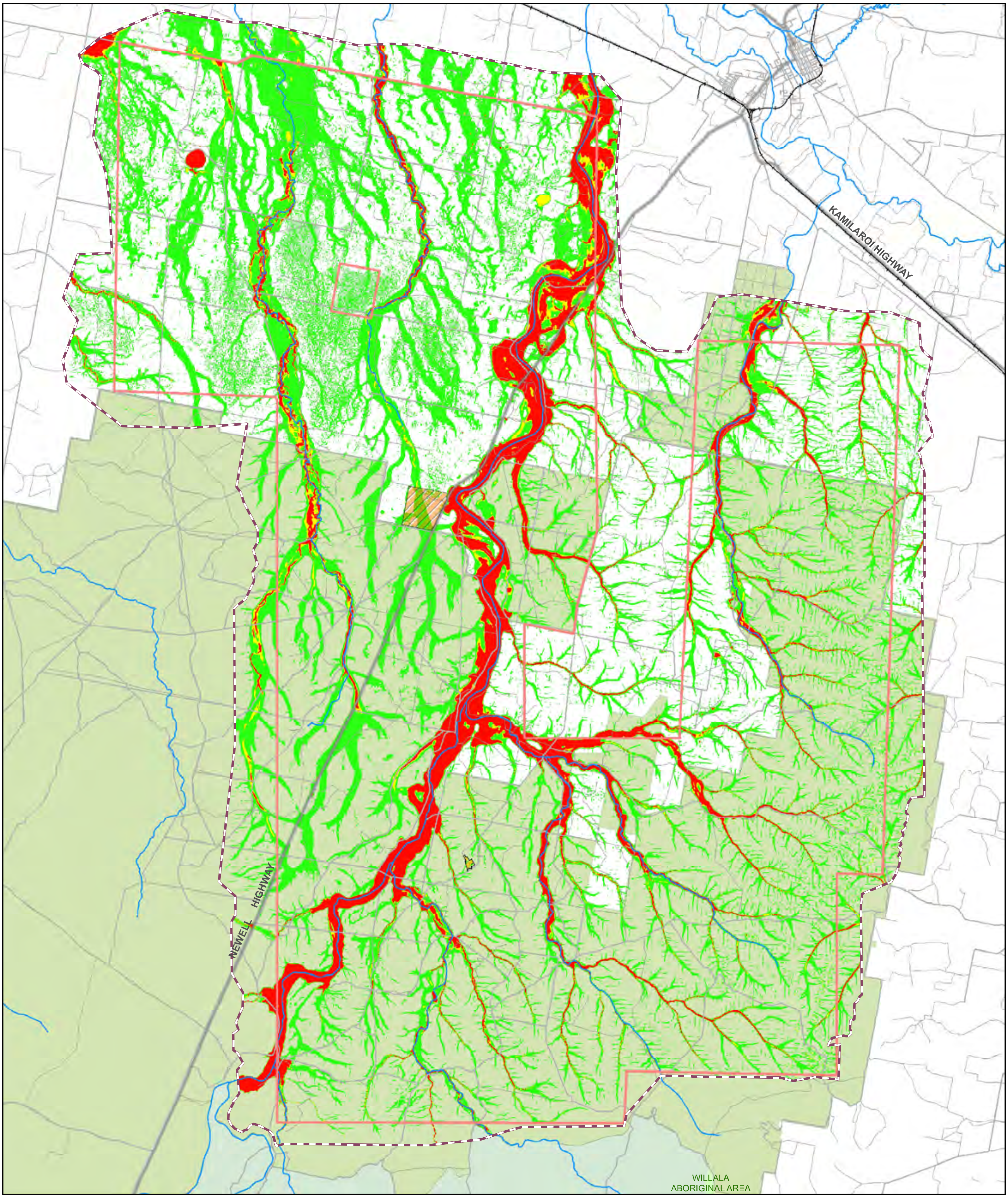
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Hazard risk

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

1% AEP Hazard Categories
Baseline Conditions

Figure 4-13

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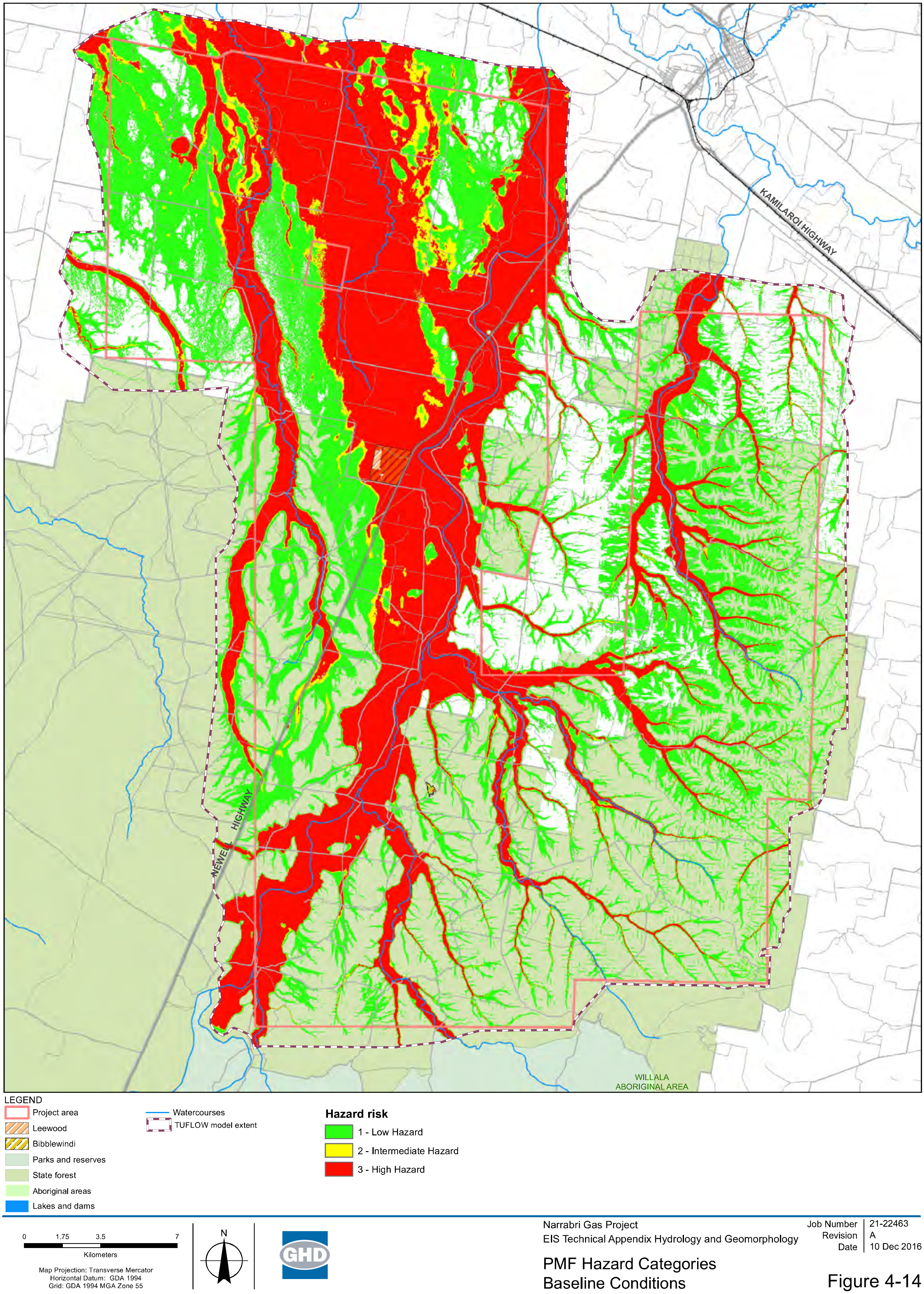
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	10 Dec 2016

PMF Hazard Categories
Baseline Conditions

Figure 4-14

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Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy

Hydraulic categorisation

The draft *Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully* was recently completed by WRM (October 2016). The following definitions of hydraulic categories were adopted in that study:

- Floodway – five per cent AEP high hazard extent
- Flood storage – one per cent AEP extent
- Flood fringe – residual area between one per cent AEP and PMF

For consistency with the region, similar categories were adopted for this study. However, to capture major flow paths that would otherwise have been excluded from the floodway, the floodway definition was amended in this study to incorporate the one per cent AEP high hazard extent. Flood storage and flood fringe areas were as per WRM (2016).

A hydraulic category map at Leewood is provided in Figure 4-15.

Flood planning area

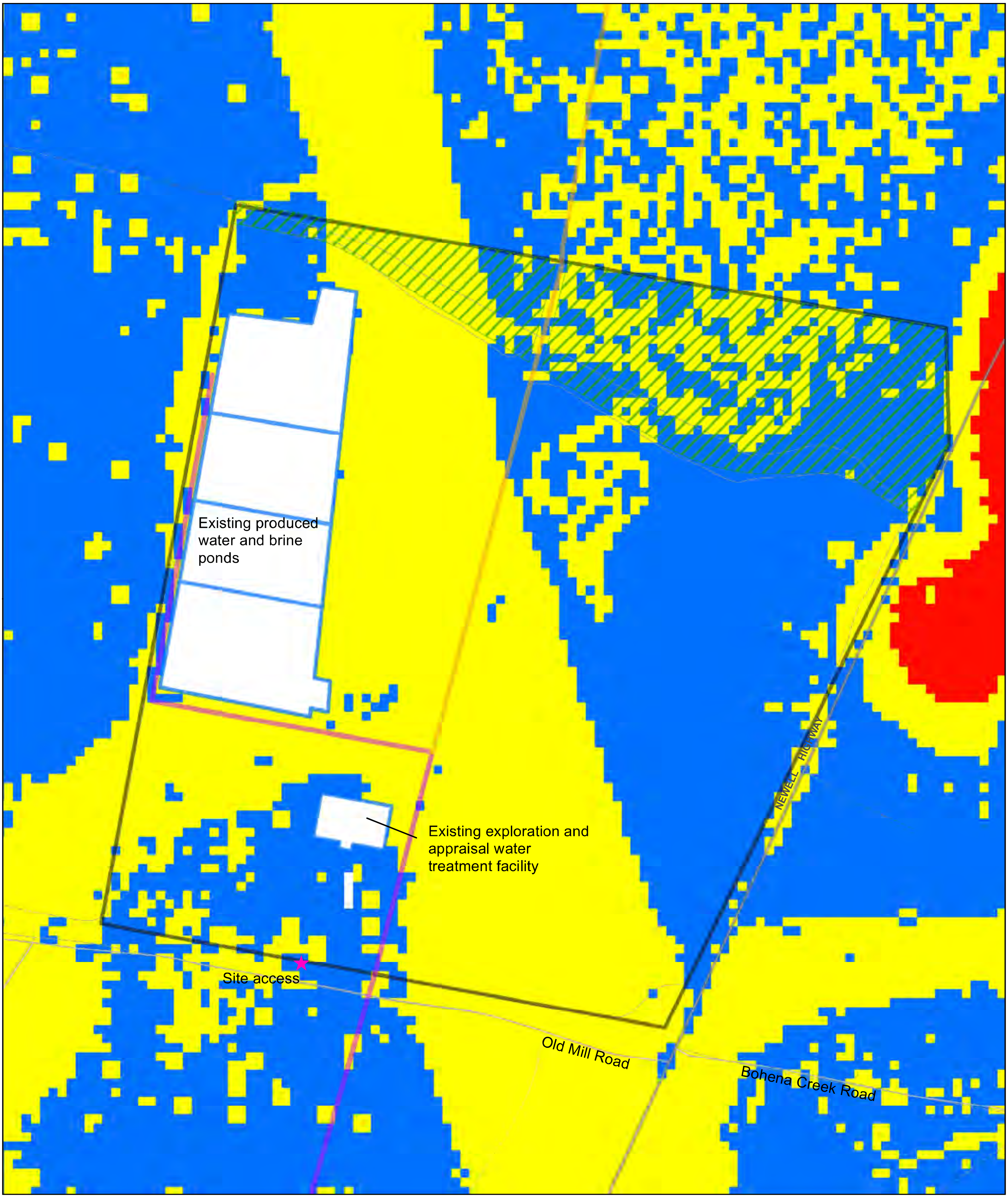
Not all development within flood prone land (the PMF extent) is typically protected against flooding. The flood planning level is the flood level below which flood related development controls apply and the flood planning area is the area located below the flood planning level. The *Floodplain Development Manual* notes the need to weigh the implications of restricting land use in flood prone areas against the flood risk. The flood planning area adopted for the draft *Narrabri Flood Study* was the one per cent AEP flood level plus an additional 500 mm freeboard. For residential developments, this is generally considered the standard level at which to set fill levels or floor levels. For the project area, the one per cent AEP event has been used as the flood planning level for new site infrastructure and has been incorporated into the Field Development Protocol (section 5.2 and EIS Appendix C).

Sensitive receivers

With around two thirds of the project area being located in State forests, and the remaining land consisting predominantly of rural properties, the number of sensitive receivers within the project area is relatively low. Sensitive receivers in this context refers to occupied rural dwellings and have been identified within the project area (refer Figure 4-16).

Residential properties are particularly sensitive to changes in flood conditions which may influence risk in terms of:

- Increasing flood hazard through increased flood velocities and depths resulting in increased threat to life.
- Changes in flood levels resulting in more frequent inundation of residences.



LEGEND

- Leewood
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Existing facilities

Leewood Infrastructure

- Approved water treatment (Not constructed)
- Brigalow

Proposed use of existing infrastructure corridor

- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor

Hydraulic Category

- 1 - Flood Fringe
- 2 - Flood Storage
- 3 - Floodway

0 0.075 0.15 0.3
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Hydraulic Categories at Leewood Baseline Conditions

Job Number	21-22463
Revision	A
Date	07 Dec 2016

Figure 4-15

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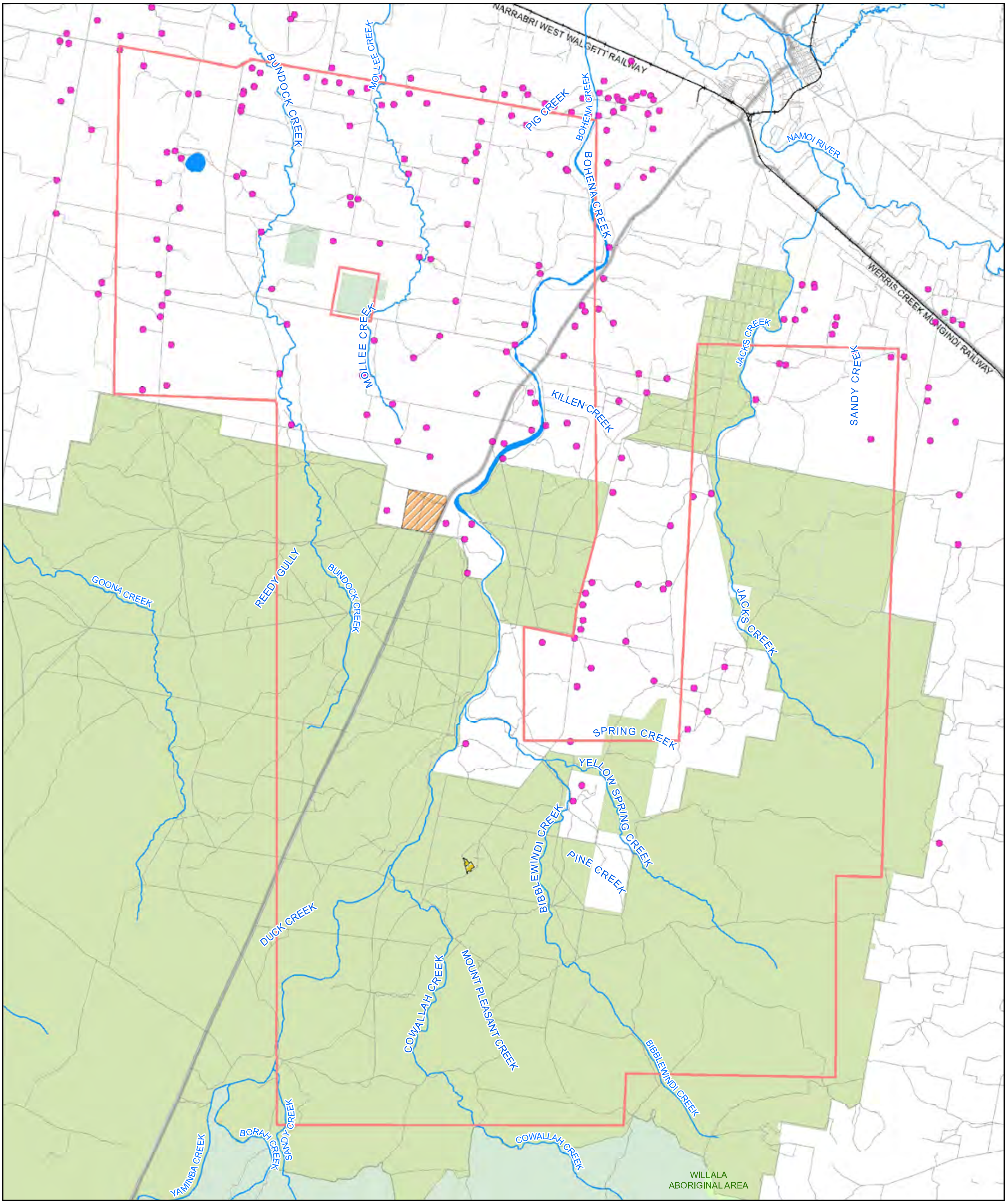
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Roads
- Train line
- Sensitive receivers

0 1,75 3,5 7

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	30 Nov 2016

Sensitive Receivers

Figure 4-16

N:\AU\Sydney\Projects\21\22463\GIS\Maps\21_22463_KBM29_.mxd [KBM: 93]

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

Existing flood depths have been estimated at each receiver and are tabulated in Appendix B.

The model uses 20 m x 20 m square grid cells and receivers have been estimated at a point location. The results should be considered as broadly representative of the existing flooding at each location to a level of accuracy appropriate for the purposes of comparison with future changes.

4.6 Flood emergency management

The project area is covered by the Narrabri Shire Local Flood plan (2015), an endorsed NSW SES plan and a sub-plan of the Narrabri Shire Local Emergency Management Plan (EMPLAN). The plan documents the flood preparedness, flood response and immediate flood recovery operational measures for the Narrabri Shire. This includes the roles and responsibilities of the emergency services, Council, other agencies and the community in preparing for, responding to and recovering from flood events.

The plan has relevance to the project with respect to the existing management of flooding in the area and any potential impacts of the project on emergency management of flooding including evacuation.

Narrabri Shire falls within the Namoi Division of the NSW SES. A local SES headquarters is located in Narrabri and unit operations centres are also located in Boggabri, Wee Waa and Pilliga.

The NSW SES Narrabri Local Headquarters provides advice to the NSW SES Namoi Region Headquarters on current and expected impacts of flooding in the Narrabri Shire Council local government area. The NSW SES Namoi Region Headquarters issues flood bulletins, evacuation warnings and evacuation orders to media outlets and agencies on behalf of the local flood units. The SES Wee Waa unit monitors the gauge at Bohena Creek.

The Bureau of Meteorology also issues severe weather and storm warnings and flood watches.

The Newell Highway is indicated as a potential evacuation route from Narrabri to Coonabarabran through the project area in the Narrabri Shire Local Flood Plan.

4.7 Historic flooding

Limited data relating to flooding within the project area is available, though an analysis of flow records is available for Bohena Creek. This is included in the Flood Study Appendix (Appendix A of this report).

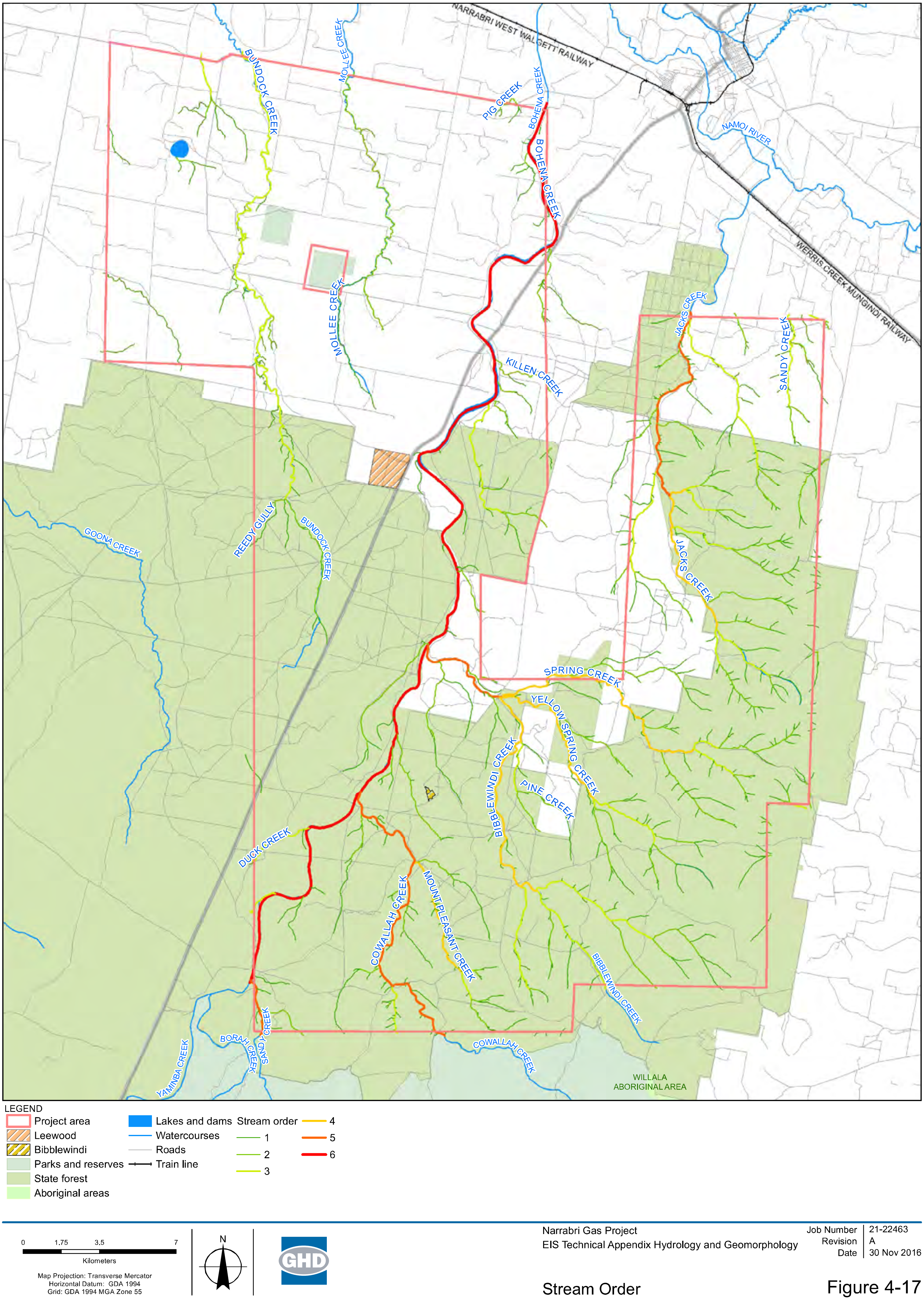
4.8 Project area watercourse geomorphology

4.8.1 Stream order

The results of applying the Strahler stream order methodology to the topographic watercourses within the project area is displayed in Figure 4-17.

This indicates that many watercourses within the project area are first to third order streamlines. The exceptions are:

- Bohena Creek is a sixth order streamline along its entire length through the project area.
- Cowallah and Sandy Creeks are fifth order streamlines along their entire length through the project area.
- Bibblewindi Creek increases from a third to fourth to fifth order streamline along its length through the project area.
- Spring and Yellow Spring Creeks are defined as fourth order stream orders along their lengths through the project area.
- Jacks Creek is a fifth order stream order along its length through the project area.



Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	30 Nov 2016

Stream Order

Figure 4-17

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

4.8.2 Watercourse types

The following sections provide a summary of the watercourse geomorphic types identified, which have been categorised into the following four main groups of watercourse systems:

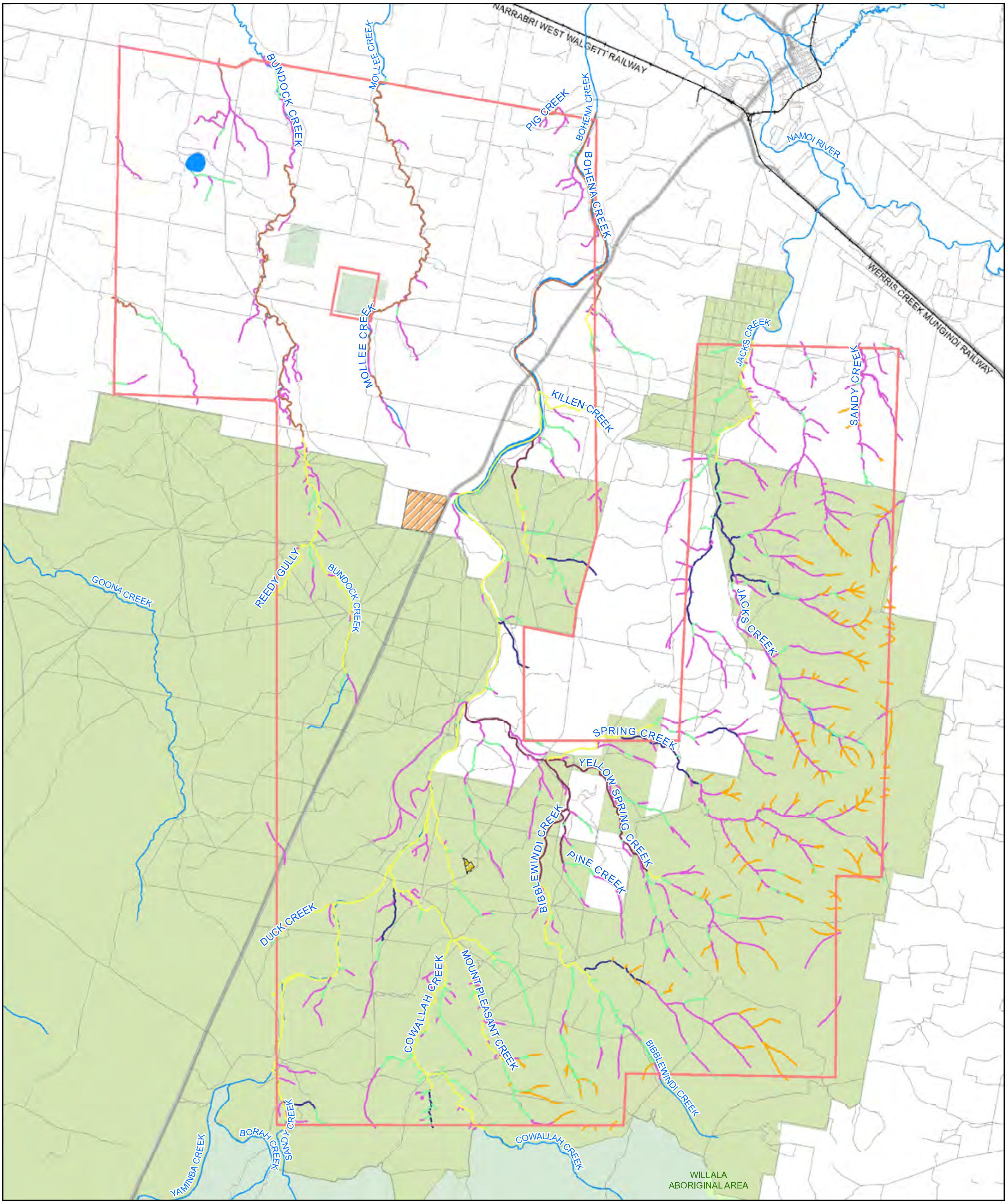
- unchannelised systems
- confined systems
- partly-confined systems
- unconfined systems.

Classification of the watercourse geomorphic type provides an understanding of the character and behaviour of the watercourse. Following classification, inferences on lateral stability and scour potential can be made. A total of seven different stream types were identified during the desktop and field assessment of the watercourses within the project area as follows:

- valley fill systems
- chain of pond systems
- headwater systems
- confined valley sand systems
- partly confined, low sinuosity sand systems
- low sinuosity, sand systems
- channelised fill systems.

The distribution of stream types within the study area is displayed in Figure 4-18 and their characteristics are described in the following sections.

Further analysis of watercourse condition and disturbance risk was carried out and results are shown in Figure 4-19 and Figure 4-20. The analysis is further described in the following sections.



LEGEND

Project area	Lakes and dams	Watercourse types
Leewood	Watercourses	Headwater
Bibblewindi	Roads	Confined valley sand
Parks and reserves	Train line	Partly confined low sinuosity sand
State forest		Low sinuosity sand
Aboriginal areas		Channelised fill
		Valley fill
		Chain of ponds

0 1,75 3,5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 30 Nov 2016

Watercourse Types

Figure 4-18

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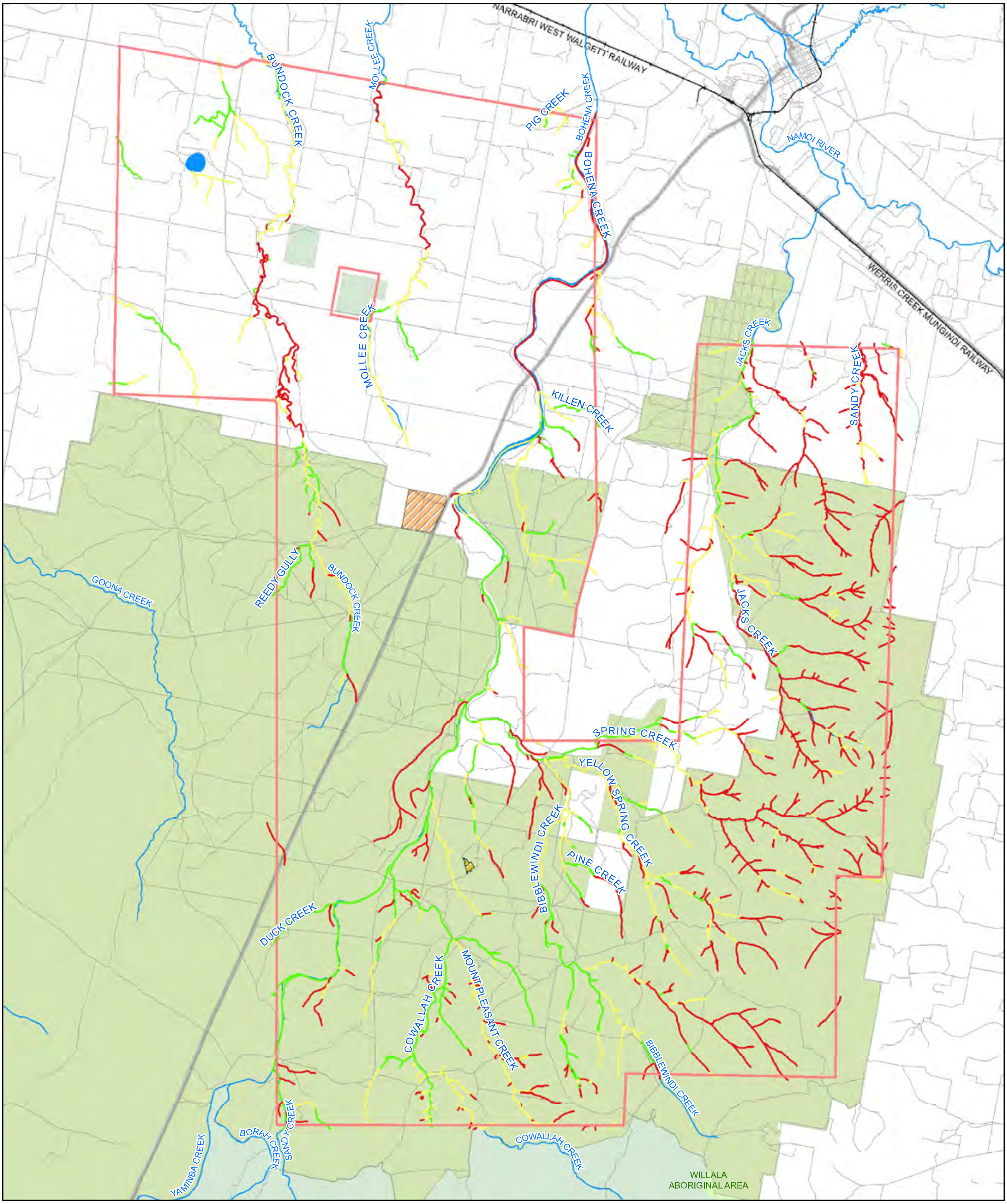
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Roads
- Train line

Watercourse condition

- Good
- Moderate
- Poor

0 1,75 3,5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 30 Nov 2016

Watercourse Condition

Figure 4-19

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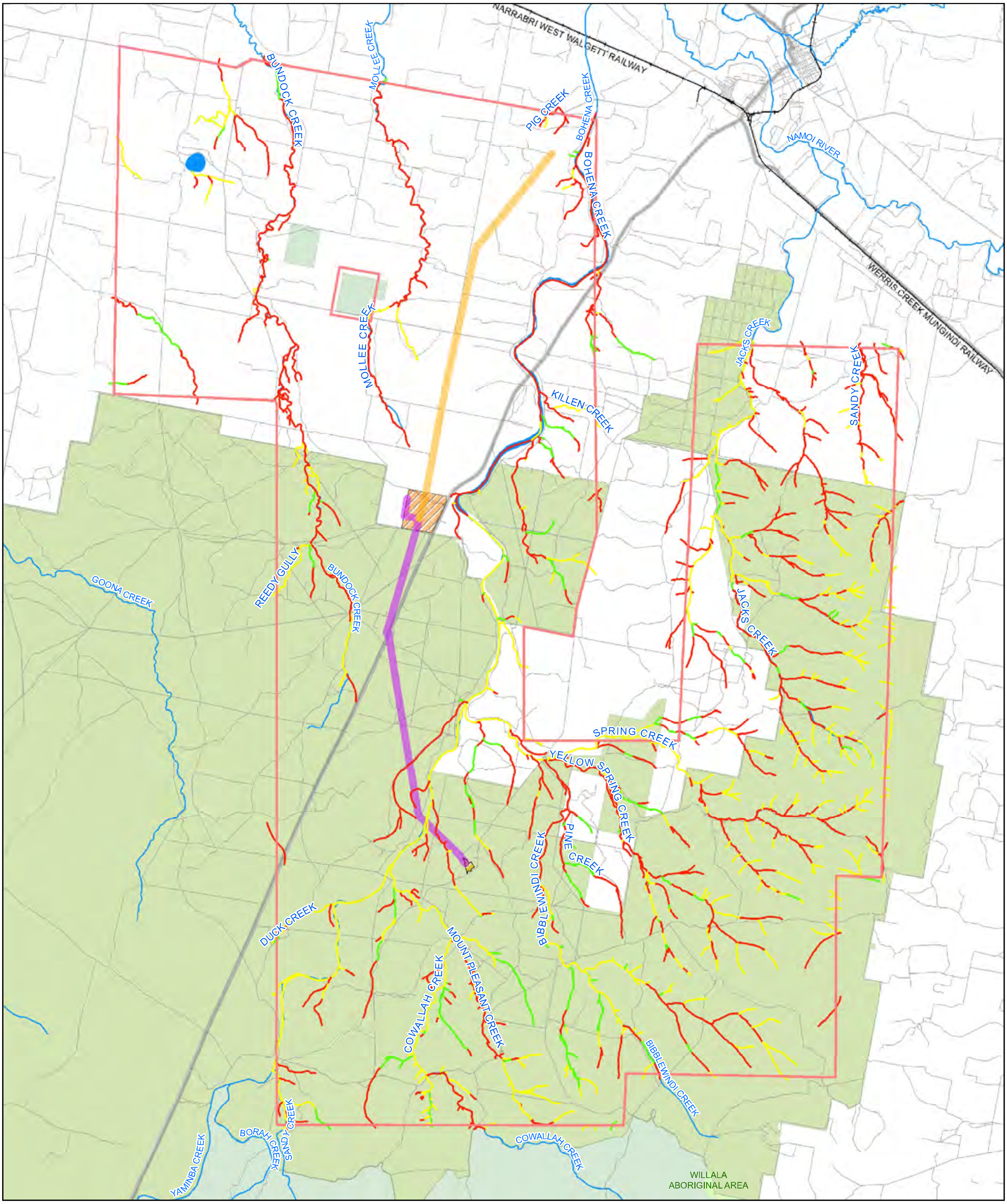
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy



LEGEND

Project area
Leewood
Bibblewindi
Parks and reserves
State forest
Aboriginal areas
Lakes and dams
Watercourses
Roads
Train line
Watercourse disturbance risk
High
Moderate
Low
Leewood to Wilga Park infrastructure corridor
Bibblewindi to Leewood infrastructure corridor

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 30 Nov 2016

Watercourse Disturbance Risk

Figure 4-20

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

Unchannelised Systems

Unchannelised systems are characterised by a relatively flat, unincised valley floor surface with substrates comprised of alluvial fine silts, sands and muds (refer to schematic in Figure 4-21). Such systems are typically formed by flows that lose their velocity as they spread over an intact valley floor and deposit their sediment load. Coarse material (i.e. sand sized and greater) eroded from the upstream catchment is not transported through the reach, which is often on a relatively flat longitudinal grade.

Being largely unchannelised, such systems are non-scouring and laterally stable. However, they are prone to incision through the upstream retreat of a gully head to form a continuous channel.

Unchannelised systems in the project area included valley fill systems and chain of ponds systems.

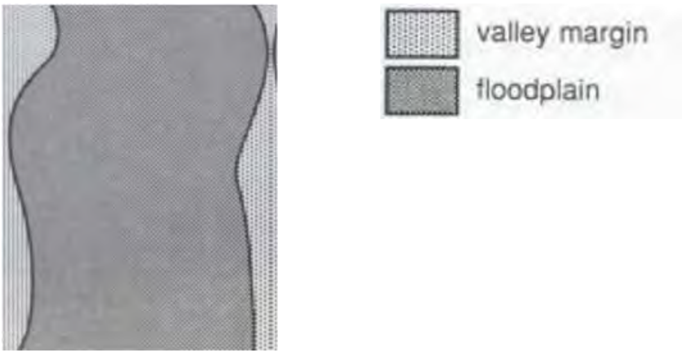


Figure adapted from Brierley and Fryirs (2002).

Figure 4-21 Plan view schematic of an unchannelised system

Valley fill systems

Valley fill systems consist of flat valley floor with no defined channel such that the whole valley floor acts as a channel with valley margins as the banks (refer Figure 4-22). During high intensity rain events water flows across the surface as sheet flow. As such, the flow energy is dissipated across the valley floor, resulting in the deposition of fine-grained suspended sediments. Low energies associated with flow dissipation lead to long term accumulation of sediments. If the valley floor is disturbed a headcut may be initiated (refer also to *Channelised fill,* further below). This will form a continuous channel that will incise, enlarge and progress up stream with each subsequent flow event. This significantly alters the behaviour of the system (refer to *Channelised fill,* further below).

Valley fill systems are located throughout the project area along first to fourth order streamlines.

Chain of ponds systems

Chain of ponds systems display a series of symmetrical (occasionally irregular) ponds (refer Figure 4-23) that occur at irregular intervals along a poorly defined drainage line set within an alluvial valley floor. The ponds tend to retain water throughout the year and are separated by poorly defined channel depressions, swampy fills and / or sand splay deposits. During moderate to high flow events sand and suspended sediment is transported.

Chain of ponds systems occupy lower catchment positions along streamlines set within Pilliga outwash sediments, namely Bohena, Mollee, Bundock and Oakyhole creeks.

Figure 4-22 Upstream view of a valley fill in the eastern drainage area

Figure 4-23 Downstream view of a chain of ponds section of Bundock Creek

Confined Systems

Confined systems (refer to schematic plan in Figure 4-24) are characterised by a single, symmetrical channel often in bedrock controlled, irregular V- or U-shaped valleys. Channel geometry and sinuosity is valley controlled. The bed is composed of bedrock although deposits of boulder, cobble, gravel and / or sand can be present. Confined systems are geomorphically stable systems that are subject to relatively slow rates of change due to the high degree of valley confinement. As a result, such systems have limited capacity to scour or migrate laterally.

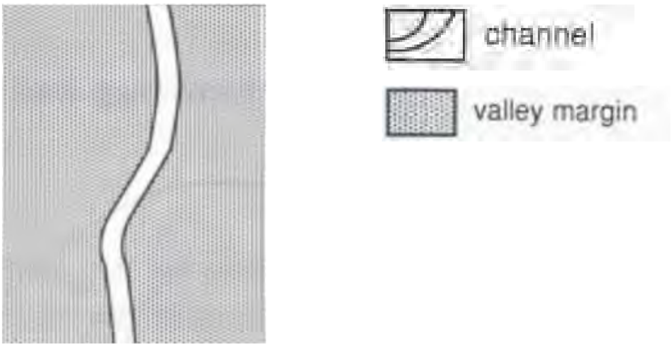


Figure adapted from Brierley and Fryirs (2002).

Figure 4-24 Planview schematic of a confined system

Confined systems in the project area included headwater systems and confined valley sand systems. Both systems are addressed further below.

Headwater systems

Headwater systems which consist of steep gradient channels in a narrow valley (less than five metres wide). Headwater systems typically exhibit a thin colluvial fill (refer to Figure 4-25) overlying weathered bedrock and are susceptible to minor bed erosion through gullying processes.

Headwater systems are largely located in upper catchment positions along first and second order tributaries feeding the eastern drainage streamlines.

Confined valley sand systems

Confined valley sand systems consist of a low sinuosity channel set within narrow bedrock or terrace bound valley. They are laterally stable systems, although the channel may slowly erode the valley wall if not composed of bedrock (i.e. terrace bound). Occasional small floodplain pockets are observed along some reaches, in areas of locally wider valleys. The flat, featureless bed, which resembles a valley fill, is dominated by sand (refer to Figure 4-26) with some fines and organic materials. The bed is usually highly mobile but in undisturbed situations the surface is stabilised by a dense growth of grasses. These intermittent systems do not typically retain surface water between flow events.

Confined valley sand systems are located in middle to upper catchment positions, typically along second to thirds order streamlines.

Figure 4-25 Upstream view of a headwater in the eastern drainage area

Figure 4-26 Upstream view of a confined valley, sand section of Jacks Creek

Partly Confined Valley Systems

The lateral movement of the channel of partly confined valley systems is dictated largely by the confinement of the valley that can control between 10 and 90 per cent of the length of the channel. The two broad categories of partly confined systems can be defined as either bedrock controlled or planform controlled as described further below and illustrated in Figure 4-27 and Figure 4-28. Identified partly confined valley systems are further differentiated based on bed material substrate of either cobble, gravel, sand or fine-grained (i.e. silt and mud). Scour potential of those systems will vary from low to high dependant on bed material and the presence of outcropping or near-surface bedrock.

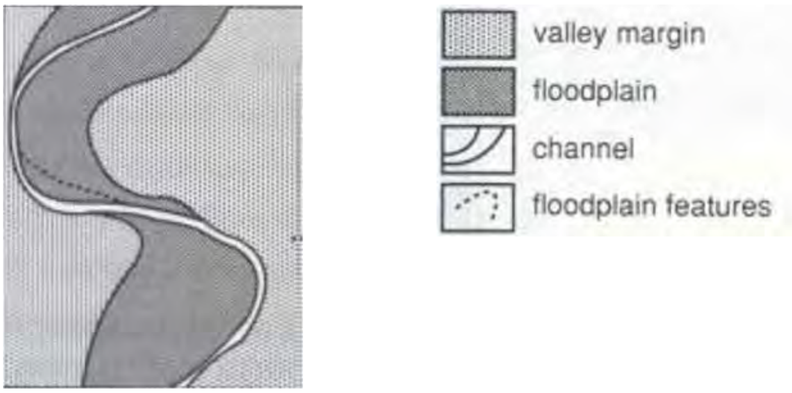


Figure adapted from Brierley and Fryirs (2002).

Figure 4-27 Planview schematic of a bedrock controlled system

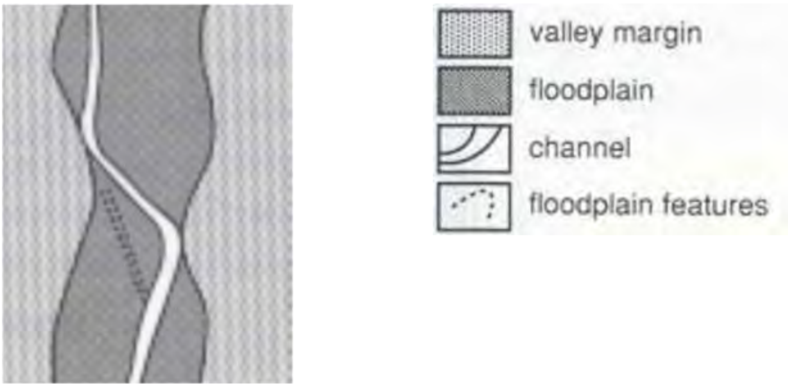


Figure adapted from Brierley and Fryirs (2002).

Figure 4-28 Planview schematic of a planform controlled system

Partly confined systems in the project area included planform controlled, low sinuosity sand systems.

Planform controlled, low sinuosity sand systems

Planform controlled, low sinuosity sand systems are set within a slightly irregular valley. Valley margins, which may be bedrock or terrace, limit lateral migration of channel. Discontinuous floodplains are formed as the channel crosses the valley floor from one valley margin to the other. The channel bed is a relatively featureless, mobile sand sheet with scattered gravels. Banks are typically vegetated and composed of fine sands with some silt and organic matter. Such intermittent systems do not retain surface water between flows. Low to moderate stream energies generated by higher flows will mobilise the unvegetated sand bed and rework bars and benches. Hydraulic diversity is low due to the generally featureless, mobile sand bed, low levels of large woody debris and only scattered instream vegetation. Sediment throughput is generally in balance. However, sand will accumulate rapidly when there is upstream incision or erosion.

Planform controlled, low sinuosity sand systems are located in middle to lower catchment positions typically along third to sixth order streamlines. The majority of Bohena Creek (refer to Figure 4-29) within the project area consists of this system.

Figure 4-29 Downstream view of Bohena Creek

Laterally Unconfined Valley Systems

Laterally unconfined valley systems have limited or no valley influence on the channel and exhibit floodplains bounding both sides of the channel (refer to Figure 4-30). As a result, the channels of such systems have the potential to migrate laterally across the valley floor. Bed controls are also limited or non-existent such that these systems have a moderate to high potential for scour dependant on bed material type. Identified laterally unconfined valley systems were further differentiated based on bed material substrate of either gravel, sand or fine-grained (i.e. silt and mud). Those systems can also be differentiated based on channel sinuosity, however only low to moderate sinuosity channel systems were identified.

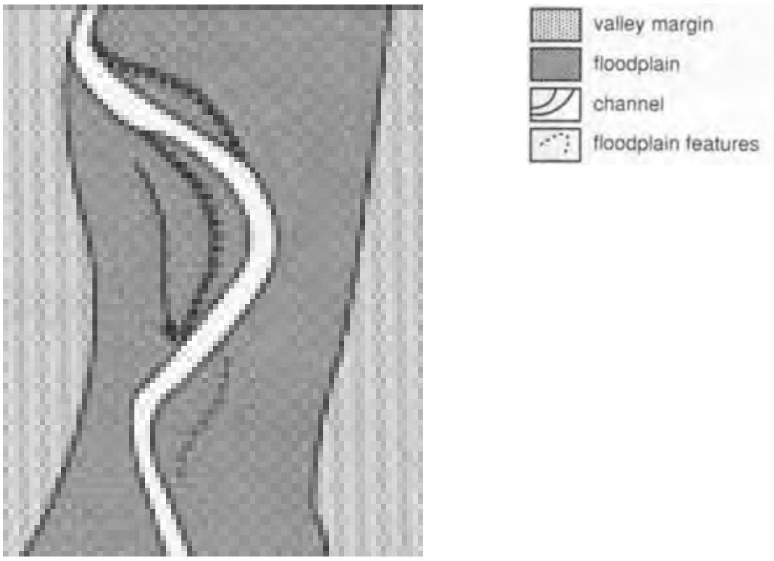


Figure adapted from Brierley and Fryirs (2002)

Figure 4-30 Planview schematic of an unconfined low sinuosity system

Laterally unconfined systems in the project area included low sinuosity sand systems and channelised fill systems.

Low sinuosity sand systems

Low sinuosity sand systems exhibit continuous floodplains on both sides of a low to moderate sinuosity channel. The channel bed is a relatively featureless, mobile sand sheet with scattered gravels. Banks are typically vegetated and composed of fine sands with some silt and organic matter. Such intermittent systems do not retain surface water between flows. Low to moderate stream energies generated by higher flows will mobilise the unvegetated sand bed and rework bars and benches. Hydraulic diversity is low due to the generally featureless, mobile sand bed, low levels of large woody debris and only scattered instream vegetation. Sediment throughput is generally in balance. However, sand will accumulate rapidly when there is upstream incision or erosion.

Low sinuosity sand systems are located in middle to lower catchment positions on third to fourth order segments of Bibblewindi (refer to Figure 4-31) Pine and Sawpit creeks.

Figure 4-31 Upstream view of Bibblewindi Creek

Channelised fill systems

Channelised fill systems exhibit a continuous channel that has incised, probably since European settlement, into valley fill or chain of ponds through headcut retreat and channel expansion (refer to Figure 4-32). The floodplains represent former valley fill or chain of ponds surfaces and are generally flat and featureless. Channelised fill systems generally have an intermittent flow regime and do not usually retain surface water between flow events. Moderate stream energies generated during higher flow events can re-activate erosional processes. Headcuts will progress upstream and unprotected banks will erode, releasing large amounts of sediment. Most channels have incised to a point where all flows are contained within the channel such that the former fill surfaces are rarely inundated. Consequently, flow energy concentrates within the channel resulting in increased rates and occurrences of channel erosion.

Channelised fill systems are located throughout the project area in middle to upper catchment positions, typically along first to third order streamlines.

Figure 4-32 Downstream view of a channelised fill section of tributary to Cowallah Creek

4.8.3 Geomorphic condition

The geomorphic condition of the assessed streamlines in the project area was displayed in Figure 4-19. Despite the area being largely vegetated, the geomorphic condition of many of the streamlines is assessed to be moderate (31.5 per cent) to poor (23 per cent) in response to past channel incision and enlargement. It is likely most of the disturbed streamlines were either valley fill or chain of ponds systems prior to European settlement. With the introduction of grazing and then logging in the area, watercourses have been subject to both:

- Direct disturbances (e.g. construction of tracks across watercourses resulting in channel bed disturbance, leading to scour and incision).
- Indirect disturbances (e.g. clearing and altered fire frequencies leading to increased run-off rates, more peaked flow events, hillslope erosion and increased sediment delivery to channels).

As a result, many streamlines exhibit planar, mobile sand beds of limited form and aquatic habitat value. Ongoing incision through gully processes (refer to Figure 4-33) is also still evident across the project area.

Figure 4-33 Downstream view of a gully head in the eastern drainage area

Good condition watercourses make up approximately 45.5 per cent of the assessed stream length. Figure 4-34 and Figure 5-2 provide a comparison of watercourse geomorphic condition against stream order and stream type respectively. The comparison indicates that good condition reaches are primarily located on first order streamlines and are largely associated with valley fill and headwater stream types.

Figure 4-34 also indicates a decreasing trend in the percentage length of good condition watercourses with increasing stream order, with no fifth order streamlines assessed to be in good condition. It is noted, however, that the percentage length of good condition watercourse increases for sixth order streamlines. This is comprised of the downstream section of Bohena Creek in the project area specifically associated with where the watercourse has been assessed as a chain of ponds stream type.

4.8.4 Geomorphic Fragility and Disturbance Risk

Stream fragility refers to the sensitivity or susceptibility of a stream to changes or alterations in its geomorphic form and / or type when exposed to disturbances. Streams with higher fragility have a lower threshold to threatening processes and will show more geomorphic and physical change than streams that are less fragile or susceptible. Understanding geomorphic categories and their potential fragility with respect to watercourse types is important for management of watercourse as a means of assessing watercourse vulnerability to disturbances.

Lampert and Short (2004) defined the fragility of watercourse geomorphic types in the Namoi River catchment. Their assessment was based on the potential for watercourse types to adjust.

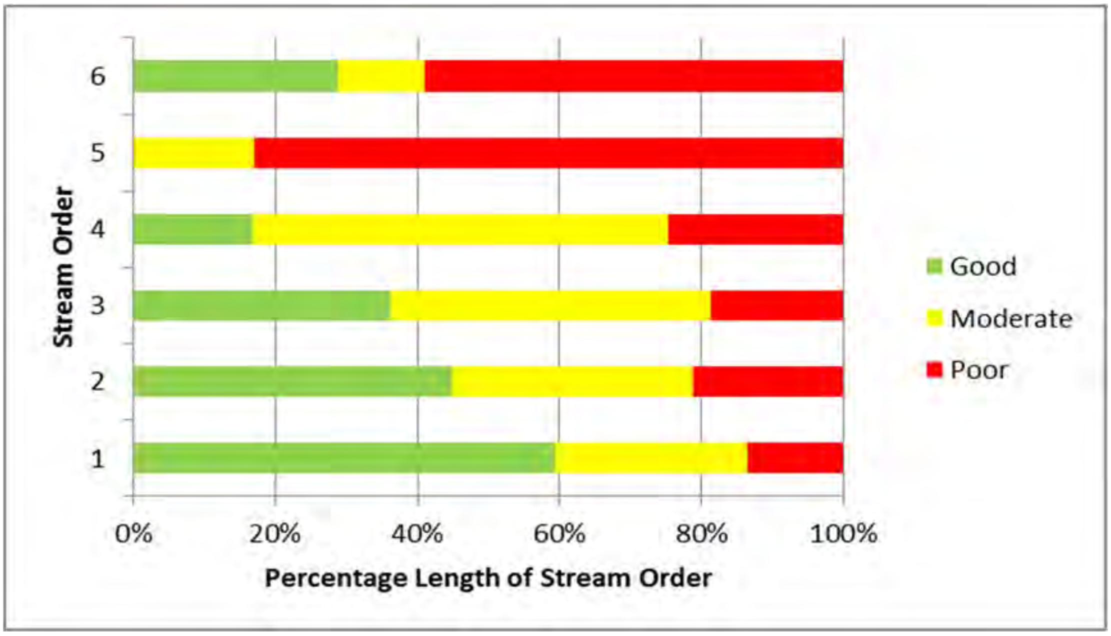


Figure 4-34 Percentage length of geomorphic condition of watercourse by stream order

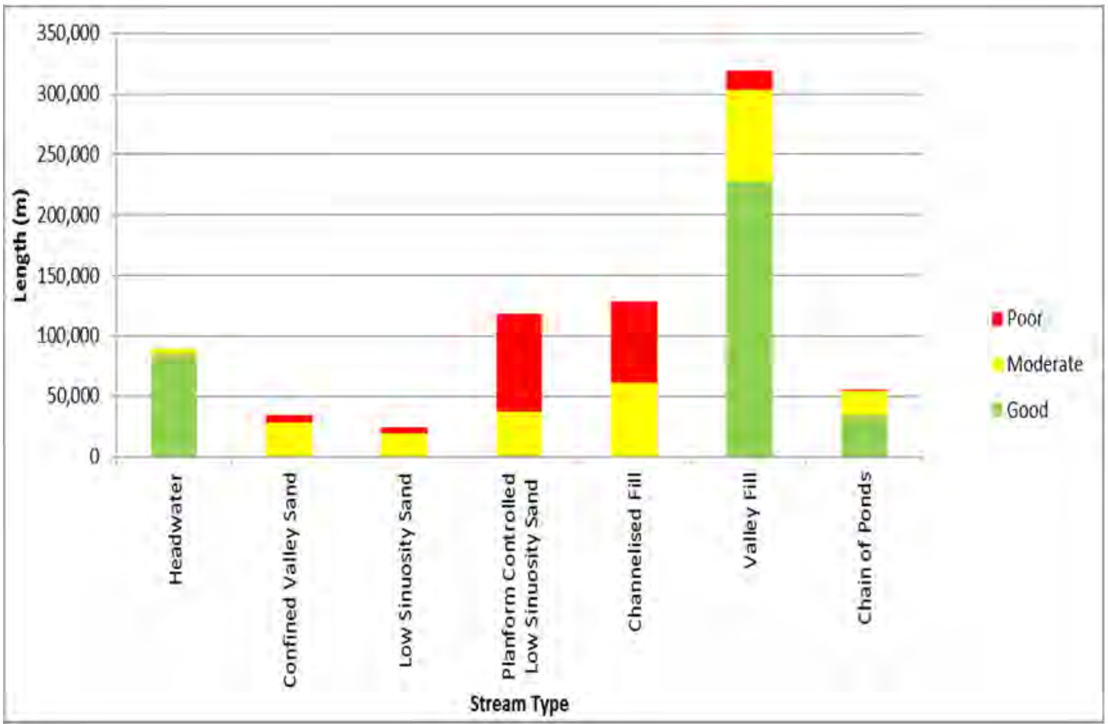


Figure 4-35 Length of geomorphic condition of watercourse by stream type

In respect to the following key three key river characteristics over three spatial and temporal scales (being minimal, localised and significant):

- Channel attributes – dimensions and geometry.
- River planform – sinuosity, number of channels.
- Bed character – bedforms and bed materials.

The fragility of watercourses types identified in the study area as defined by Lampert and Short (2004) is provided in Table 4-1.

Table 4-1 Fragility of watercourse types in the study area

Watercourse type	Fragility
Headwater	Low
Confined valley sand	Moderate
Channelised fill	Moderate
Partly confined low sinuosity sand	High
Low sinuosity sand	High
Valley fill	High
Chain of ponds	High

The above understanding of watercourse fragility when combined with the assessment of watercourse geomorphic condition provides a framework for defining watercourse geomorphic disturbance risk. This risk framework is displayed in Table 4-2 such that higher disturbance risk is placed on high value (good condition) watercourses which are susceptible to disturbance (high fragility). Conversely, watercourse types with low fragility (i.e. more resilient) that are already disturbed are assigned low disturbance risk rating.

The application of applying the geomorphic disturbance risk framework to watercourses within the project area is displayed in Figure 4-20.

Table 4-2 Watercourse geomorphic disturbance risk matrix

Fragility	Condition		
	Good	Moderate	Poor
High	High	High	Moderate
Moderate	High	Moderate	Low
Low	Moderate	Low	Low

4.9 Detailed site conditions

Specific comment regarding hydrology and geomorphology conditions at key project infrastructure locations is provided in the following subsections.

4.9.1 Leewood

Facilities located at the Leewood property are detailed in Chapter 6 of the EIS, and include:

- a central gas processing facility and safety flare
- water management facilities including:
  - produced water and brine storage
  - a water treatment plant including brine treatment and salt crystalliser
  - salt storage
- optional power generation
- a telecommunication tower and other supporting infrastructure such as administration buildings.

A flood flow path traverses through the existing Leewood property from south to north. In a one per cent AEP flood event, flow depths of up to 400 mm are predicted on parts of the Leewood property under baseline conditions.

The main flow path through the Leewood site is classified as low hazard in the one per cent AEP flood event and in the 10 per cent AEP flood event. The site would be within the high hazard area in the PMF (refer to Figure 4-14) with no project infrastructure in place.

From the definitions used in this study, the floodplain at Leewood would be categorised as flood storage for the 10 per cent and one per cent AEP events. In an extreme event such as the PMF, the majority of the site would constitute a floodway.

4.9.2 Bibblewindi

Bibblewindi hosts existing infrastructure established for gas exploration and appraisal activities, including:

- compressor station
- safety flare
- water balance tank
- water storage ponds
- storage and utilities area
- staff amenities
- car parking.

The project will utilise or upgrade existing infrastructure where practicable. The existing compressor station will be replaced with expanded in-field gas compression facilities. The existing safety flare will be upgraded. The water balance tank, water storage ponds, storage and utilities area, staff amenities and car parking will be utilised in their existing form.

Bibblewindi is not located near a defined watercourse. Very minor ponding and overland flow is predicted at the site under existing conditions. During the PMF, shallow depth ponding is expected at Bibblewindi around the existing ponds. The northern extent of the site remains flood free.

4.9.3 Bibblewindi to Leewood infrastructure corridor

A new underground medium pressure gas pipeline, a water pipeline, and underground power and communication lines would be constructed between Bibblewindi and Leewood parallel to the existing water and gas pipelines, which would continue to be utilised.

The infrastructure corridor would be widened to 30 metres to accommodate construction of the new infrastructure and the intermediate gas pipeline would be enclosed within a nominal 900 mm diameter pipe for the section of the route beneath the Newell Highway.

The Bibblewindi to Leewood infrastructure corridor crosses Bohena Creek including parts of the watercourse defined as moderate risk. The infrastructure corridor also crosses several minor (stream order 1 and 2) watercourses and overland flow paths with potential to flood during periods of high rainfall.

4.9.4 Leewood to Wilga Park infrastructure corridor

A new underground power line would be constructed between Leewood and Wilga Park power station in an existing corridor parallel to an existing underground gas pipeline. The new power line will fit within the existing corridor.

No crossings of watercourses are proposed along the alignment. The corridor would cross potential overland flow paths which would be part of the surface water management considerations during construction.

4.9.5 Westport workers' accommodation

There is existing approval for accommodation of 64 workers at the Westport workers' accommodation and it is proposed to expand this capacity under the project. As detailed in the project description (EIS Chapter 6), Westport would consist of:

- demountable buildings providing sleeping quarters
- kitchen and dining room facilities and a recreation room
- other utility rooms for storage, cooling and laundry facilities
- a series of tanks for water and diesel storage.

The existing and proposed infrastructure at Westport is predicted to be outside the one per cent AEP flood event and the area is mostly at levels above the one per cent AEP flood level plus 500 mm' level.

A portion of the proposed expansion area in the north east corner is classified as flood prone (within the extent of the PMF).

During the PMF, the Westport site is predicted to be a "high flood island", which is a location which remains dry (except where noted above) but without an evacuation route. This is discussed further in the following section.

5. Impact assessment

5.1 Overview

This section provides an overview of the potential impacts. It also includes assessment against, and discussion of, the Field Development Protocol (FDP) with relevance to the potential impacts. The risk locations and quantum of impact is dependent on siting of project infrastructure. The exact locations of new wells, access tracks and gathering lines are subject to the application of the Field Development Protocol. Therefore, typical risks and mitigation measures were identified that are applicable to the project area. Further micrositing would be undertaken consistent with the method in the Field Development Protocol to confirm the appropriate site-specific mitigation measures.

As noted earlier in this report, this impact assessment excludes hydrological and geomorphological impacts associated with the proposed managed surface water discharge to Bohena Creek. Such impacts are addressed in *Narrabri Gas Project: Managed Release Study (Bohena Creek)* (refer to Appendix G1).

Activities with the potential to result in impacts to flooding and watercourse geomorphology throughout the project lifecycle have been considered including:

- Exploration including seismic activities.
- Construction of project infrastructure including:
  - Gas field infrastructure
  - Leewood facilities
  - Bibblewindi facilities
  - Westport workers' accommodation
  - The Leewood to Bibblewindi infrastructure corridor
  - The Leewood to Wilga Park infrastructure corridor
- Decommissioning activities including stockpiling and possible removal linear infrastructure.

A risk assessment of potential impacts is incorporated in section 6 of this report.

5.2 Field Development Protocol

Potential impacts to hydrology and geomorphology from the project were assessed with consideration of the Field Development Protocol (FDP).

The FDP provides the following provisions relevant to watercourses and hydrology and applies to siting of gas wells and supporting infrastructure (gathering lines, tracks and in field water management and compression facilities):

- Large ponds and dams will be located outside of the one per cent AEP to ensure long term protection of these assets and to minimise impact from the project on surface flow during large flood events.
- All other field infrastructure and activities located in accordance with the FDP will be designed and installed to ensure that where they occur within the one percent AEP, including areas of high hazard, there will be negligible modification of flows and necessary sediment and erosion controls will be implemented, and no ongoing impacts to geomorphology.

- Non-linear infrastructure would be excluded from riparian corridors, at set back distances commensurate with the stream order.

All other activities may be permitted with relevant management plans. The management plan considerations are addressed in the following sections.

The riparian corridors were determined by Ecological Australia and are assessed in Appendix G1 for the managed release.

5.3 Potential impacts

5.3.1 Catchment hydrology and hydraulics

There is potential for the proposed works to result in changes to the velocity, location and magnitude of floods and flood characteristics due to the construction or operation of infrastructure within flood prone areas if not suitably managed.

Potential risks and impacts that may occur within the project area include the following:

- Increased flood risk to downstream people and property due to reduction in available floodplain storage or alteration of existing flood flow paths.
- Risk of damage to site infrastructure due to inundation.
- Risk of geomorphological impact due to changes in hydrological regime.
- Flood risk to users of the site particularly during construction; including pipeline trenching operations.
- Potential geomorphological impacts should flooding occur during construction causing disturbance to construction stockpiles or sediment.
- Changes to surface conditions through increases in impermeable area or reduction in grassed area (Leewood for laydown areas and infrastructure), vegetated areas (Bibblewindi for laydown areas and infrastructure) and well pads across the gas field. This may potentially increase flow concentrations. The net change to the existing land surface across the project area is minor compared to the project area as a whole and there are no regional impacts on flooding predicted. However, there is potential for localised increased concentration of flows where significant localised clearing of vegetation may result in a reduction in surface resistance.

In relation to the potential for project infrastructure to impact flood conditions, well pads will be at-grade in areas vulnerable to flooding and would therefore be unlikely to increase flood levels. An increase in flood level or flow with the potential to affect flooding of residences is considered relevant in relation to establishment of new access tracks, particularly in the low-lying agricultural areas in the project area’s north west. Access tracks would typically follow the existing topography rather than being formed as raised embankments and, in such circumstances, are unlikely to impact flood levels or flow. However, if access track embankments cut off, divert or otherwise influence overland flow paths, this has the potential for localised increases in flood risks.

5.3.2 Watercourse geomorphology

Impacts to watercourse geomorphology associated with project activities may include:

- Disturbance to bed and banks of watercourse channels.
- Disturbance to floodplains.
- Stream bed degradation.

- Stream bank erosion.
- Scour potential from poor choice in pipeline alignment or poor pipeline construction.

5.4 Leewood

A site specific hydraulic modelling assessment of the existing and proposed infrastructure at Leewood was carried out.

The assessment included incorporation of a raised pad for the proposed gas processing facility and proposed produced water and brine ponds and their potential to affect flood flows and infrastructure.

The results in a 10 per cent AEP and a one per cent AEP event are provided in Figure 5-1 and Figure 5-2 respectively. In a 10 per cent AEP event, the peak increase in flood levels is similar to that in the one per cent AEP event, though the extent of predicted flood level increase is reduced. A positive value indicates an increase in flood level between the existing scenario and the proposed scenario, whilst a negative value indicates a decrease. The results show very limited change in flood levels (known as afflux) as a result of the proposed gas processing facility at Leewood in the one per cent and ten per cent AEP events. Localised increases in level of generally between 20 mm and 150 mm are predicted on the Leewood property at the south-west extent of the proposed gas processing facility.

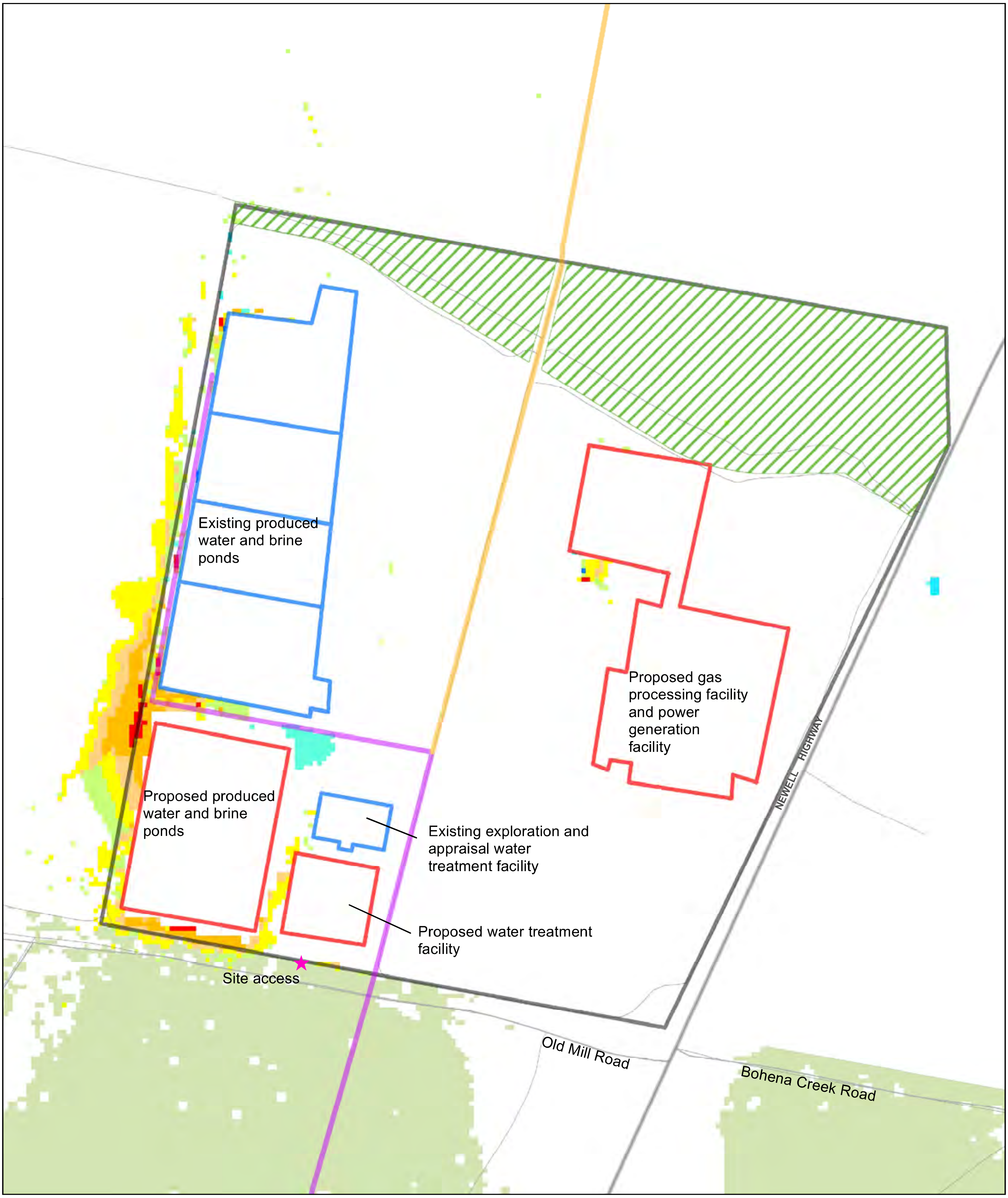
Regional flood impact from the project infrastructure at Leewood is considered to be minimal, with changes in flood levels having dissipated to less than 50 mm in some isolated areas downstream of the Leewood site as shown on Figure 5-1 and Figure 5-2.

The proposed water and brine ponds have the effect of increasing flood levels on the site along the western extent of both the existing and proposed ponds. Increases in flood levels are generally less than 250 mm, with a small area of up to 330 mm near the property boundary in the one per cent AEP event. Predicted increases in flood level are similar in a 10 per cent AEP event. The affected area is currently vegetated with no residences or other buildings in place. The only residence nearby is located on the property to the west of Leewood and is outside the one per cent AEP flood extent but within the extent of the PMF.

The Narrabri Shire Council Local Environmental Plan (LEP), 2012, Clause 6.2 “Flood Planning” describes the requirements for developing in a flood planning area. The associated flood maps do not define the Leewood property or adjacent properties as within this area. However, the clause gives an indication of the flood planning considerations that would be applied in the area through a local government assessment process. The clause states that development should not “significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties”. The proposed ponds are not considered to affect flood affectation of the residence on the adjacent property. Access to the residential property is from the west via Dog Point Road and negligible flood level increases are expected to this road in a one per cent AEP event.

The increase in flood levels at Leewood will result in increased velocities along the pond wall bunds. Consideration of requirements for scour and erosion protection on the pond bunds should be incorporated into the pond management plans.

Figure 5-3 to Figure 5-5 show the post-developed hazard and hydraulic categories at Leewood. Apart from minor redistribution of classifications within the site, the results are largely unchanged from the baseline conditions.



LEGEND

- Leewood
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Existing facilities

Leewood Infrastructure

- Proposed infrastructure
- Approved water treatment (Not constructed)
- Brigalow

Proposed use of existing infrastructure corridor

- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor

Change in Flood Level (mm)

- <-300mm
- -300mm - -200mm
- -200mm - -150mm
- -150mm - -100mm
- -100mm - -50mm
- -50mm - +50mm
- +50mm - +100mm
- +100mm - +150mm
- +150mm - +200mm
- +200mm - +300mm
- +300mm - +400mm
- +400mm - +500mm
- > 500mm

0 0.075 0.15 0.3
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 07 Dec 2016

Post Developed 10% AEP Afflux at Leewood

Figure 5-1

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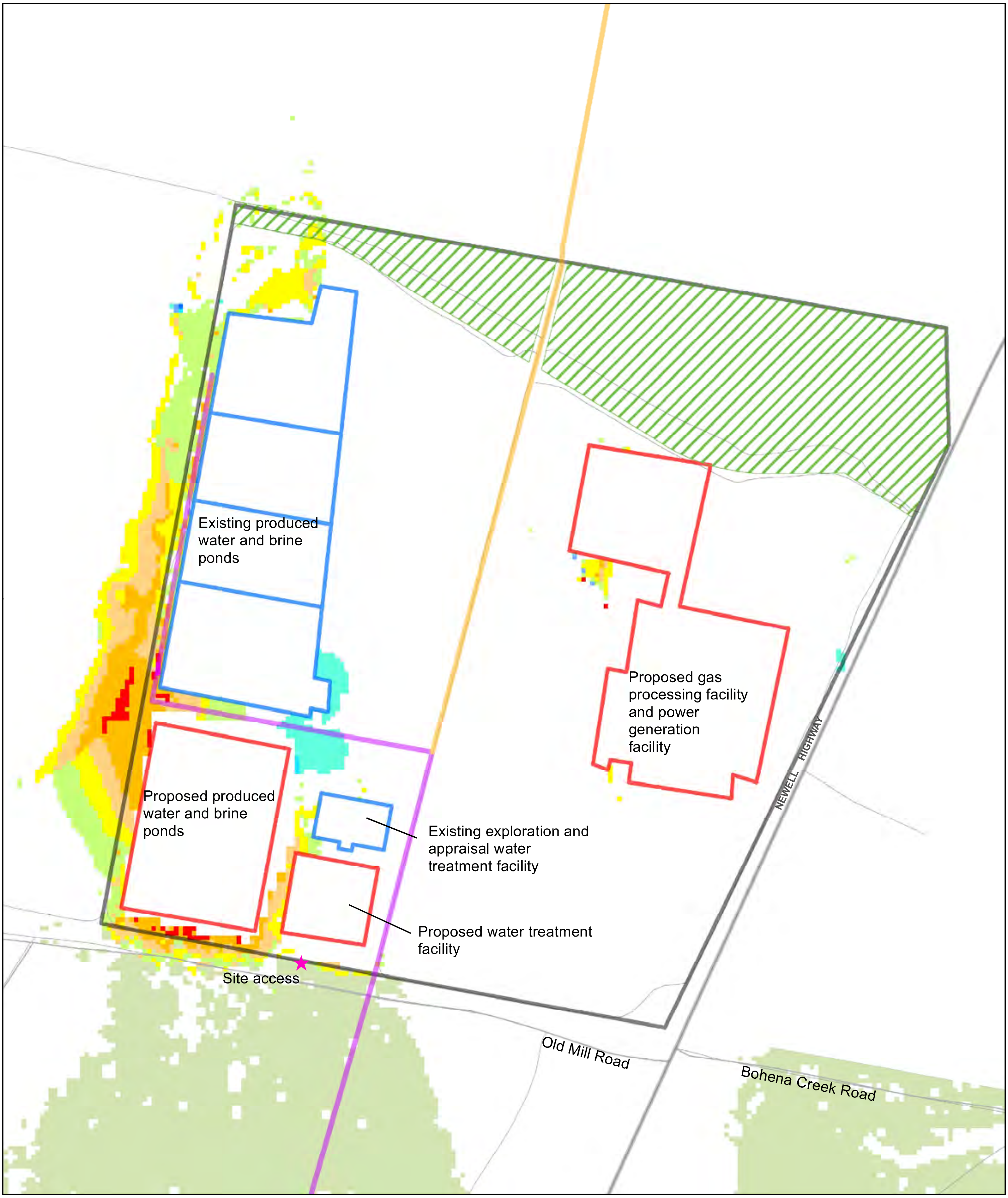
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Leewood
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Existing facilities

Leewood Infrastructure

- Proposed infrastructure
- Approved water treatment (Not constructed)
- Brigalow

Proposed use of existing infrastructure corridor

- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor

Change in Flood Level (mm)

- <-300mm
- -300mm - -200mm
- -200mm - -150mm
- -150mm - -100mm
- -100mm - -50mm
- -50mm - +50mm
- +50mm - +100mm
- +100mm - +150mm
- +150mm - +200mm
- +200mm - +300mm
- +300mm - +400mm
- +400mm - +500mm
- > 500mm

0 0.075 0.15 0.3
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 07 Dec 2016

Post Developed 1% AEP Afflux at Leewood

Figure 5-2

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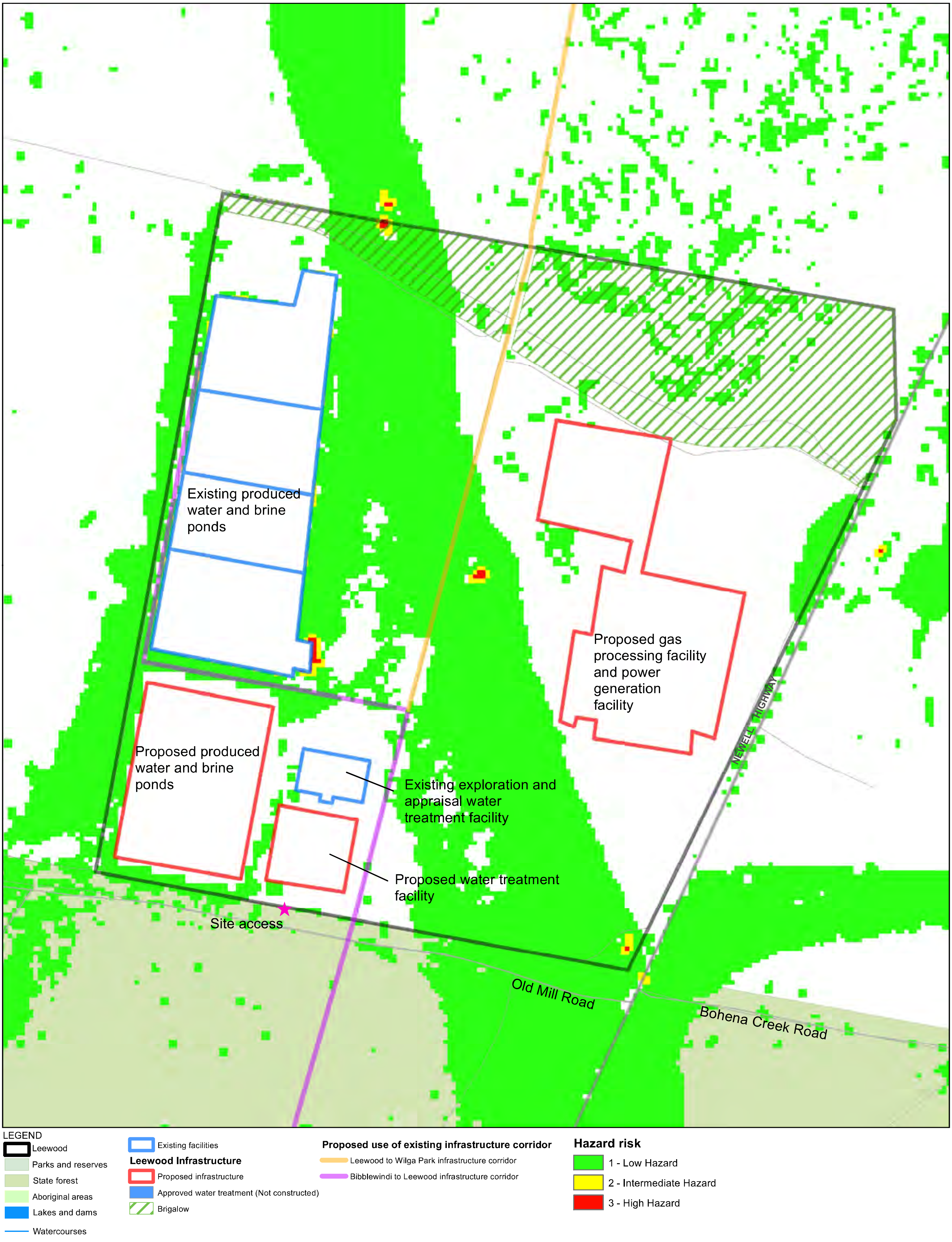
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 06 Dec 2016

Post Developed
10% AEP Hazard Categories at Leewood

Figure 5-3

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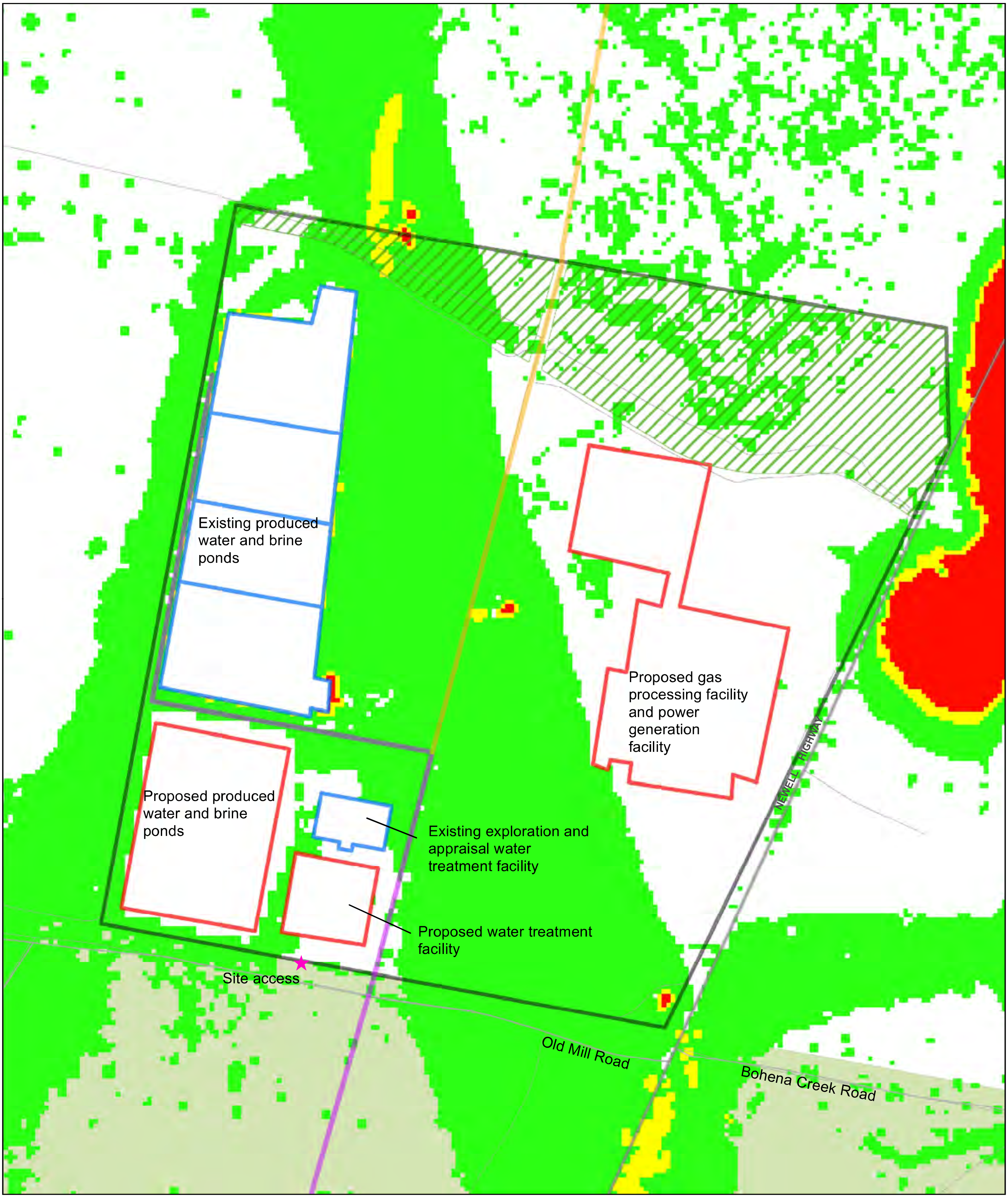
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Leewood
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Existing facilities

Leewood Infrastructure

- Proposed infrastructure
- Approved water treatment (Not constructed)
- Brigalow

Proposed use of existing infrastructure corridor

- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor

Hazard risk

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard

0 0.075 0.15 0.3
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number	21-22463
Revision	A
Date	05 Dec 2016

Post Developed
1% AEP Hazard Categories at Leewood

Figure 5-4

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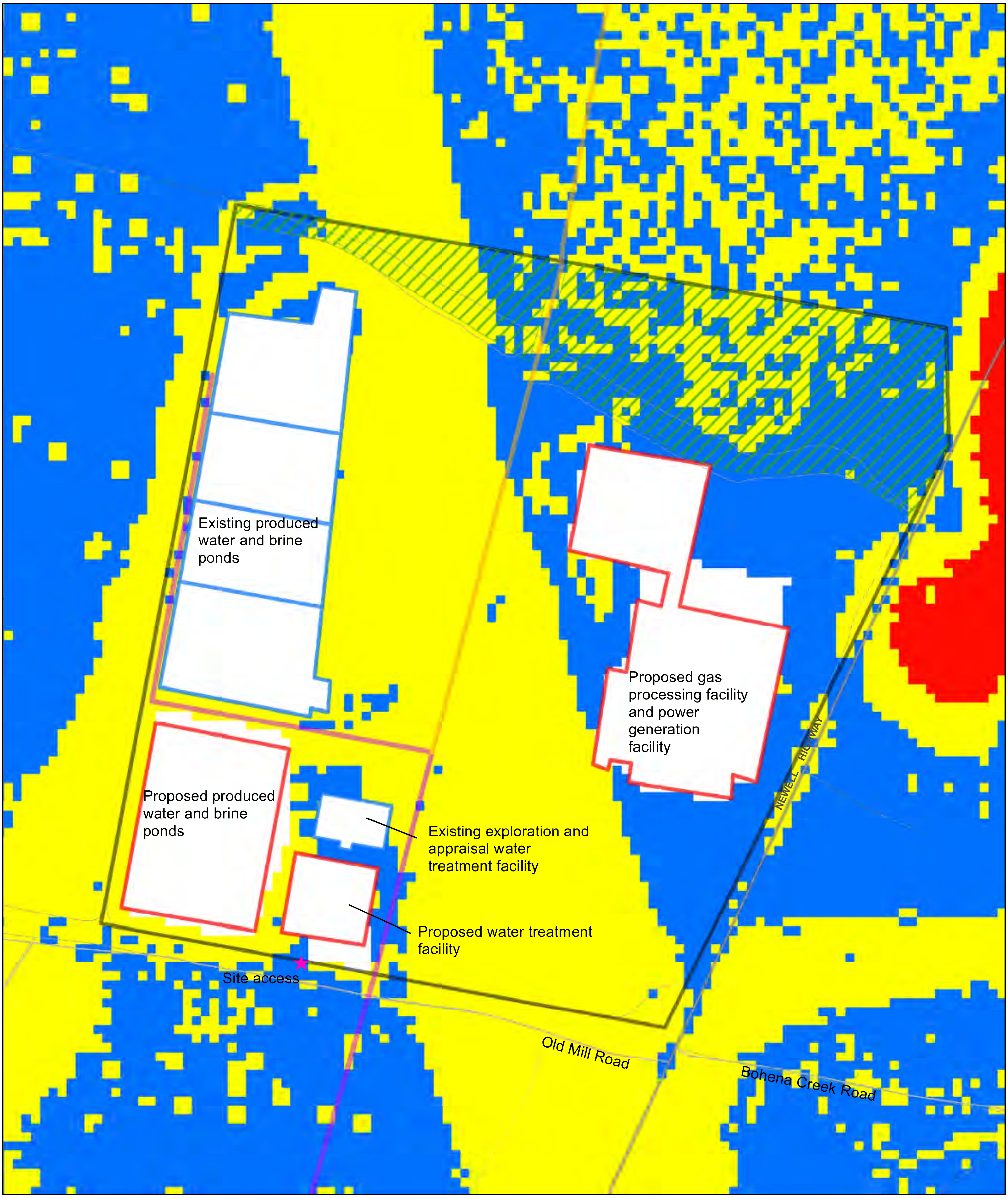
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Leewood
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Existing facilities

Leewood Infrastructure

- Proposed infrastructure
- Approved water treatment (Not constructed)
- Brigalow

Proposed use of existing infrastructure corridor

- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor

Hydraulic Category

- 1 - Flood Fringe
- 2 - Flood Storage
- 3 - Floodway

0 0.075 0.15 0.3
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 06 Dec 2016

Post Developed Hydraulic Categories at Leewood

Figure 5-5

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy

5.5 Bibblewindi

Flood modelling of the Bibblewindi infrastructure shows that it is subject to minor flooding of less than 100 mm during the one per cent AEP event. Current plans largely make use of the existing infrastructure, expanding it where necessary. It is not expected that minor changes would substantially impact flood flows. However, as detailed site plans are developed, hydraulic analysis of proposed site changes should be carried out.

Due to its position high up in a relatively small local catchment, advance warning of an extreme (PMF) flash flood would not necessarily be available a long time in advance and evacuation may not be possible. Appropriate emergency response measures would need to be developed to address the flooding characteristics at the site. These may include responses such as sheltering in place in parts of the site that are not flood prone until the flood waters recede.

5.6 Bibblewindi to Leewood Infrastructure Corridor

Potential impacts associated with watercourse crossings are documented in section 5.3.2. Corridor planning and design should identify the specific site risks at watercourse crossings and management measures implemented to address potential impacts.

5.7 Leewood to Wilga Park Power Line

The Leewood to Wilga Park Power line is not expected to pass beneath creeks and hence geomorphological impacts are not expected. Potential impacts on surface water would be associated with stormwater runoff during construction and potential mobilisation of sediments. This would be managed through the implementation of typical sediment and erosion controls on site.

5.8 Westport workers' accommodation

The proposal to increase accommodation at the Westport site do not include expansion into areas that are within the one per cent AEP flood extent. In the event of an extreme flood (the PMF), evacuation of the site would not be possible unless carried out in advance of the flood event occurring due to the expected flooding of surrounding access routes.

6. Risk assessment and mitigation

6.1 Overview

This section provides an initial and residual risk assessment along with proposed avoidance, mitigation and management measures to address the potential impacts on flooding and watercourse geomorphology from project activities assessed herein.

6.2 Risk assessment

An assessment of the initial risk, together with the residual risk remaining following implementation of mitigation measures has been carried out and is documented in Table 6-2. The initial risk considers application of the Field Development Protocol, which has been iteratively developed throughout the impact assessment process and applied to this primary risk assessment. The Protocol aims to ensure that the development of the project, particularly the siting of infrastructure, minimises the impact of the project on the environment in accordance with the environmental management measures and limits outlined in the EIS.

The risk assessment method was described in Section 2.7. In considering the initial risk in Table 6-2, the following was applied as drawn from the Protocol:

- Riparian buffer zone considerations when siting wells. Riparian corridors were determined in accordance with the riparian corridor widths detailed in Table 6-1 (and shown in Figure 10-1 of Appendix C); consistent with the NSW Guidelines for riparian corridors on waterfront land (NSW Office of Water 2012). Non-linear infrastructure and large ponds and dams will be excluded from these buffers.

Table 6-1 Riparian corridor widths

Strahler Order	Riparian corridor width
1st order	20 m plus channel width
2nd order	40 m plus channel width
3rd order	60 m plus channel width
4th order and greater	80 m plus channel width

- Large ponds and dams will be located outside of the one percent AEP event to ensure long term protection of these assets and to minimise impact from the project on surface flow during large flood events.
- All other infrastructure and activities located in accordance with the Protocol will be designed and installed to ensure that where they occur within the one percent AEP event, there will be negligible modification of flows and necessary sediment and erosion controls will be implemented, and no ongoing impacts to geomorphology. Activities within the one percent AEP event will be planned and constructed in accordance with the commitments and mitigations in Appendix H of the EIS, and the ESCP.

Additional management and mitigation measures were the adopted as required to lower the initial risk when assessing the residual risk.

Table 6-2 Risk assessment of potential impacts

Risk	Potential cause	Description of consequence or potential impact	Project Phase	Inherent design standards and operational practices applied	Likelihood	Consequence	Initial Risk rating	Site / activity specific mitigation measures / management plans to reduce risk	Residual Risk rating		
Earthworks and watercourse crossings – low, moderate and high risk watercourses	Construction works in ephemeral watercourses Operation / use of inappropriately designed and/or constructed linear infrastructure at watercourse crossings	Destabilise watercourse banks due to removal of riparian vegetation or direct disturbance resulting in erosion and sediment mobilisation, changes to hydrology and watercourse geomorphology.	Construction Operation	All other infrastructure and activities located in accordance with the Protocol will be designed and installed to ensure that where they occur within the one per cent AEP event, there will be negligible modification of flows and necessary sediment and erosion controls will be implemented, and no ongoing impacts to geomorphology.	Unlikely	Moderate	Medium	. Selection of watercourse crossing points will, where practical: • use existing vehicular crossings be located on straight sections of channel • maximise avoidance of steep, unstable banks, permanent pools and waterholes. Erosion and sediment control measures will be implemented during construction of watercourse crossings. Construction of watercourse crossings would occur during periods of no flow in the watercourse. Vehicular crossing will be designed and constructed to include appropriate stabilisation.	Unlikely	Minor	Low

Risk	Potential cause	Description of consequence or potential impact	Project Phase	Inherent design standards and operational practices applied	Likelihood	Consequence	Initial Risk rating	Site / activity specific mitigation measures / management plans to reduce risk	Residual Risk rating		
Project infrastructure placement	Inappropriate design of field/major infrastructure Inappropriate placement of field/major infrastructure	Changes to hydrology and watercourse geomorphology through alteration of surface flow paths. Changes to the frequency, extent or depth of flooding on the floodplain environment. Changes to watercourse velocity. Changes to flooding characteristics resulting in loss of floodplain/storage and significant impact on other neighbouring properties through increased flood levels / flood risk Geomorphological changes such as watercourse headcutting results in exposure of project infrastructure such as Bohena Creek managed release outfall or pipeline crossings. Placement of work sites / operations in floodplain resulting in impacts to flood access and evacuation	Design, construction and operation	Implement riparian buffer zones Large ponds and dams will be located outside of the one per cent AEP event to ensure long term protection of these assets and to minimise impact from the project on surface flow during large flood events. All other infrastructure and activities located in accordance with the Protocol will be designed and installed to ensure that where they occur within the one per cent AEP event, there will be negligible modification of flows and necessary sediment and erosion controls will be implemented, and no ongoing impacts to geomorphology.	Unlikely	Moderate	Medium	Selection of watercourse crossing points will, where practical: • use existing vehicular crossings be located on straight sections of channel • maximise avoidance of steep, unstable banks, permanent pools and waterholes. Crossings within the one in 100-year flood zone will be designed for negligible modification of flood flows. Erosion and sediment control measures will be implemented during construction of watercourse crossings. Vehicular crossing will be designed and constructed to include appropriate stabilisation. Infrastructure within the one in 100-year flood zone in the vicinity of residential dwellings will be designed for negligible modification of flood flows. The managed release activity will be undertaken in a manner that minimises erosion of the bed and banks at the release point and the build-up of sediment at that location. The Water Monitoring Plan (Appendix G3) will be implemented.	Unlikely	Minor	Low

6.3 Mitigation measures

The risk assessment shown in Section Table 6-2 indicates that with the implementation of the Field Development Protocol, and the introduction of other specific management and mitigation strategies, hydrology and geomorphologic risks are reduced to a residual risk of low.

In addition to the those management and mitigation measures specified in the Field Development Protocol as shown in Section Table 6-2, the mitigation measures presented in Table 6-3 would be applied and would become project commitments.

Table 6-3 Management and mitigation: hydrology and geomorphology

Management / mitigation
Crossings within the one in 1% AEP flood zone will be designed for negligible modification of flood flows.
Infrastructure within the one in 1% AEP flood zone in the vicinity of residential dwellings will be designed for negligible modification of flood flows.
Selection of watercourse crossing points will, where practical: • use existing vehicular crossings • be located on straight sections of channel • maximise avoidance of steep, unstable banks, permanent pools and waterholes.
Erosion and sediment controls would be implemented during construction of watercourse crossings.
Construction of watercourse crossings would occur during periods of no flow in the watercourse.
Vehicular crossings would be designed and constructed to include appropriate stabilisation.
The managed release activity will be undertaken in a manner that minimises erosion of the bed and banks at the release point and the build-up of sediment at that location.
The Water Monitoring Plan (Appendix G3) will be implemented.

** Note: 1% AEP is used in this report and is equivalent to 100 year (ARI) event used in the project commitments chapter*

6.4 Other considerations

6.4.1 General

The following should also be considered during project design, construction, operation and decommissioning and rehabilitation as it relates to hydrology and geomorphology:

- Large ponds and dams should be designed to accommodate (at a minimum) a one per cent AEP storm event, and also manage an average three-month wet season.
- Siting of infrastructure would be carried out with reference to the one percent AEP flood extent, including consideration of potential for downstream impacts, particularly for flood affectation to residences within the project area.
- Inclusion of flood warning and management in the appropriate management plan for the project area for construction and operational stages, including appropriate emergency management procedures for those areas located within the PMF.

- The management of potential localised scour as a result of construction and operation of the well pads would be addressed in the Erosion and Sediment Control Plan (ESCP), which would be consistent with *Managing Urban Stormwater: Soils and Construction* (Volume 1) - “The Blue Book”.
- Culvert design, as required, should be consistent with the procedures in *Australian Rainfall and Runoff* (Book 7, 2001).
- Decommissioning and rehabilitation of linear infrastructure would be carried out in accordance with the project’s Decommissioning Report and Rehabilitation Plan; including monitoring and maintenance.

6.4.2 Watercourse crossings

Vehicular watercourse crossings would be fords (crossings level with the watercourse bed) which are suitable for ephemeral watercourses within the project area. The surface of frequently used ford crossings would be constructed using erosion resistant material such as interlocking angular rock for example.

Mitigation of watercourse crossing risk would be through good design, location, construction techniques and timing of construction. Watercourse crossings would only be constructed during periods of no flow in the watercourse.

The selection and planning of watercourse crossings will be aided by the watercourse geomorphology assessment, which includes GIS mapping of watercourse geomorphology disturbance risk.

In particular, unchannelised geomorphic watercourse types (Chain of ponds and Valley Fill), are sensitive to disturbance and concentration of flow can lead to the development of a continuous channel. The primary mitigation measure would be to avoid disturbing such watercourse types by identifying them at the planning stage and seeking alternative locations for project activities where possible. If project activities such as pipeline and track crossings must be located such that they will cross or disturb these watercourse types, the additional mitigation measures will need to be considered, together with site specific assessment and development of mitigation measures as required.

7. Conclusion

This Hydrology and Geomorphology Assessment identifies the potential environmental issues associated with construction, operation and decommissioning of the Narrabri Gas Project in respect to the specific hydrology and geomorphology components of the Secretary's environmental assessment requirements for the project (see section 3.2.1).

Project activities that have the potential to result in environmental impacts to hydrology and watercourse geomorphology are:

- Site selection for project facilities and infrastructure where facilities are to be located within the one per cent AEP flood extent or otherwise interfere with watercourses.
- Construction activities including installation of field infrastructure (predominantly wells, access tracks and water and gas gathering lines)
- Construction of water and gas treatment and processing, and gas compression facilities at Leewood and Bibblewindi respectively.
- Construction of gas and water pipelines between Leewood and Bibblewindi; including watercourse crossings.
- Construction of large ponds and dams.
- Decommissioning activities including stockpiling and the removal of gas and water gathering lines at watercourse crossings.

Potential unmitigated impacts include:

- Erosion and generation of sediment during construction, operation and decommissioning.
- Increases in watercourse bed and bank erosion in flow events.
- Initiation of erosion heads along reaches of unchannelised watercourses leading to the development of a continuous channel.
- Changes in on-site and off-site flooding behaviour.

A number of mitigation measures and impact avoidance strategies have been considered in section 6.

As the project develops and planning and design are furthered, site specific details for infrastructure installation should be contemplated in accordance with the Field Development Protocol, with appropriate additional mitigation measures identified and implemented.

With the application of the avoidance, mitigation and management measures described herein, the impacts from project activities can be managed to reduce residual impacts from site activities to a very low or low level.

8. References

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Appendices

Appendix A – Flood Study

Santos Ltd

Narrabri Gas Project – Environmental Impact Statement

Flood Study

December 2016

Table of contents

Table index

Figure index

Disclaimer

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1. Introduction

1.1 Background

The Narrabri Gas Project (or simply, the project) would be located in north-western NSW, approximately 20 kilometres south-west of Narrabri, within the Narrabri local government area (LGA) as shown in Figure 1-1. The project lies within Petroleum Exploration Licence (PEL 238 and Petroleum Assessment Lease (PAL) 2 as described in Chapter 6 of the EIS.

1.2 Purpose of This Report

The purpose of this flood study is to determine the extent of flooding under existing conditions as well as to inform the Narrabri Gas Project – Environmental Impact Statement, Hydrology and Geomorphology technical report. The primary objectives of this flood study are to:

- Develop hydrologic and hydraulic models of the contributing catchment and associated floodplain across the entire assessment lease, and
- Develop flood level, depth and velocity maps for the 10 per cent and one percent Annual Exceedance Probability (AEP) flood events as well as the Probable Maximum Flood (PMF) event.

1.3 Scope and Limitations

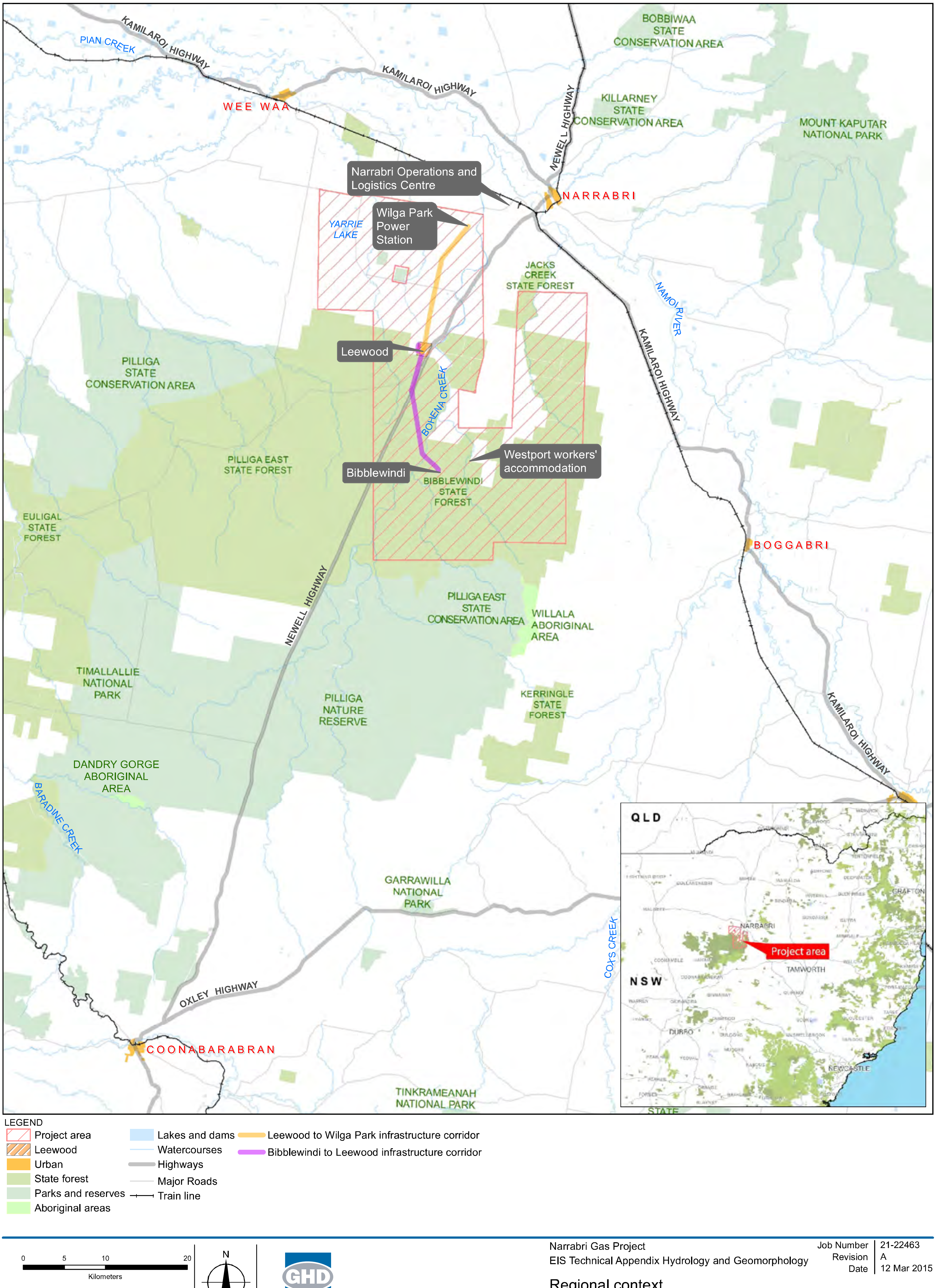
The scope of works included modelling of the 10 per cent, one per cent AEP and PMF events for the site under existing conditions and limited modelling of proposed infrastructure at the Leewood site based on preliminary concept plans. A regional flood model for the project area was prepared and later refinements to the model were made for a site specific model of the Leewood site.

1.4 Assumptions

The main assumption made in this report relates to the accuracy of the data provided. In particular, on the accuracy of:

- the rating curve at the calibration gauge
- the accuracy of the measured rainfall depth
- the accuracy of the LiDAR data
- the correct estimation of the Bureau of Meteorology Intensity Frequency Duration (IFD) rainfall depth for the 10 per cent and one per cent AEP events.

Additionally, there are limitations in the representation of the PMF given the large project area and the variability in size and nature of catchments across the site.



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 12 Mar 2015

Regional context
and location of key infrastructure

Figure 1-1

C:\Users\AFoddy\Desktop\21_22463_KBM29.mxd [KBM: 222]

Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

2. Data Collection

The following data was obtained and used to complete the study:

- Aerial photography.
- Topographic survey.
- Rainfall, stream flow and rating curve data.
- Previous reports.

The details associated with each one of these items are provided below.

2.1 Aerial Photography

Aerial photography of the proposed development site was obtained online from www.arcgis.com. The aerial picture helped inform the extent of the land use categories.

2.2 Topographic Data

The following topographic data sets were obtained for this flood study and were used in development of the hydraulic model:

- LiDAR data sets provided by Santos on a one kilometre square grid.
- The 10 metre contour line from the (then) NSW Department of Environment and Resource Management (DERM).

2.3 Historic flooding

Based on available flow records at a gauge located on Bohena Creek, the highest flows on Bohena Creek were recorded during 1996, 1998, 2000, 2004 and 2010. The largest event recorded occurred in 1998. It is also understood from local emergency planning documents that inflows from Bohena Creek played a significant role on flooding downstream on the Namoi River due to backwater effects in the town of Narrabri during the floods of 1984, though no flow records on Bohena Creek are available for this event.

2.4 Rainfall Data

Within a 100 kilometre radius of Narrabri there are 13 rainfall stations recording rainfall depths at a 3-hour interval, however only 5 stations were opened to record the rainfall depth in the 1998 calibration event. The locations of the open rainfall stations are indicated in Figure 2-1 while the available pluviograph data are listed in Table 2-1.

Table 2-1 Pluviograph Rainfall Data Availability (sub-daily data)

Station No	Station Name	Source	Period of 3-hour Record-First	Period of 3-hour Record-Last	1998 event	Data usable
053030	Narrabri West Post Office	Bureau of Meteorology	1962 Jan	2002 Jul	✓	✓
054038	Narrabri Airport Aws	Bureau of Meteorology	2001 Aug	2014 Feb	×	×
054003	Barraba Post Office	Bureau of Meteorology	1969 Jan	2014 Feb	✓	×
055202	Gunnedah Airport Aws	Bureau of Meteorology	2001 Sep	2014 Feb	×	×
055023	Gunnedah Pool	Bureau of Meteorology	1965 Jan	2011 Dec	✓	✓
055024	Gunnedah Resource Centre	Bureau of Meteorology	1965 Jan	2014 Feb	✓	✓
054004	Bingara Post Office	Bureau of Meteorology	1965 Jan	1975 Dec	×	×
053002	Baradine Forestry	Bureau of Meteorology	1986 Jan	2012 Jul	✓	✓
053027	Moree Post Office	Bureau of Meteorology	1960 Jan	1965 May	×	×
053000	Moree Autosonde	Bureau of Meteorology	2000 Jul	2001 Oct	×	×
053115	Moree Aero	Bureau of Meteorology	1995 May	2014 Feb	✓	×
053048	Moree Comparison	Bureau of Meteorology	1964 Mar	1998 Jul	×	×
064008	Coonabarabran	Bureau of Meteorology	1960 Jan	2014 Feb	✓	✓

2.5 Gridded Daily Rainfall Data

Gridded daily rainfall data was sourced from the Bureau of Meteorology. The Bureau of Meteorology provides the following description of the grid data online (available at http://www.bom.gov.au/climate/austmaps/metadata-daily-rainfall.shtm):

"The analyses (grids) are computer generated using a sophisticated analysis technique. It incorporates an optimised Barnes successive correction technique that applies a weighted averaging process to the station data. Topographical information is included by the use of rainfall ratio (actual rainfall divided by monthly average) in the analysis process.

On the maps each grid-point represents an approximately square area with sides of about 5 kilometres (0.05 degrees). The size of the grids is limited by the data density across Australia.

This grid-point analysis technique provides an objective average for each grid square and enables useful estimates in data-sparse areas such as central Australia. However, in data-rich areas such as southeast Australia or in regions with strong gradients, "data smoothing" will occur resulting in grid-point values that may differ slightly from the exact rainfall amount measured at the contributing stations".

The grids are a continuous spatial representation of daily rainfall across the Bohena Creek catchment. A review of the data shows some small spatial variability in daily rainfall across the catchment during the selected calibration events.

2.6 Stream Flow Data

The only recorded stream flow data that was available for this study is the flow gauge station 419905, Bohena Creek at Newell Highway. The location of this stream gauge is shown in Figure 2-1. This Station has recorded flow from the 1st of September 1995 onward and 18.5 years of stream flow data were available at the time of the analysis.

The length of recorded flow data is not sufficient to develop a Flood Frequency Analysis (FFA) however this data has been used to calibrate the hydrological model.

2.7 Hydraulic Structures

No hydraulic structures were included within the model at this stage.

2.8 Previous Reports

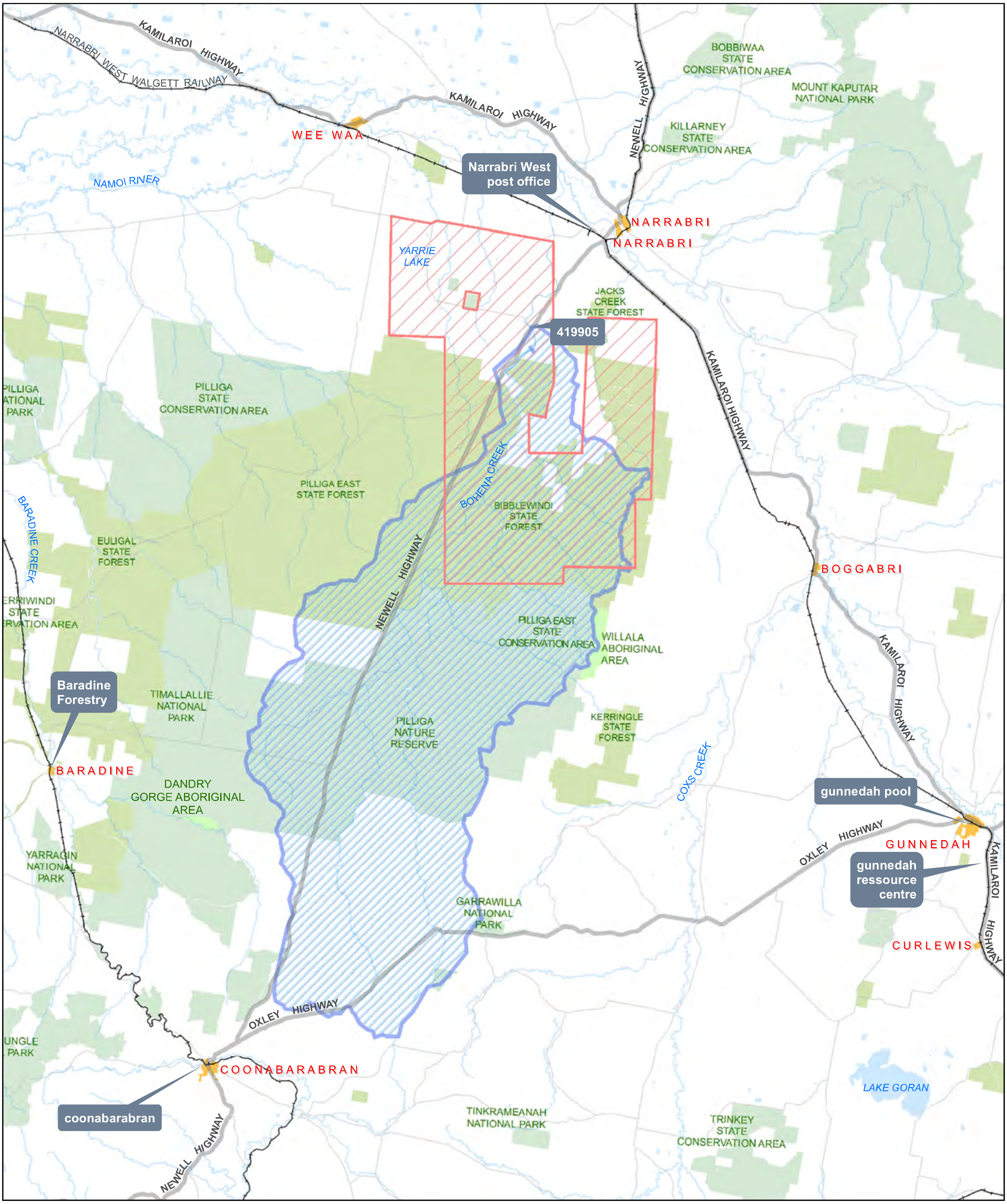
A review of previous studies associated with flooding in the project area was undertaken with a summary of key finding provided below.

Santos Narrabri Gas Project, Flood Study Assessment –Leewood ponds (Golder Associates 2013)

This report provided Santos Ltd with the flood extent associated with the 50 and 100-year Average Recurrence Interval (ARI) design event (equivalent to two per cent and one per cent AEP events respectively) on a limited area along Mollee Creek at the location of Leewood ponds. The hydrological inflow was estimated using the Rational Method on a 1,060 hectare and 2,180-hectare basis.

Narrabri Gas Project, Managed Release Study: Bohena Creek (Ecological Australia 2016)

This Managed Release Study (MRS) identifies and evaluates the potential impacts on the receiving environment associated with managed release of up to 12 ML/day of treated water to Bohena Creek and documents how Santos would avoid, manage and / or mitigate unacceptable impacts.



LEGEND

- Project area
- Urban Areas
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Flow gauging station
- Rainfall station
- Hydrological catchment

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 06 Dec 2016

Rainfall and Stream Gauge Location

Figure 2-1

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Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

3. Hydrological Model

This section presents the development of the hydrologic model for the Bohena Creek catchment.

3.1 Methodology

GHD developed a hydraulic model with a direct rainfall on grid approach over the project area to estimate the flood extent for the 10 per cent, one per cent AEP and PMF events. To estimate inflow of water into the project area, it was necessary to develop a separate hydrological model. The hydrological model was extended as far downstream as the Bohena Creek gauge for the purposes of calibration.

Key steps in the development of the calibrated model included:

- Delineation of the sub-catchment and development of the hydrological catchment network.
- Derivation of the catchment characteristics such as slope, area and roughness.
- Identification of a suitable calibration flood event from the stream gauge data records.
- Estimation of the rainfall depth from the daily rainfall grid from the Bureau of Meteorology, associated with the selected calibration event.
- Adoption of a typical rainfall pattern based on the available recorded pluviograph data.
- Calibration of the model by adjusting the rainfall loss parameters, roughness and typical flow velocity in the catchment links to provide an adequate match to the recorded data.
- Reporting on the sensitivity of the model to rainfall losses, link lag time, and roughness.
- Extraction of the Intensity Frequency Duration (IFD) curve design rainfall depths from the Bureau of Meteorology website.
- Develop the 10 per cent, one per cent AEP design hydrographs for a range of storm durations at the catchment upstream of the 2D domain model.
- Calculate PMP rainfall depths using the BoM’s Revised Generalised Tropical Storm Method (GTSMR) and Generalised Short Duration Method (GSDM), varying spatially across the catchment.
- Develop the PMP design hydrographs for the critical storm duration for Bohena Creek at the catchment upstream of the 2D domain model.

3.2 Sub-catchment Characteristics

Sub-catchment boundaries were defined from the available topographic mapping information in Figure 3-1). Key sub-catchment parameters included as input to the RAFTS hydrological model developed for the study are:

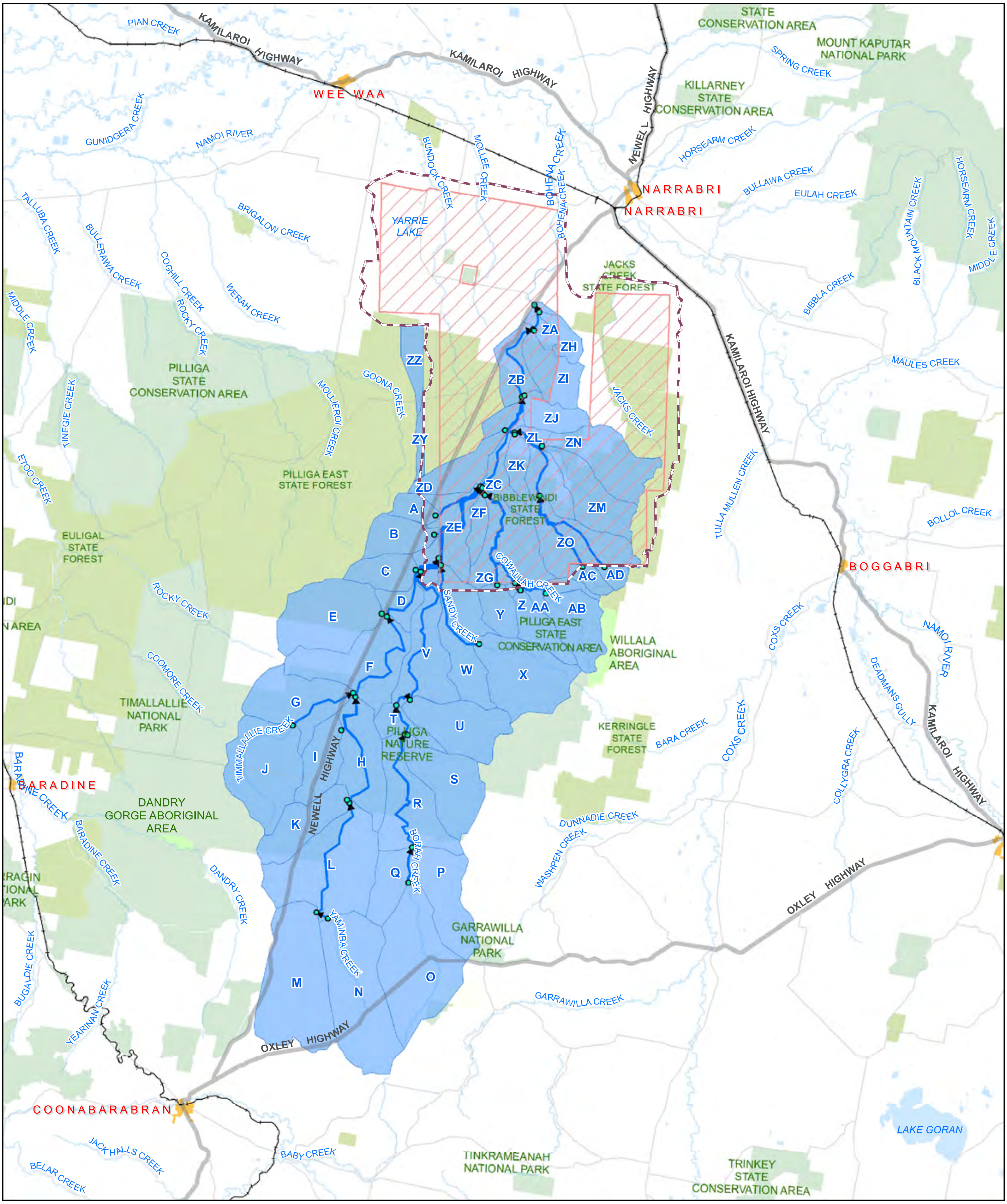
- sub-catchment area
- slope
- surface roughness
- percentage impervious.

A single rainfall loss model was adopted for the proposed catchment given that the catchment is essentially fully rural and substantially pervious. The Manning's "n" was set at a constant 0.08.

The sub-catchments were broken down into areas of relatively similar sizes between 1,043 and 11,228 hectares (ignoring catchment AD upstream of the 2D domain). The adopted sub-catchment parameters are listed in Table 3-1.

Table 3-1 Sub-catchment parameters

Name	Area (ha.)	Catchment slope (%)
A	13,46	0.75
B	2,914	0.70
C	2,635	0.82
D	2,732	0.34
E	7,727	0.69
F	7,447	0.62
G	6,082	0.64
H	5,668	0.54
I	3,443	1.24
J	8,308	1.10
K	4,304	1.31
L	10,623	0.98
M	11,228	1.11
N	11,167	1.10
O	10,563	0.89
P	5,361	0.95
Q	3,175	1.65
R	6,607	0.55
S	5,766	0.89
T	1,709	0.95
U	5,562	0.64
V	5.711	0.43
W	6.176	0.56
X	7.435	0.81
Y	2.047	0.91
Z	2.492	1.10
AA	1.593	1.11
AB	4.079	0.78
AC	1.023	1.59
AD	728	1.70
ZA	1.042	0.79
ZB	2669	0.30
ZC	3.125	0.29
ZD	3.193	0.36
ZE	3.629	0.40
ZF	1.306	0.46
ZG	5.937	0.67
ZH	1.326	0.70
ZI	3.408	0.42
ZJ	2.251	0.44
ZK	1.572	0.39
ZL	3.251	0.48
ZM	4.581	0.88
ZN	5.422	0.95
ZO	5.653	0.91



LEGEND

- Project area
- Urban Areas
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Sub-catchment Outlets
- Model streams
- Model sub-catchments
- TUFLOW Model Extent

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 06 Dec 2016

Sub catchment Map

Figure 3-1

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

3.3 Stream Gauge Data Availability

The stream gauge data at station 419905 Bohena Creek at Newell Highway was extracted from the NSW government website. Figure 3-2 shows all the recorded flow discharge. At 496 cubic metres per second (m^3/s) the highest recorded discharge occurred on the 5th of September 1998. This event has been selected as the calibration event for the current study.

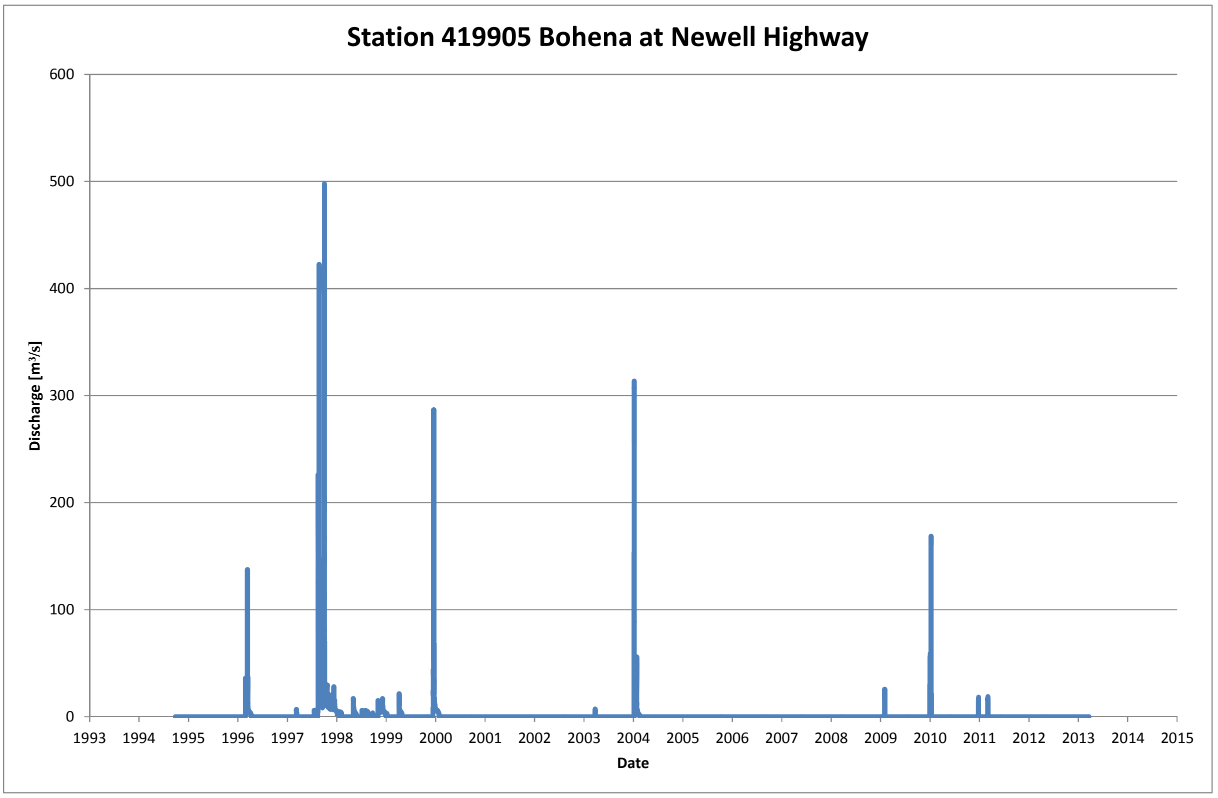
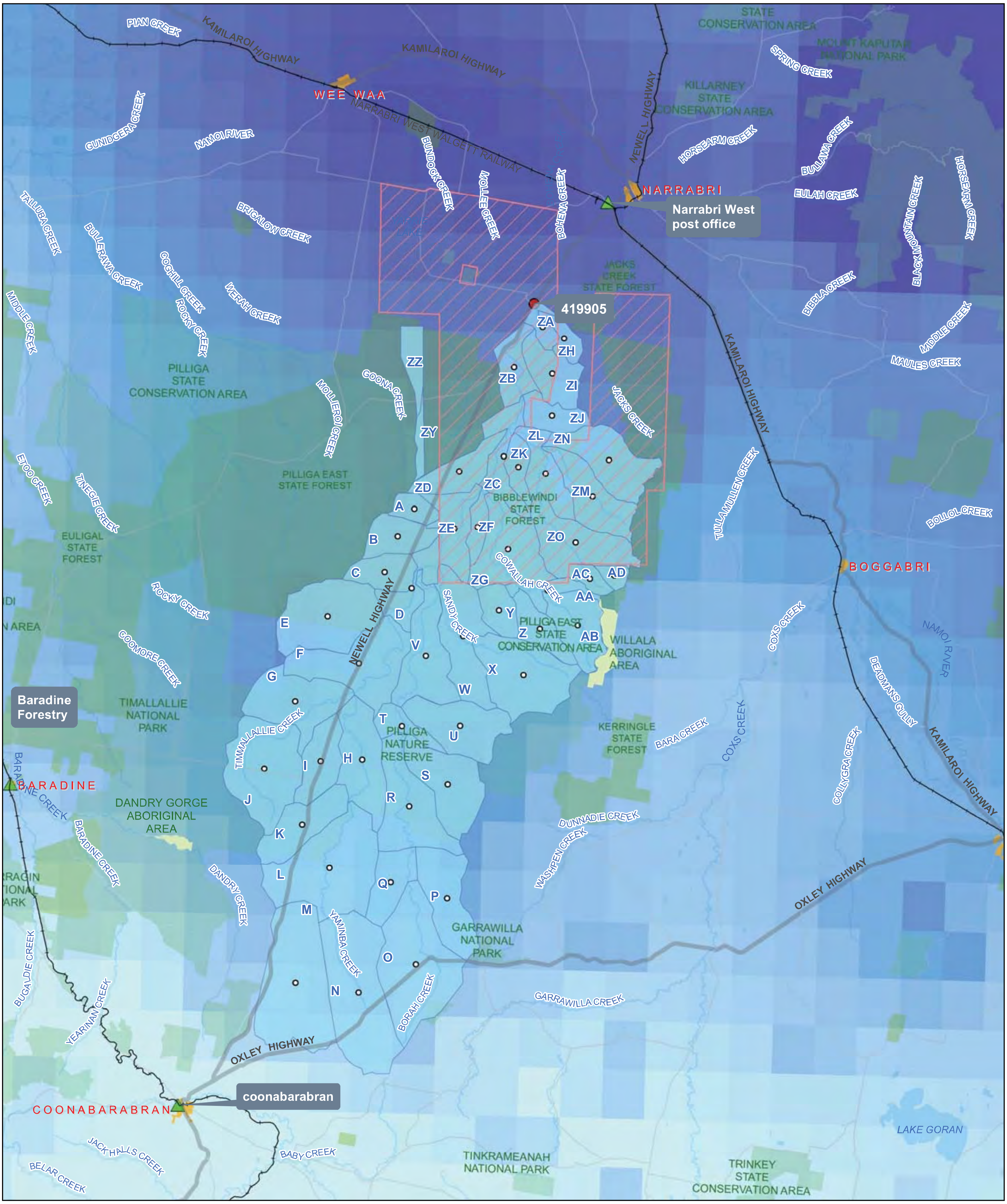


Figure 3-2 Recorded flow

3.4 1998 Rainfall Depth

The volume of rainfall that fell on the catchment was estimated by using the daily rainfall grid from the Bureau of Meteorology. At each of the centroid of the sub-catchment of the XP-RAFTS hydrological model, the rainfall depth was extracted for the 5th and 6th of September 1998. The average rainfall depth over the all catchment was 69.5 millimetres over these two days, with a maximum and minimum depth of 84 and 55 millimetres respectively. Figure 3-3 shows the measured rainfall depth over the 5th and 6th of September 1998.



LEGEND

Project area	Lakes and dams	Flow gauging station
Urban Areas	Watercourses	Centroid of catchment
State forest	Highways	Model sub-catchments
Parks and reserves	Major Roads	
Aboriginal areas	Train line	

Rainfall depth (mm)
High : 95
Low : 45

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Hydrology and Geomorphology

Job Number 21-22463
Revision A
Date 25 Jul 2016

Rainfall Depth 1998 Event

Figure 3-3

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: jrichardson

3.5 1998 Rainfall Pattern

The rainfall data available during the September 1998 event are limited. It was found that only four rainfall stations had usable data. Figure 3-4 shows the cumulative measured rainfall depth, as well as the adopted depth in the XP-RAFTS model, derived from the daily rainfall grid.

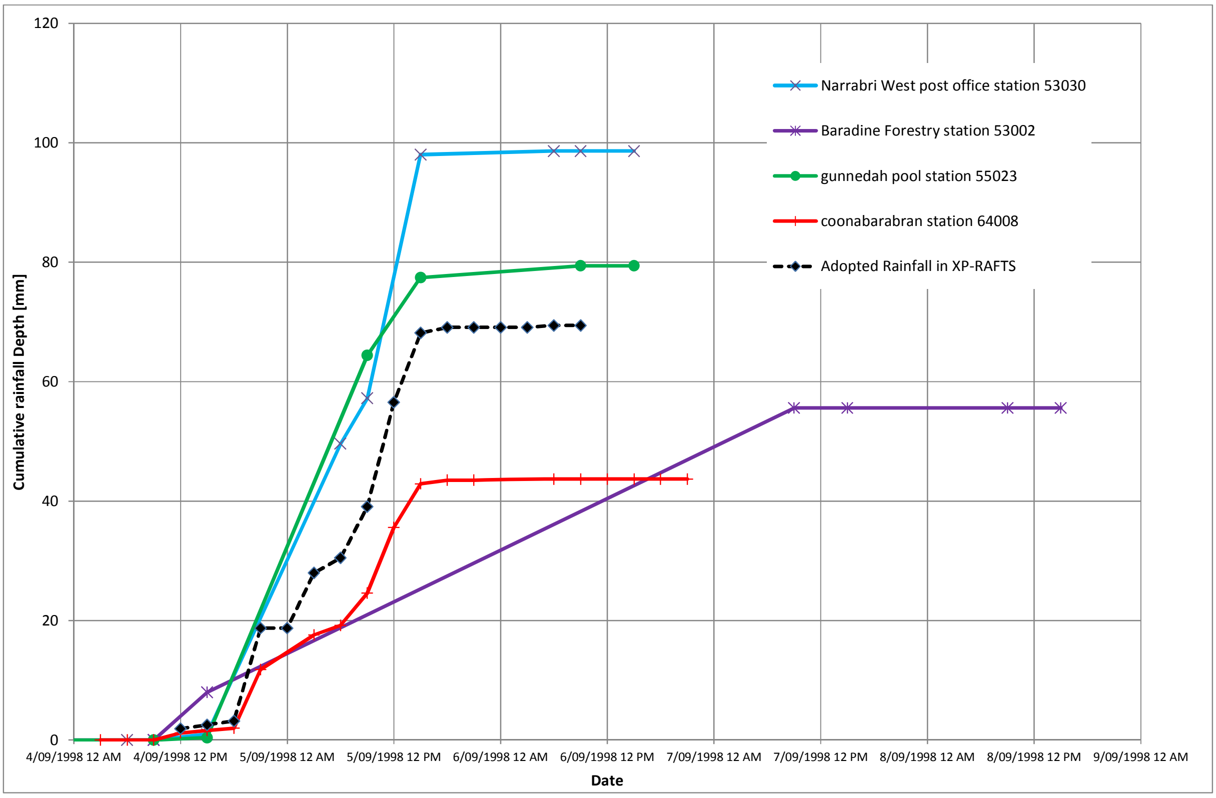


Figure 3-4 Cumulative rainfall pattern measured and adopted

3.6 Calibration Results

A range of value for the manning's roughness coefficient "n", rainfall losses and catchment lag parameter were investigated. The values that were adopted for the study and were found to provide the best fit to the recorded flow rate at station 419905 Bohena Creek at Newell Highway were:

- Manning's roughness coefficient "n": 0.08
- initial and continuous losses: 10 millimetres; 2 millimetres per hour
- catchment lag link time based on a standard velocity of four metres per second.

The comparison between the calibrated model and the recorded flow rate is shown in Figure 3-5. This figure shows that the timing of the modelled hydrograph is occurring 7.5 hours later than the recorded hydrograph. This discrepancy in the timing is most likely caused by the poor definition of the rainfall pattern. The model gives a good match to the recorded peak flow rate.

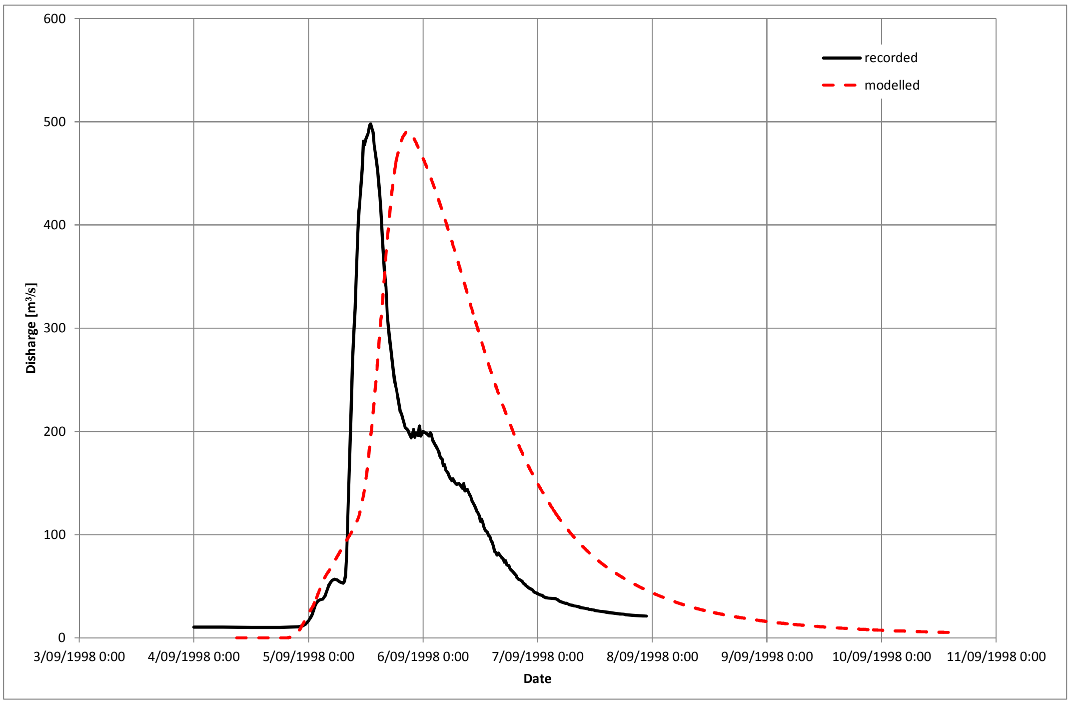


Figure 3-5 Comparison of recorded and modelled flow hydrograph at Bohena Creek

3.7 Sensitivity Analysis

As part of the hydrologic modelling, sensitivity analysis of the hydrologic model was carried out with respect to the Manning's roughness coefficient "n", the rainfall losses and the catchment lag link. Figure 3-6, Figure 3-7 and Figure 3-8 show the sensitivity of the hydrological model results to changes in these parameters.

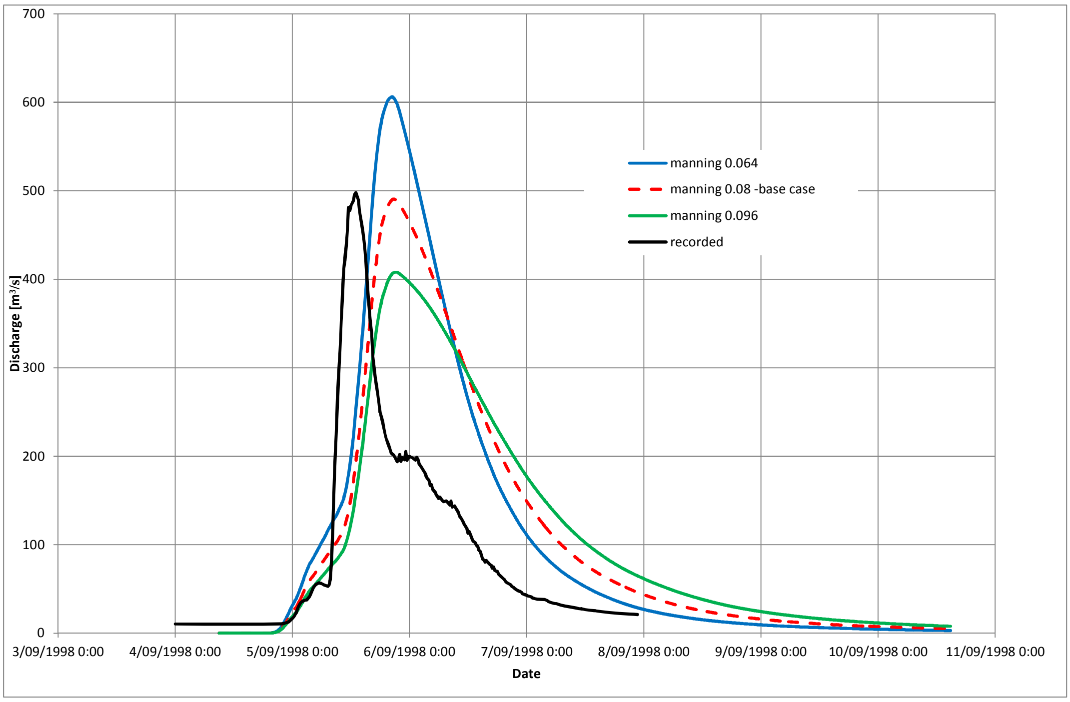


Figure 3-6 Hydrological model sensitivity to +-20% changes in roughness

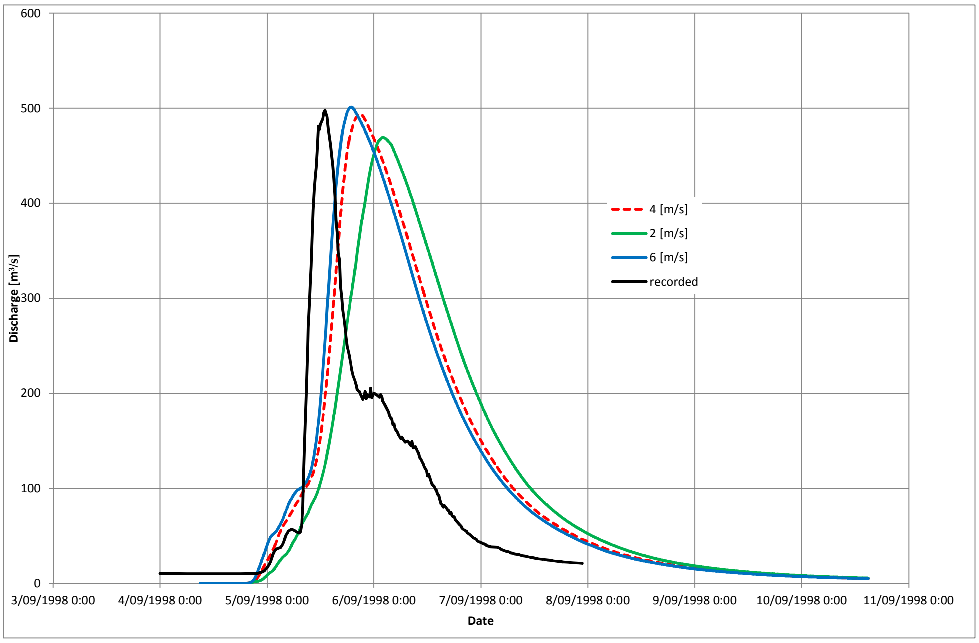


Figure 3-7 Hydrological model sensitivity to lag link based on 2,4 and 6 m/s

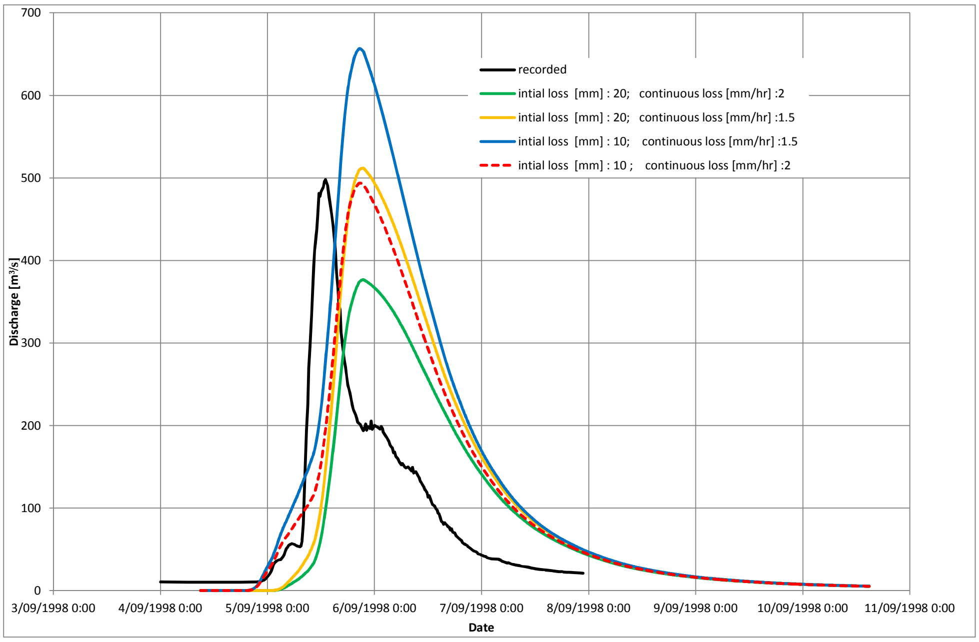


Figure 3-8 Hydrological model sensitivity to initial and continuous loss

3.8 Design Run Results

The purpose of the hydrological model is to provide 10 per cent and one per cent AEP and PMP design inflow hydrographs for a range of storm duration to the TUFLOW hydraulic model.

The design rainfall estimates were based on the AR&R87 Intensity Frequency Duration (IFD) curves from the Bureau of Meteorology, applied in conjunction with the zone 2 temporal rainfall pattern as per the methodology from the Australian Rainfall & Runoff manual.

The IFD was developed for a point situated at the centre of the catchment at the following coordinates: easting 749,000 and northing 6,660,000. Figure 3-9 shows the adopted IFD curves.

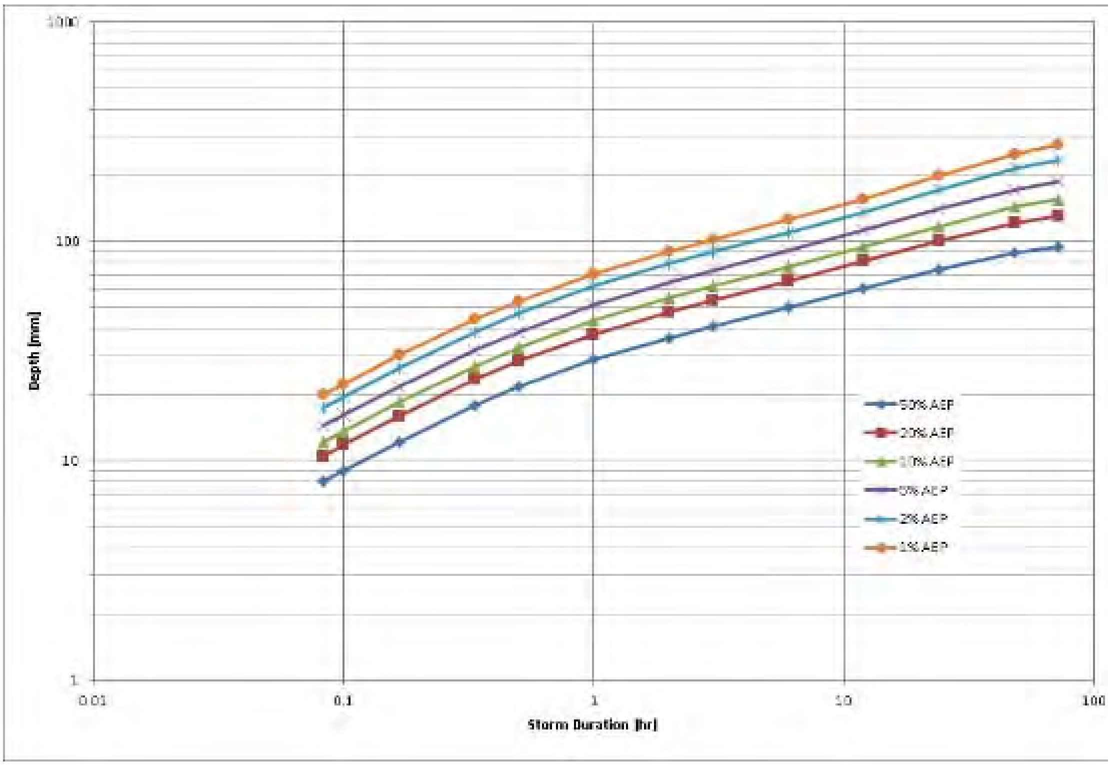


Figure 3-9 IFD at the catchment

In order to provide the critical 10 per cent and one per cent AEP flood levels, a range of storm durations need to be assessed. Transient inflow boundary conditions for a range of storm durations were defined as part of the hydraulic modelling. Total inflow hydrographs (as per RAFTS nomenclature) were extracted for all catchments contributing runoff at the upstream boundaries of the 2D domain. These catchments are as follows: ZZ, ZY, A, B, W, Y, AA, AC and AD (Figure 3-1).

The outlet of catchment D was adopted to represent the main flow from Bohena Creek. Table 3-2 and Table 3-3 show the peak total flow rate predicted by the hydrological model for a range of storm durations in Bohena Creek (catchment area of approximately 1,500 square kilometres at this location).

Table 3-2 Modelled 10% AEP Peak Flow Rates in Bohena Creek for a Range of Storm Durations

Storm Duration	10 min	15 min	20 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	36 hr
Peak Flow rate (m^3/s)	9	44	140	216	381	537	636	809	909	1005	972

Table 3-3 Modelled 1% AEP Peak Flow Rates in Bohena Creek for a Range of Storm Durations

Storm Duration	10 min	15 min	20 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr	36 hr
Peak Flow rate (m^3/s)	186	296	380	544	898	1,254	1,494	1,921	2,173	2,375	2,293

As seen from the table, the critical storm duration in Bohena Creek for both events is 24 hours. The peak flow rate associated with the 10 per cent AEP critical storm duration is 1005 cubic metres per second and 2,375 cubic metres per second for the one per cent AEP critical storm duration.

3.9 Probable Maximum Flood Hydrology

3.9.1 Probable Maximum Precipitation

The theoretical definition of the PMP is “the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of year” (World Meteorological Organisation, 1986a). The Bureau of Meteorology developed procedures for estimation of the Probable Maximum Precipitation across Australia. In practice, these estimates are based on very limited information and are considered “operational” estimates of the PMP rather than true values.

Estimates of the AEP of the PMP vary by catchment area. The AEP of the PMP for catchments of less than 100 km^2 is 1 in 1 x 10^{-7} whilst that of a catchment of 1,000 km^2 is 1 x 10^{-6}.

3.9.2 Probable Maximum Flood

The Probable Maximum Flood (PMF) is defined as the limiting value of a flood that could reasonably be expected to occur. The PMF has been used as the extreme flood in this study. Alternatives (such as the PMP Design Flood) have not been assessed.

Estimation of the PMF was made using the very low losses in accordance with Australian Rainfall and Runoff together with the rainfall and temporal patterns provided with generalised PMP methods, which are discussed in the following sections.

3.9.3 Generalised PMP methods

The Generalised Short Duration Method (GSDM) is the PMP technique used across Australia for catchments less than 1,000 square kilometres in area and is applicable for storm durations of up to 3 hours or 6 hours (depending on location). The long duration techniques vary by region. The applicable long duration method for the project area is the Generalised Tropical Storm Method Revised (GTSMR), coastal region.

The PMP techniques are used to provide flood estimates at a specific location with rainfall varying spatially across the catchment to result in the maximum flood at that location. Estimation of the PMF across a large area with many different catchment sizes (such as the project area) is complex due to the many possible combinations of rainfall variability in space and intensity during the storm.

Estimates of the PMF were made for selected scenarios for this study, giving consideration to the location of key infrastructure and the major watercourses within the project area. The aim was to provide a reasonable estimate of extreme flood conditions across most of the site, including particular consideration of Bohena Creek and the Leewood site. Estimates of the PMF in the upper reaches (south-east) of the site are not as well defined but were not considered critical for the assessment.

A summary of PMF hydrology estimates undertaken is provided in Table 3-4.

Table 3-4 Table 3-4 PMF scenarios

Technique	Storm durations assessed (hours)	Watercourse	Description
GTSMR	24	Bohena Creek	Estimate centred on Bohena Creek near Leewood
GSDM	0.25, 0.5, 1, 3, 4, 6, 24	Mollee Creek	Estimate centred on Mollee Creek at Leewood
GSDM	0.25, 0.5, 1, 3, 4, 6	Jacks Creek	Estimate centred on Jacks Creek catchment within the boundary of the site

4. Hydraulic Model Setup

This section of the report details the hydraulic modelling undertaken for the area covered by the project area. For convenience, the one per cent AEP event is used to assist in describing the data input and study methodology. The results of the modelling, including those for the one per cent AEP, 10 per cent AEP, and PMF events, are presented on the flood maps in the following chapter.

4.1 Methodology

A hydraulic model of the project area was established to simulate the behaviour of the surface water during a flood. The key steps in the development of the hydraulic model include model setup, simulation of design flood events and post-processing of the results. The rainfall on grid methodology was applied to ensure that all parts of the project area were taken into consideration.

Two major inflows were considered in the hydraulic modelling process: design rainfall intensities for a range of different storm durations (10, 20 minutes, 0.5, 1, 2, 3, 6, 12 and 24 hours) together with the corresponding design inflow hydrographs in Bohena Creek and the external catchments contributing substantial run-offs volumes: A, B, W, Y, AA, AC, AD, ZZ and ZY.

4.1.1 Design Storm Hydrographs

To give an indication of a typical hydrograph at key locations determining the inflows into the hydraulic model, Figure 4-1 and Figure 4-2 show total flow hydrographs for the one per cent AEP, 24-hour duration storm event.

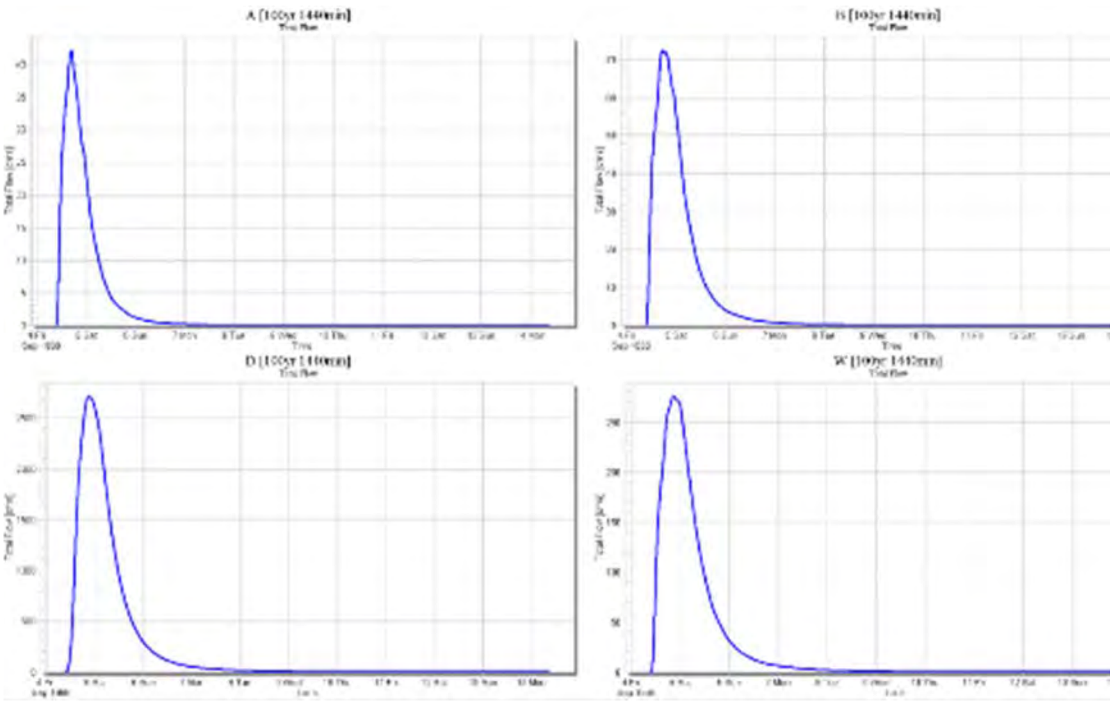


Figure 4-1 1% AEP, 24-hour Duration Design Storm Hydrographs at Catchment Nodes A, B, D and W

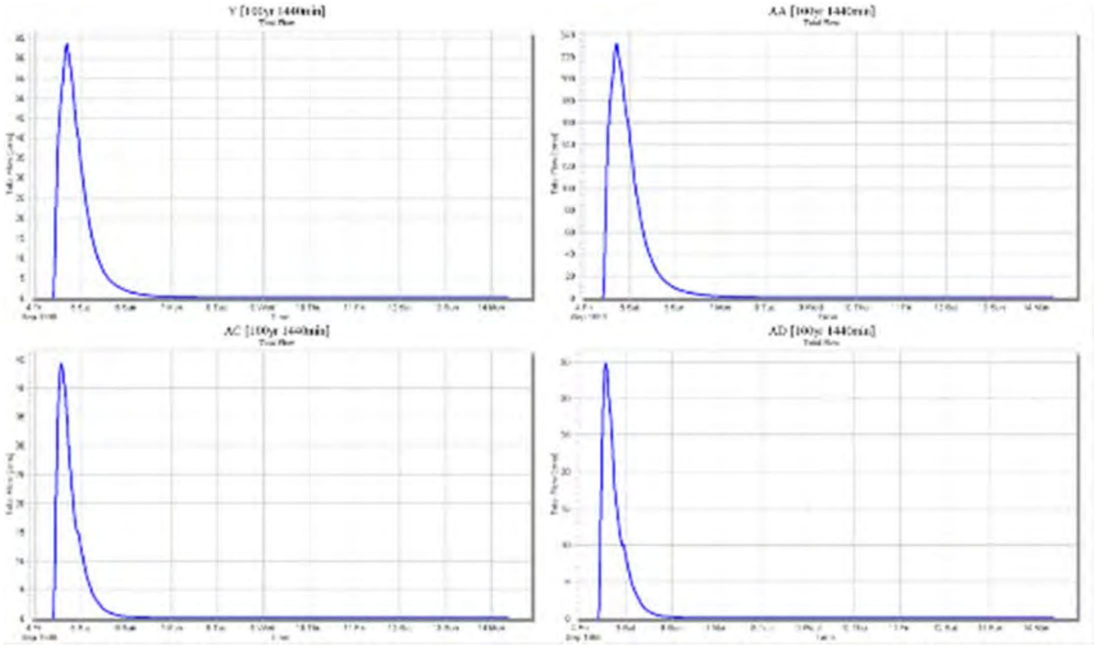


Figure 4-2 1% AEP, 24-hour Duration Design Storm Hydrographs at Catchment Nodes y, AA, AC and AD

4.2 Modelling Software

Hydraulic modelling was undertaken using TUFLOW software. TUFLOW is a hydraulic modelling package that integrates one-dimensional and two-dimensional schematisations into a single, dynamically coupled hydraulic modelling system that is capable of unsteady flow calculations. An essential component of TUFLOW is the generation of digital elevation model (DEM) files that represent the terrain and roughness of the modelled region.

Boundary conditions are specified in the model at selected locations (e.g. external catchments A, B, W, Y, AA, AC, AD, ZZ and ZY). The range of boundary condition types includes time series of rainfall depth, water levels, discharges, velocities and stage discharge relationships.

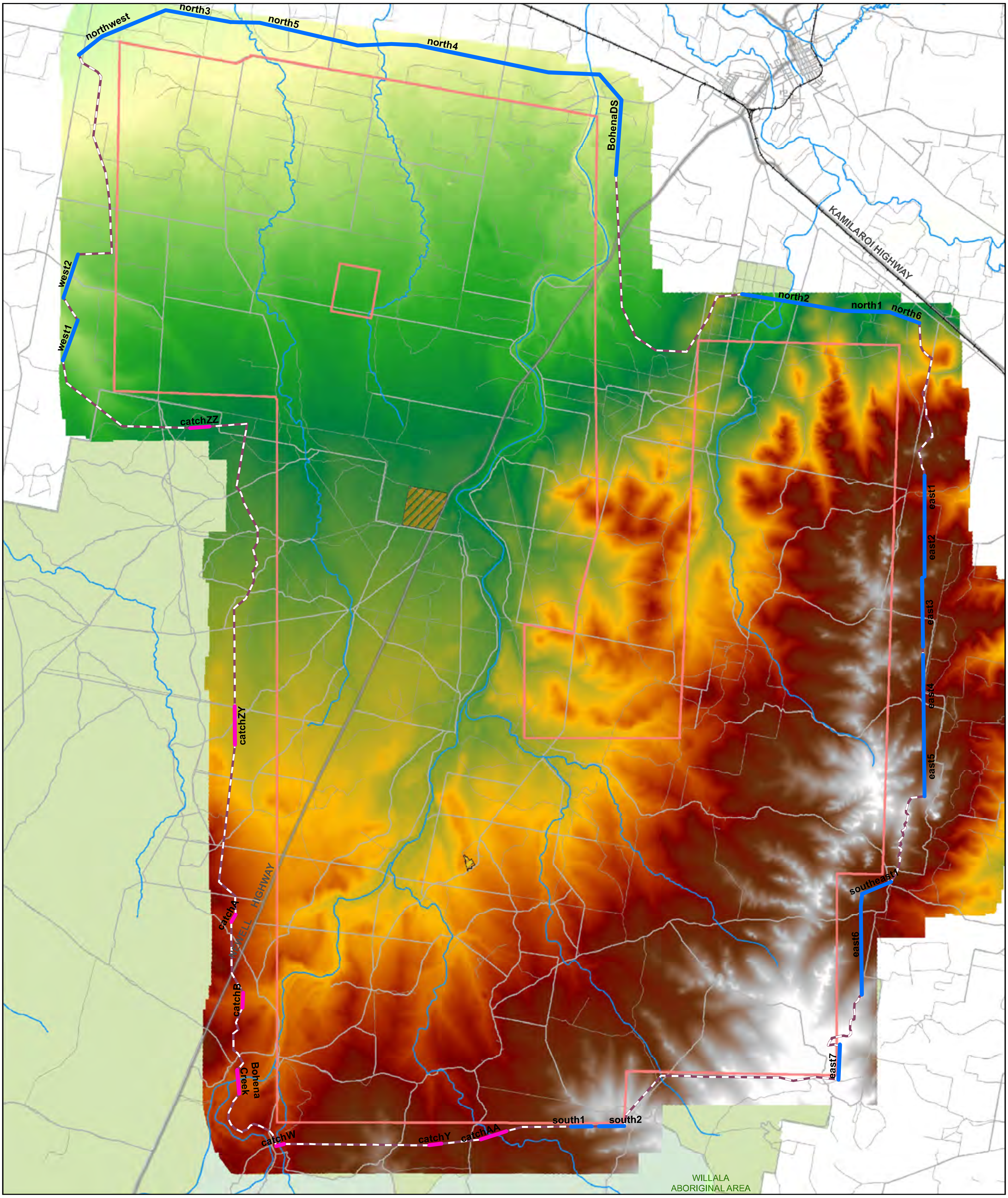
TUFLOW computes velocity and water depths at every nodal point in a model grid for each time step and produces a corresponding output file. The specification of “monitoring stations” and “cross sections” can also be used to obtain a time history of water depth, velocity and discharge at desired locations.

4.3 Model Details

4.3.1 Model Extent

The extent and details of the hydraulic model developed for this study are provided in Figure 4-3. The project area was modelled in a two-dimensional hydraulic model domain. In order to accurately represent the topography and key features of the floodplain in this area, a 20 metres cell size was used in the 2D domain.

The model was extended one to two kilometres past the project area boundary to limit the influence of the downstream boundary conditions on the model results within the project area.



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Hydrograph boundary conditions
- Stage-Discharge boundary conditions
- TUFLOW model extent
- Hydrograph boundary conditions
- Stage-Discharge boundary conditions

Elevation (m AHD)
High : 400
Low : 180

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 02 Dec 2016

Narrabri Tuflow Model Set-up

Figure 4-3

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy

4.3.2 Digital Elevation Model

In order to represent the bathymetry and topography of the river and floodplain located over the project area a two dimensional digital elevation model was developed to inform the TUFLOW model.

The digital elevation model was developed using the LiDAR data sets provided by Santos.

4.3.3 Hydraulic roughness

The Manning's 'n' roughness coefficient was used to represent the hydraulic resistance of watercourses and floodplains in the TUFLOW model.

Figure 4-4 illustrates the spatial distribution of the Manning's 'n' roughness coefficients adopted in the 2D model domain.

Manning's roughness coefficients were determined through, recent aerial photographs, vegetation mapping and land use maps. The Manning's 'n' values were assigned in accordance with the values provided in Table 4-1.

Table 4-1 Adopted Hydraulic Roughness Values

Land type	Adopted Manning's "n" roughness coefficients
River bed	0.03
Low scrub	0.045
Forest	0.08

4.3.4 Hydraulic structures

Due to limitations on the availability of data no hydraulic structures were represented in the hydraulic model. Due to the flat nature of the catchment, structures such as the Newell Highway bridge are expected to have limited effect on the model results given the depths of flooding predicted.

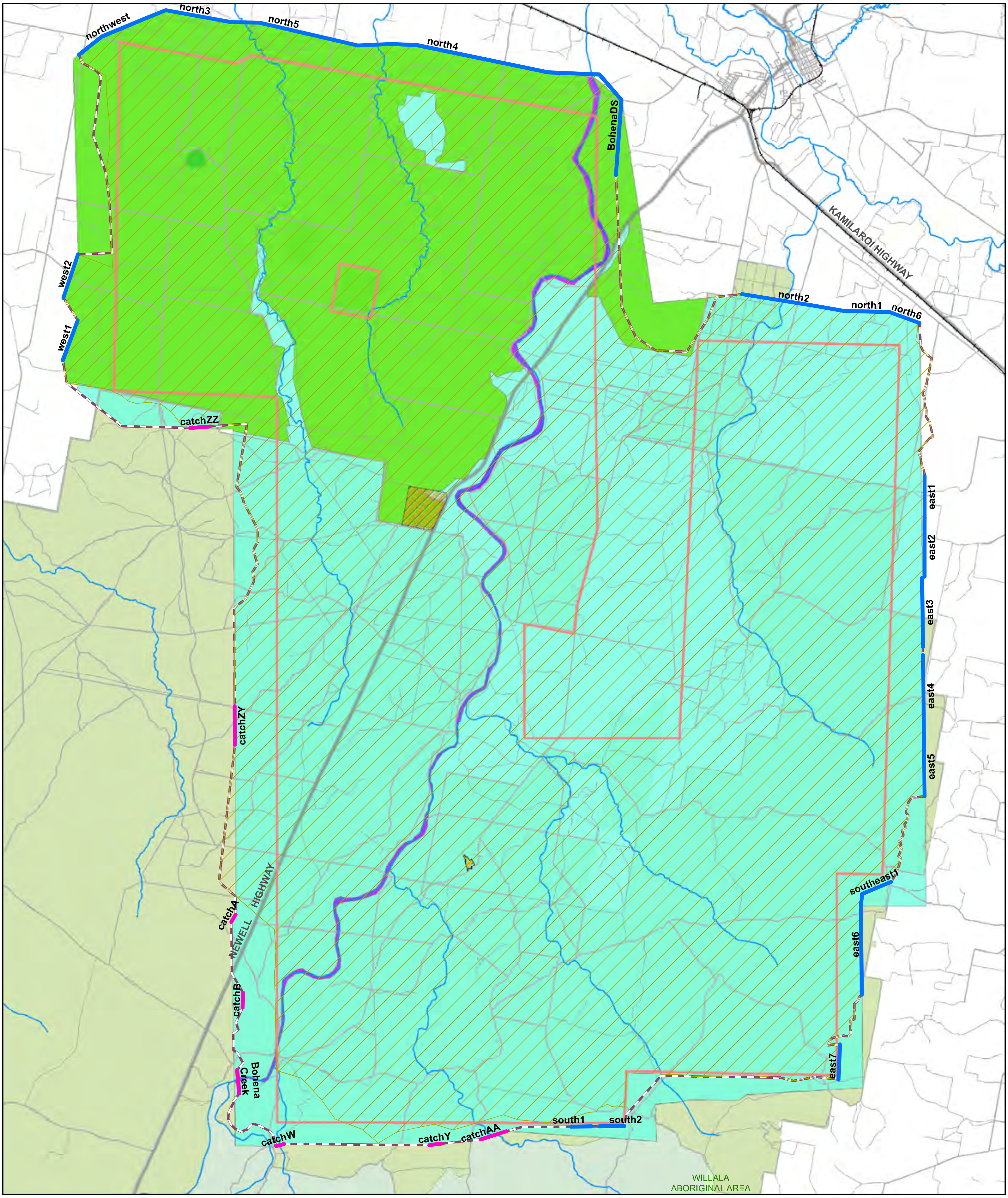
4.3.5 Rainfall on Grid

Nine different storm durations were assessed: 10-minute, 15-minute, 30-minute, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour and 24-hour.

The IFD data extracted from the Bureau of Meteorology as explained, and the rainfall pattern associated with zone 2 was used to develop the design rainfall as per the standard Australian Rainfall & Runoff methodology.

The applied rainfall patterns associated with each storm duration are illustrated in Figure 4-5 and show that the small duration events are associated with a very intense rainfall, while longer duration storm event have a smaller intensity for a longer period of time.

Losses adopted for the rainfall on grid model were as per the calibrated hydrology model.



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- Hydrograph boundary conditions
- Stage-Discharge boundary conditions
- Rainfall on grid area
- TUFLOW model extent

Roughness (Manning's "n")

- 0.03
- 0.045
- 0.08

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number	21-22463
Revision	A
Date	05 Dec 2016

Roughness Map Rainfall on Grid Area

Figure 4-4

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Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy

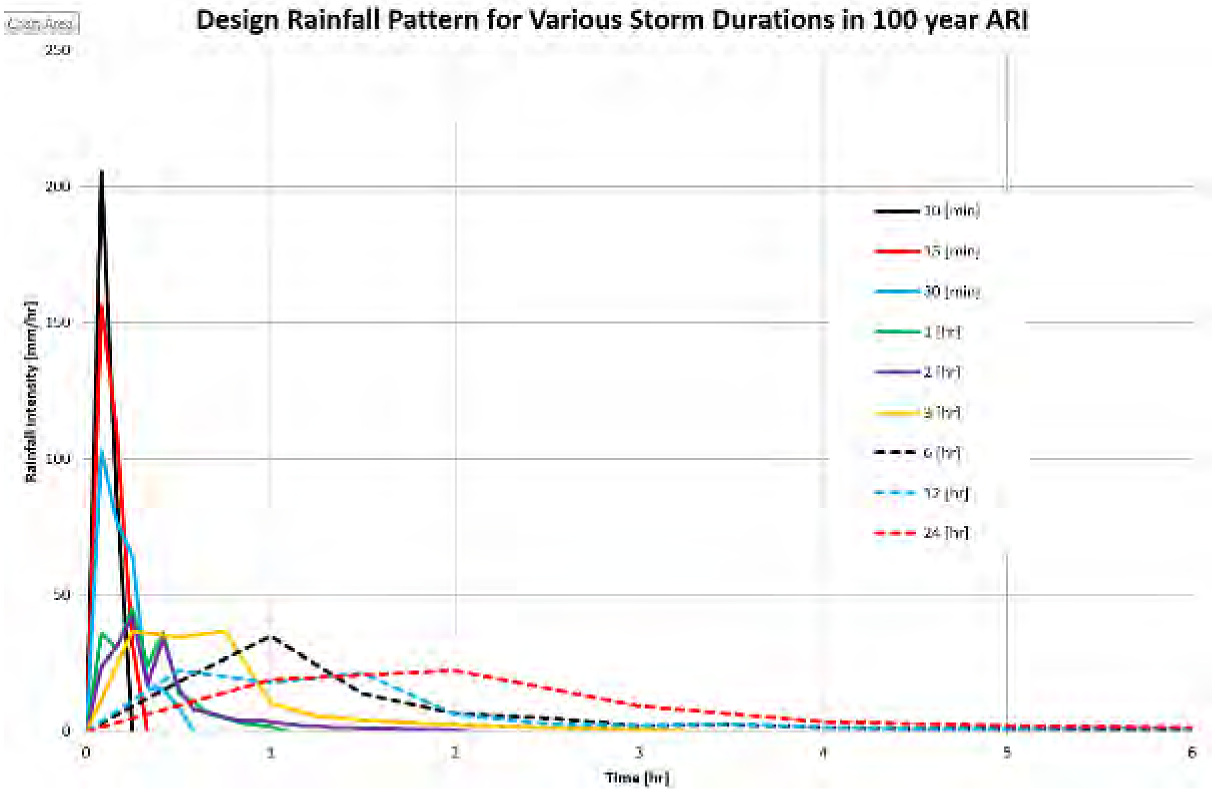


Figure 4-5 Rainfall pattern

Table 4-2 shows the cumulative rainfall depth associated with each storm duration.

Table 4-2 Cumulative Rainfall Depth

Storm duration	Cumulative Rainfall Depth (mm)
10 min	30.3
20 min	44.0
30 min	53.5
1 hr	71.2
2 hr	90.2
3 hr	102.3
6 hr	125.4
12 hr	156
24 hr	198

4.3.6 Boundary Conditions

Figure 4-3 illustrates the location of the boundary conditions. These include:

- Eight-stage discharge boundaries at the downstream end of the model using a normal slope of 0.01.
- Ten inflow hydrographs derived on the basis of run-off estimated from the RAFTS hydrological model with Bohena Creek contribution peaking at 2717 cubic metres per second for the critical (24 hour) storm duration.

Peak flow rates for the remaining nine inflow hydrographs are given in Table 4-3.

Table 4-3 Peak Flow Rate for 24 (hr) Storm 1% AEP (m^3/s)

Location	ZZ	ZY	A	B	W	Y	AA	AC	AD
Peak Flow (m^3/s)	29	25	42	73	276	64	232	44	35

5. Hydraulic Model Results

Hydraulic (flood) analysis has been carried out using:

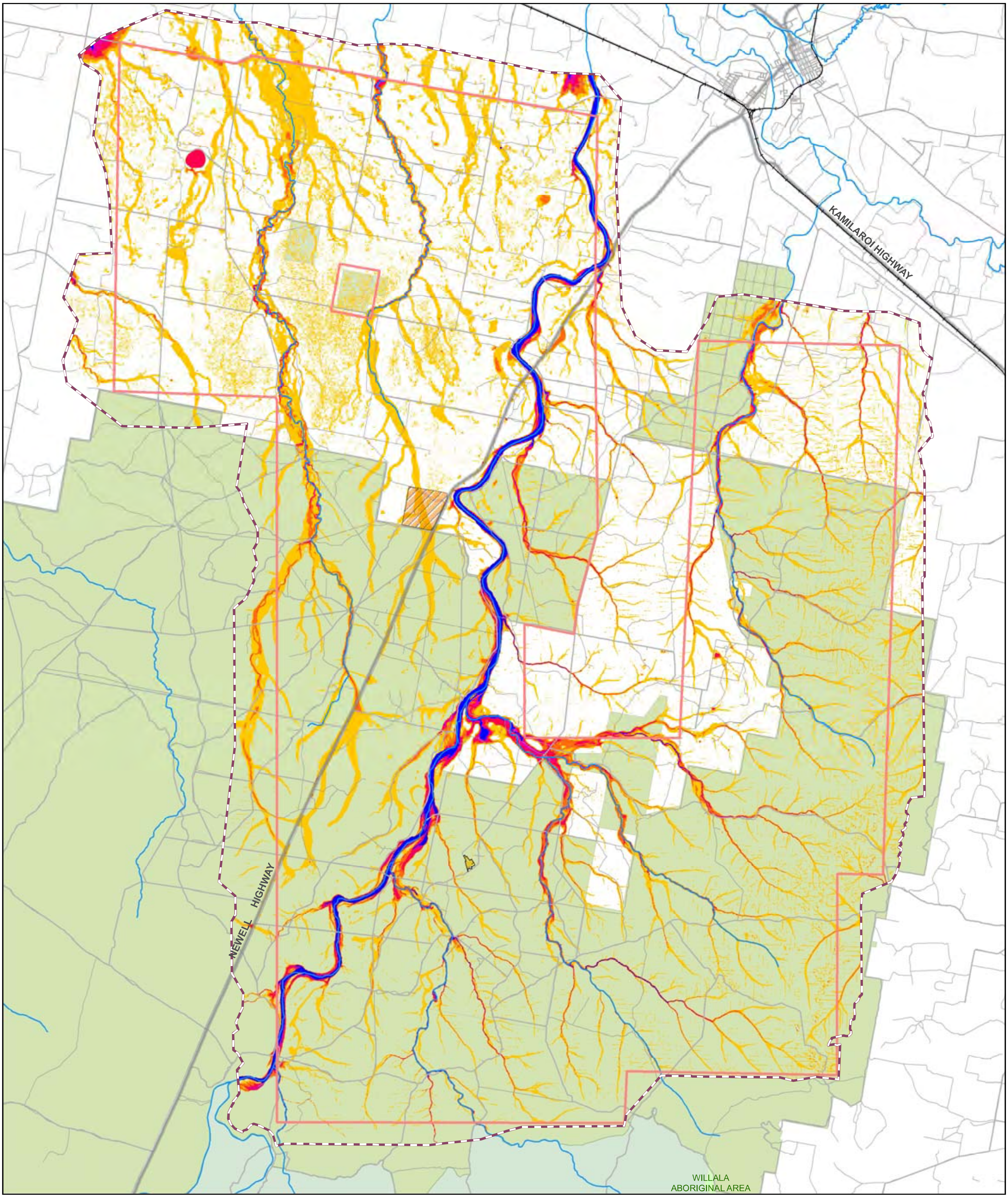
- the best available topographic data at the time of inception of the project
- an XP-RAFTS hydrological model based on AR&R87 Intensity Frequency Duration (IFD) curves and calibrated reasonably well to peak flow by varying Manning’s roughness coefficient “n”, rainfall losses and catchment lag parameters
- run-off volumes estimated from the hydrological model to represent time-varying design inflows (hydrographs) in a 35x45 km hydraulic TUFLOW model developed on a 20 metre grid thus generating flood estimates at a horizontal accuracy limited to +/- 10 metres.

5.1 Processing of Results

Model results for all nine storm durations (10, 20 minutes, 0.5, 1, 2, 3, 6, 12 and 24 hours) were combined to create maximum flood envelopes for the one per cent AEP and 10 per cent AEP events. Similarly, maximum flood envelopes were produced for all PMF events.

Figure 5-1 to Figure 5-9, show the water depth, velocity and flood level envelopes. To generate these envelopes, all nine sets of numerical results have been filtered yielding maps of flooded areas with water depth greater than 0.1 metres or water velocity greater than 0.3 metres per second.

Figure 5-10 and Figure 5-11 shows the spatial variation in critical storm duration for the 10 per cent and one per cent events. As expected the critical storm duration increases as the water progresses downstream.



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood depth (m)

- 0.00 - 0.50
- 0.5 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- >2

0 1.75 3.5 7

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Baseline Conditions
Maximum Flood Depth, 10% AEP

Figure 5-1

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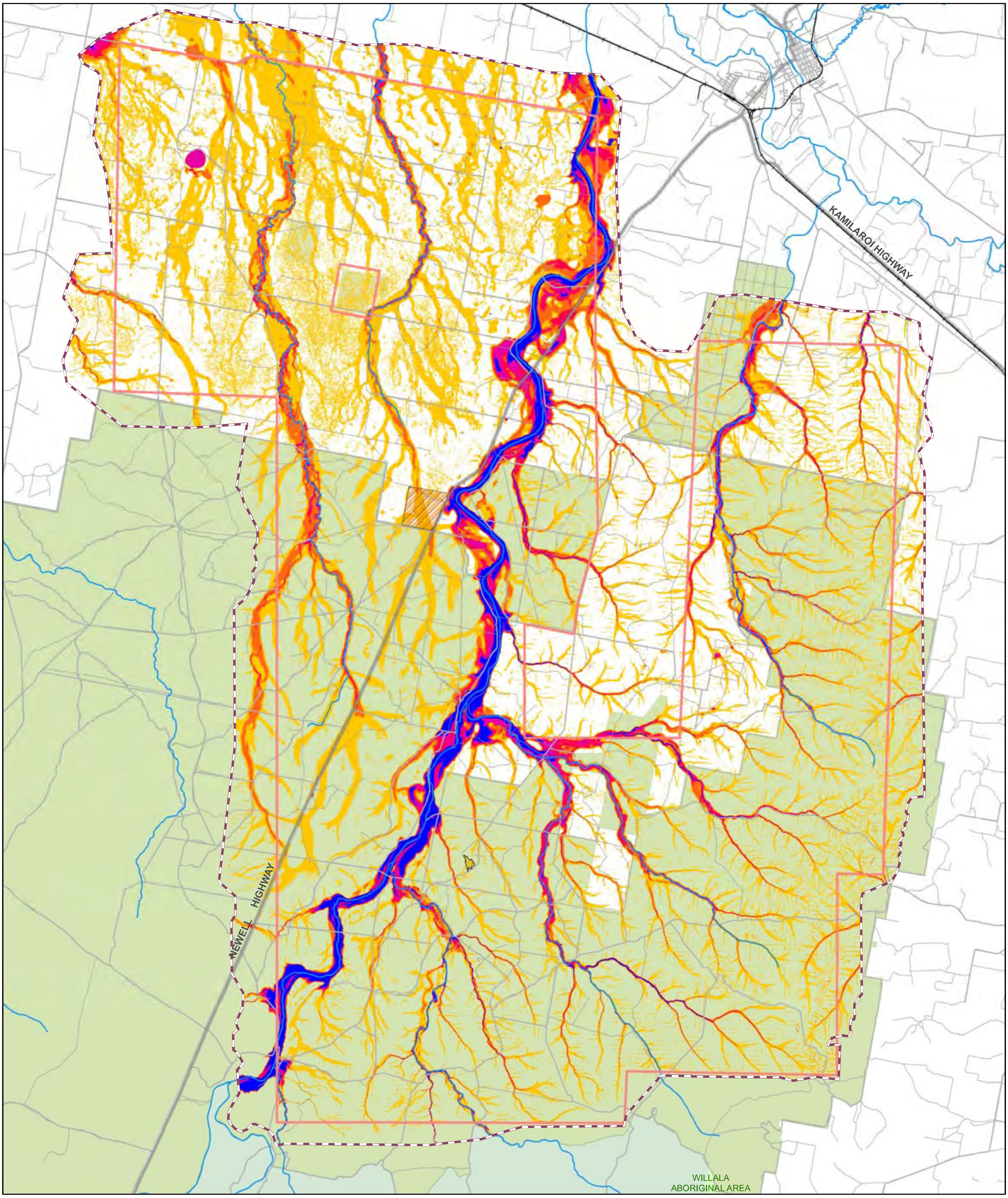
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood depth (m)

- 0.00 - 0.50
- 0.5 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- >2

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number	21-22463
Revision	A
Date	12 Dec 2016

Baseline Conditions
Maximum Flood Depth, 1% AEP

Figure 5-2

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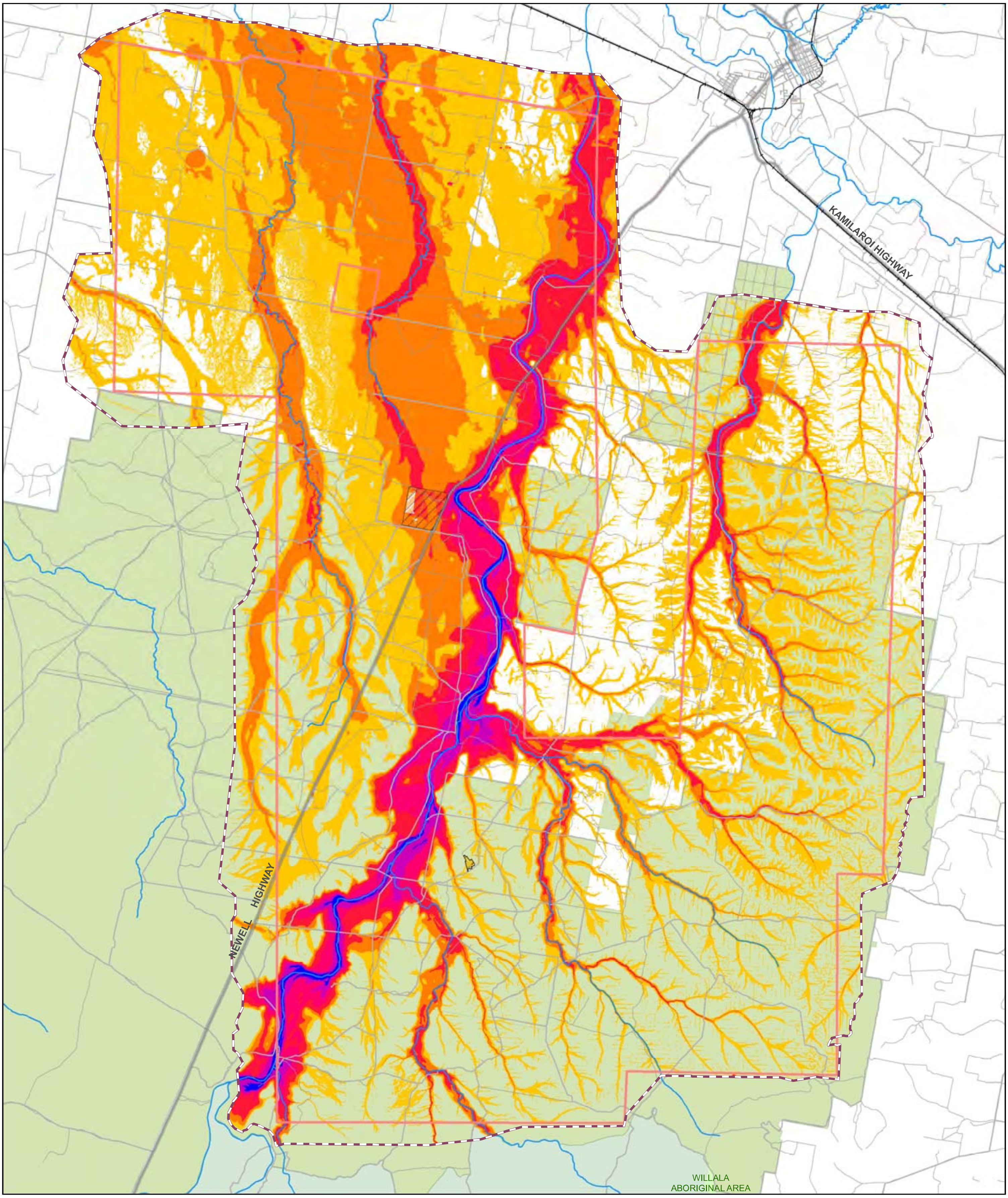
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood depth (m)

- 0 - 1
- 1 - 2.5
- 2.5 - 5
- 5 - 7.5
- 7.5 - 10
- 10+

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Baseline Conditions
Maximum Flood Depth, PMF

Figure 5-3

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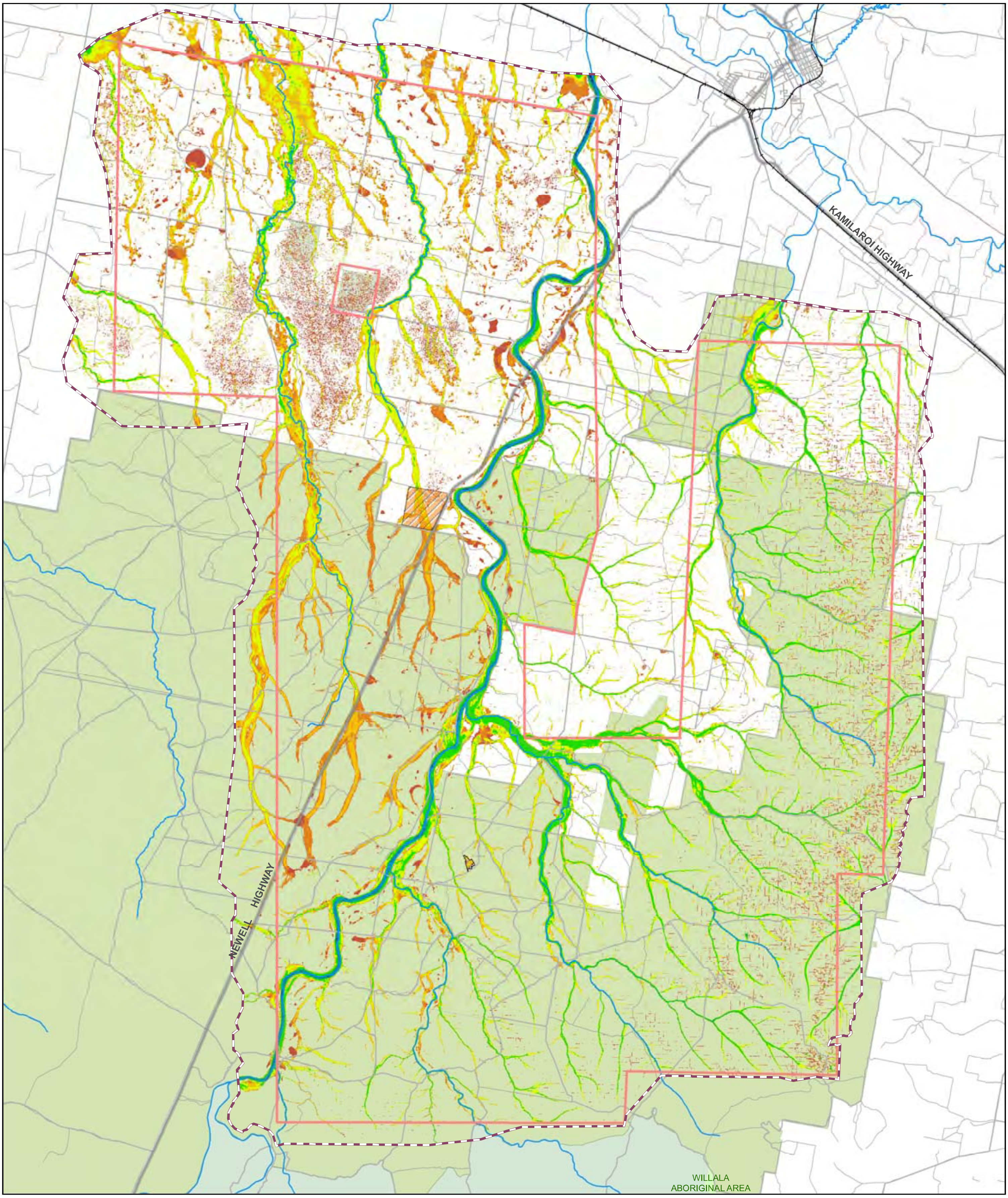
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood velocity (m/s)

- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- >3

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Baseline Conditions
Maximum Flood Velocity, 10% AEP

Figure 5-4

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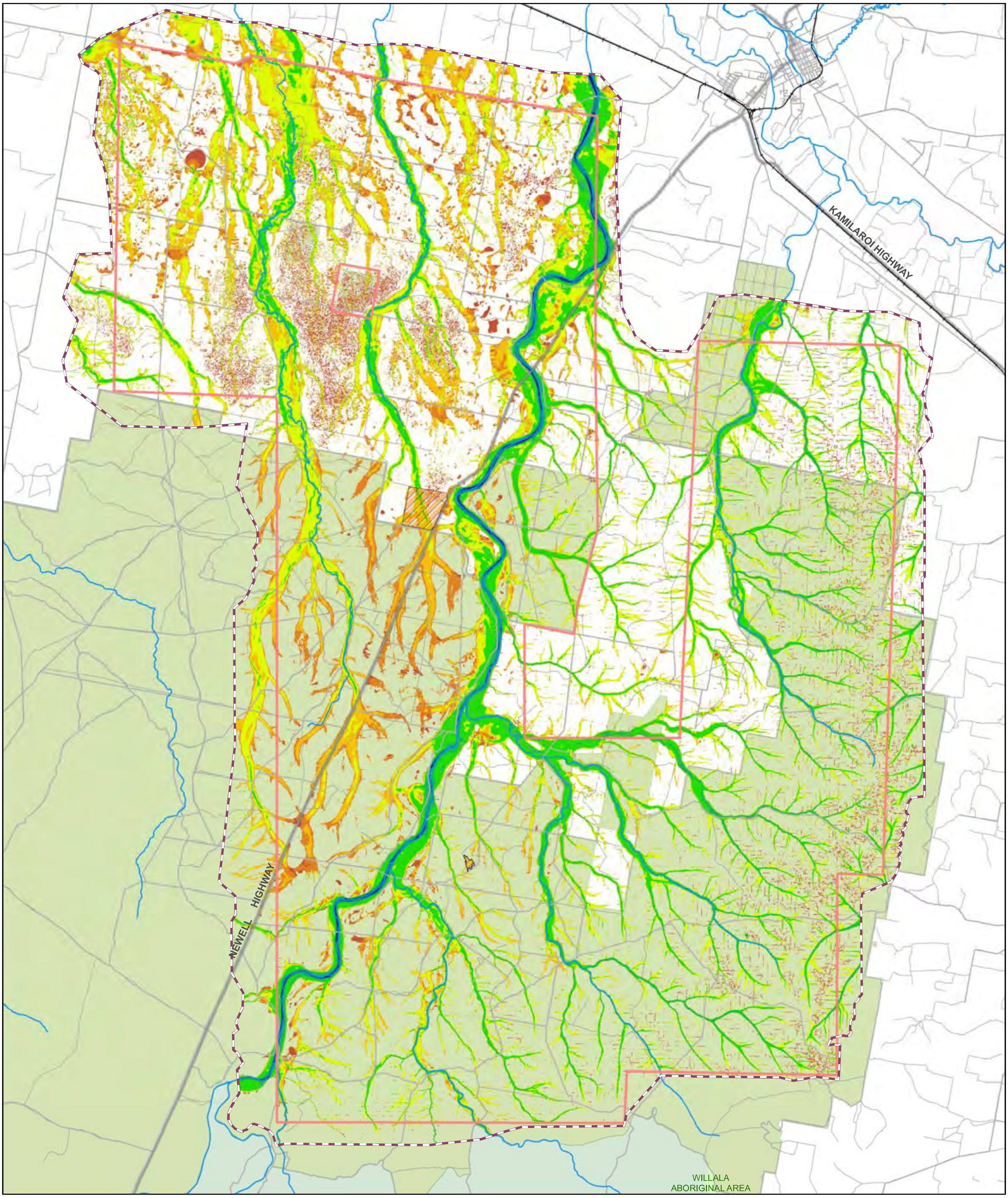
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood velocity (m/s)

- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- >3

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number	21-22463
Revision	A
Date	12 Dec 2016

Baseline Conditions
Maximum Flood Velocity, 1% AEP

Figure 5-5

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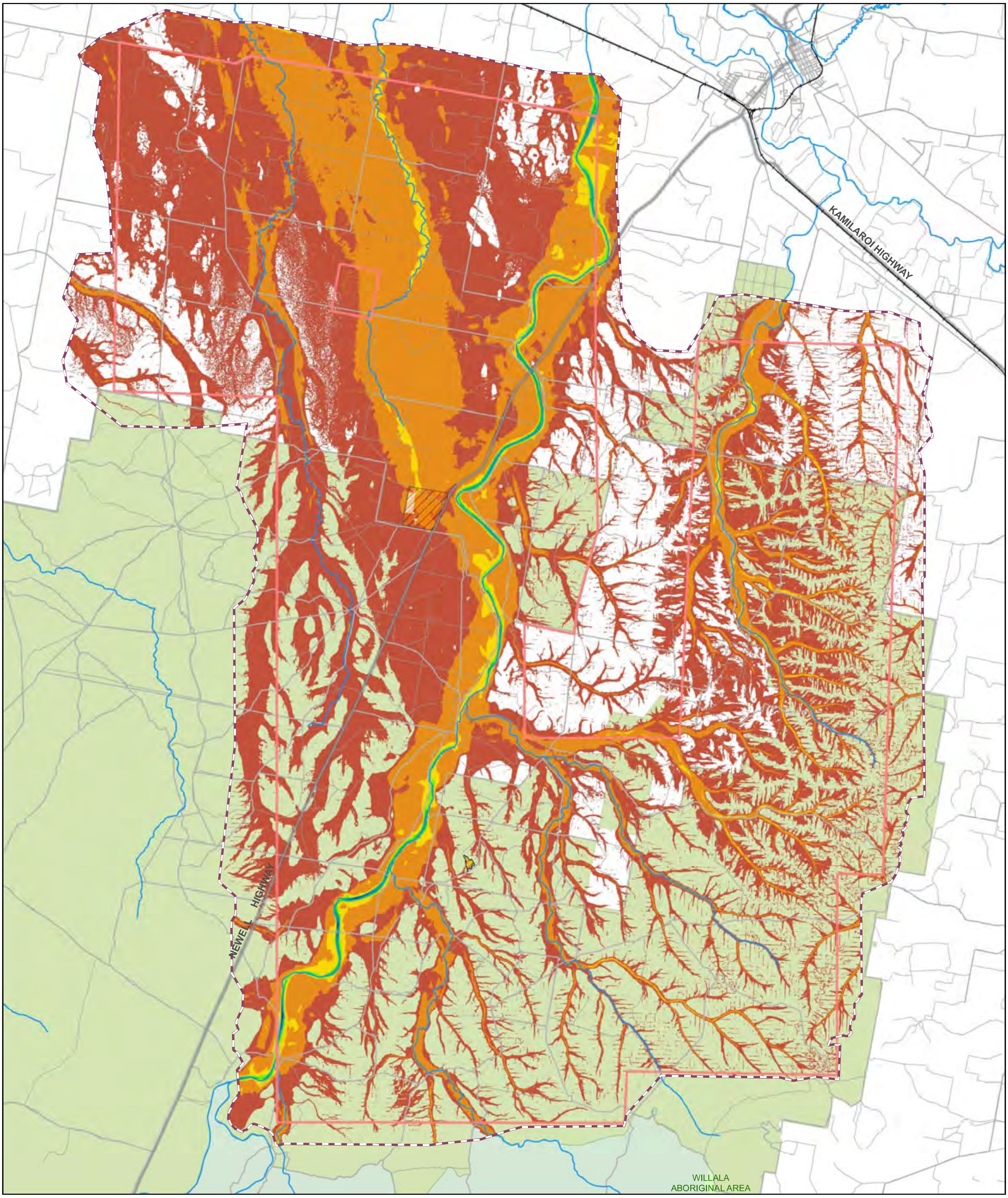
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood velocity (m/s)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6+

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Baseline Conditions
Maximum Flood Velocity, PMF

Figure 5-6

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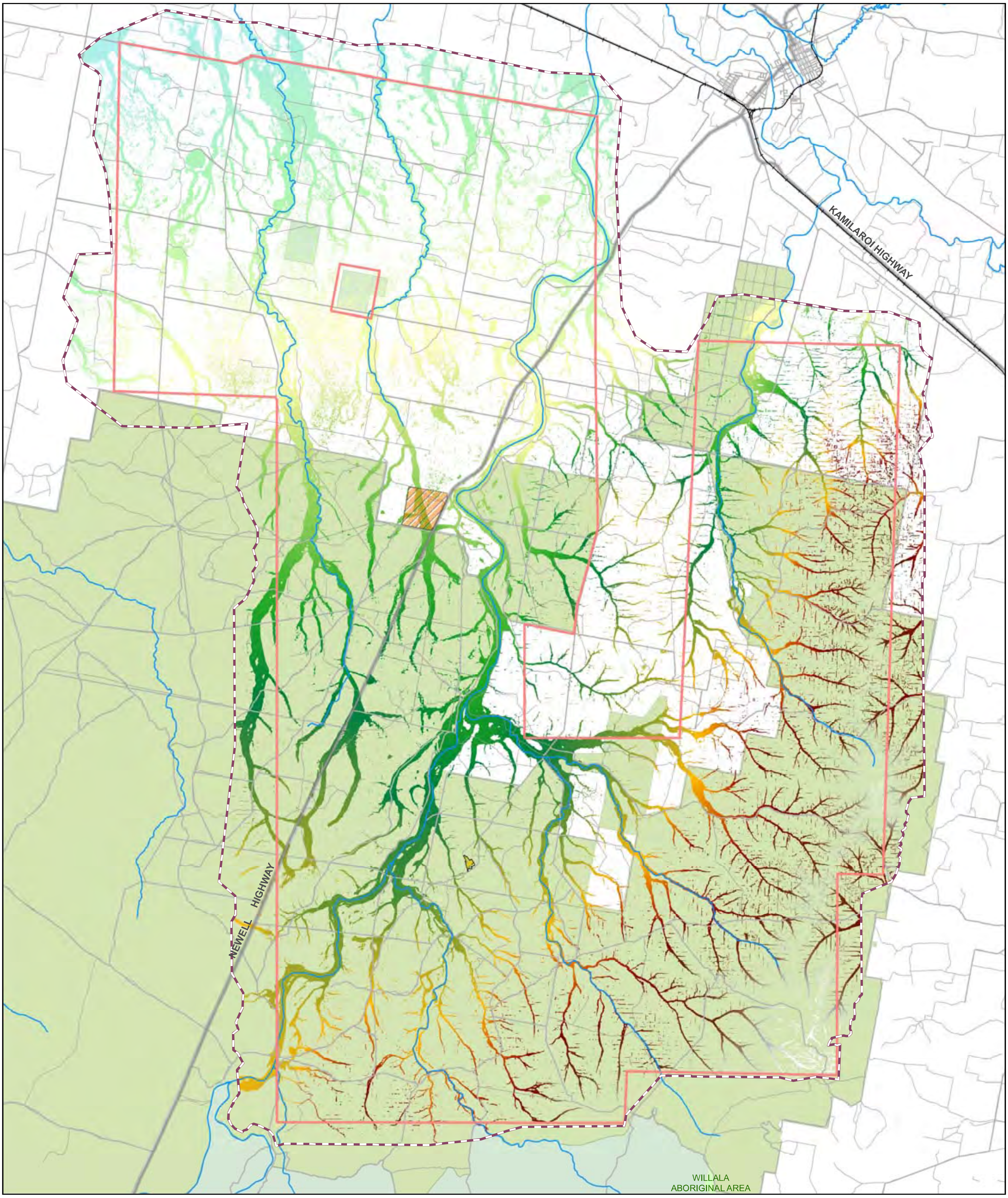
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood level (m AHD)

High : 470.588

Low : 204.995

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Baseline Conditions
Maximum Flood Level, 10% AEP

Figure 5-7

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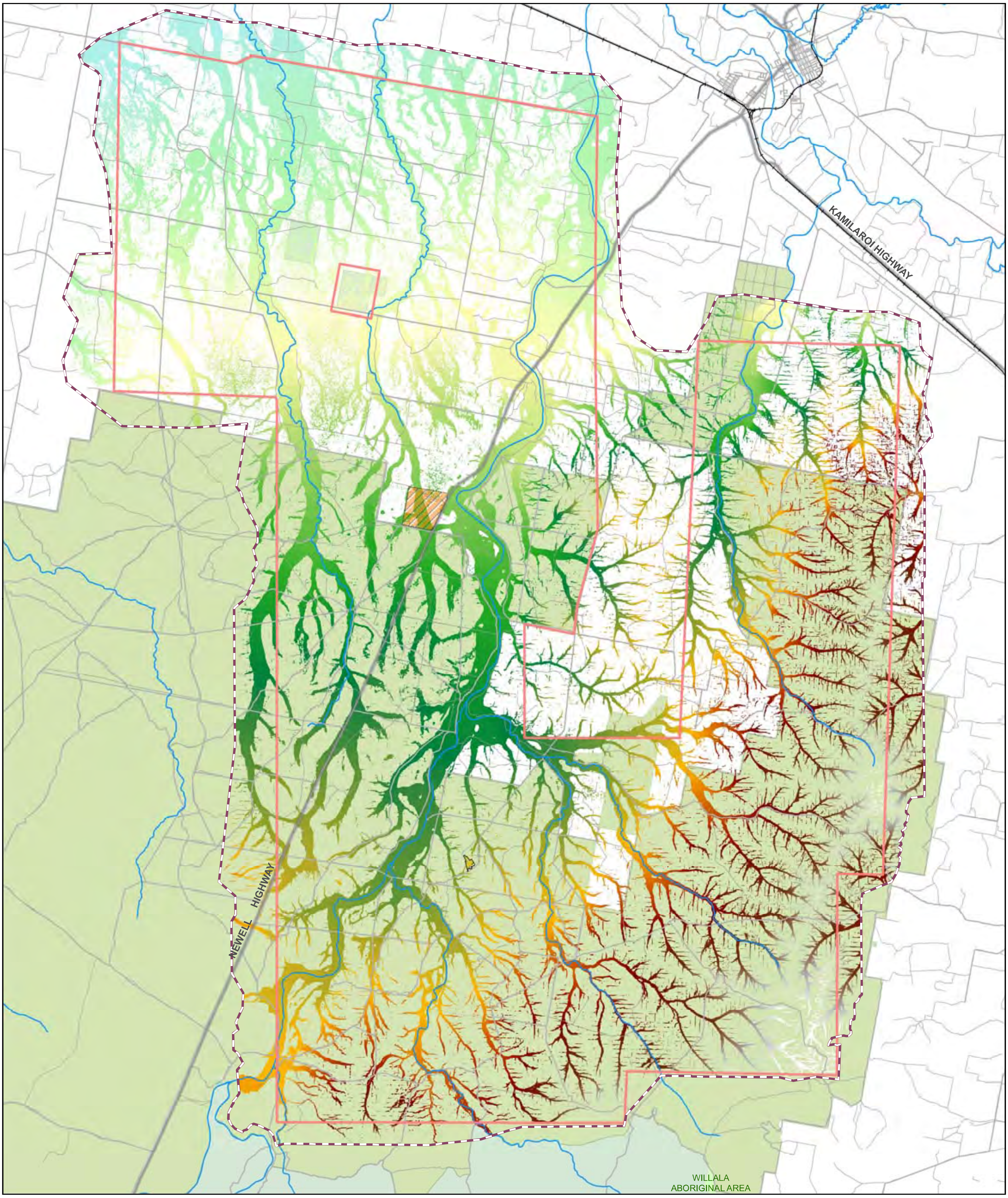
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood level (m AHD)

High : 470.591

Low : 204.996

0 1.75 3.5 7

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Baseline Conditions
Maximum Flood Level, 1% AEP

Figure 5-8

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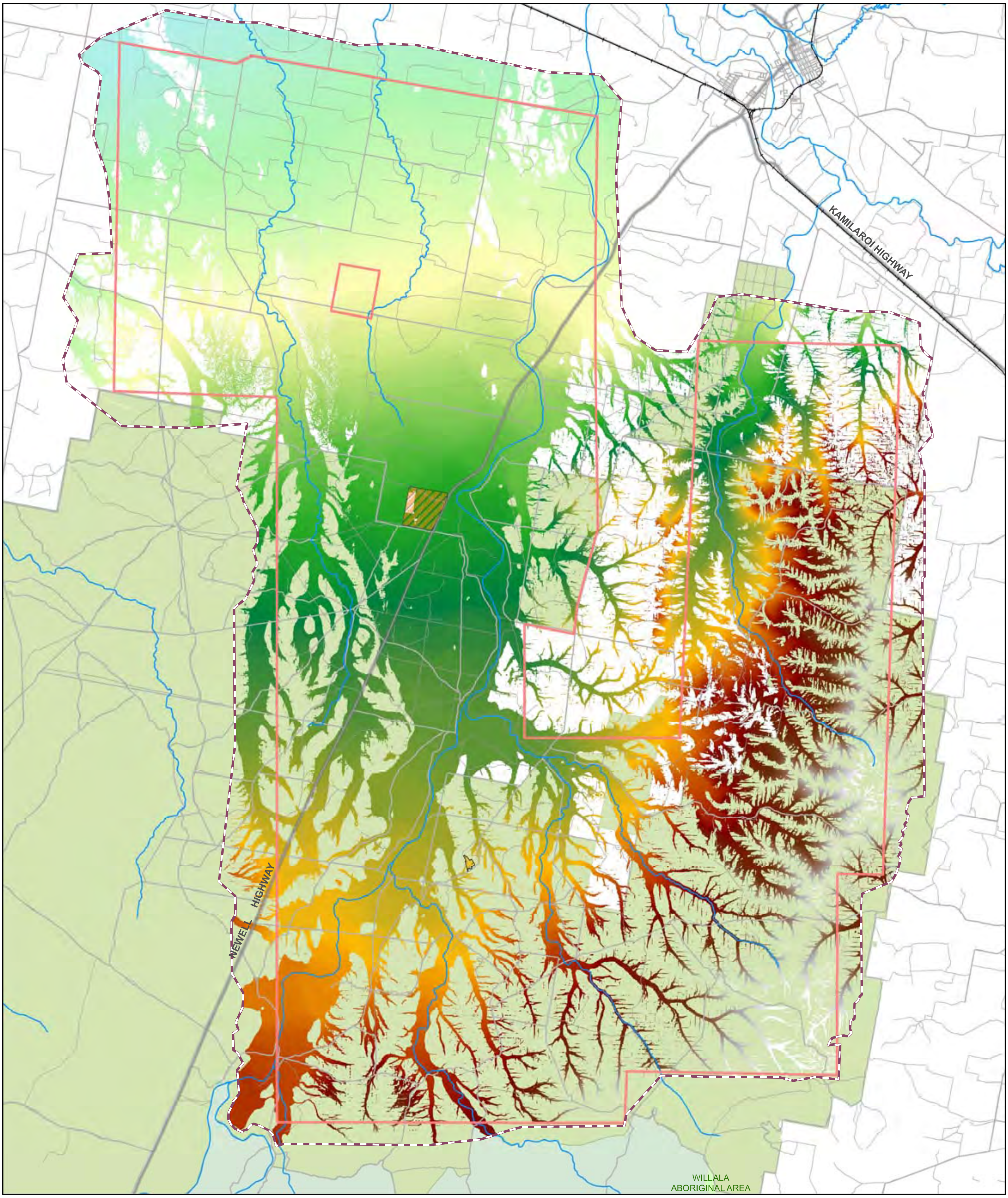
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Maximum flood level (m AHD)

High : 470.587

Low : 205.012

0 1.75 3.5 7

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Baseline Conditions
Maximum Flood Level, PMF

Figure 5-9

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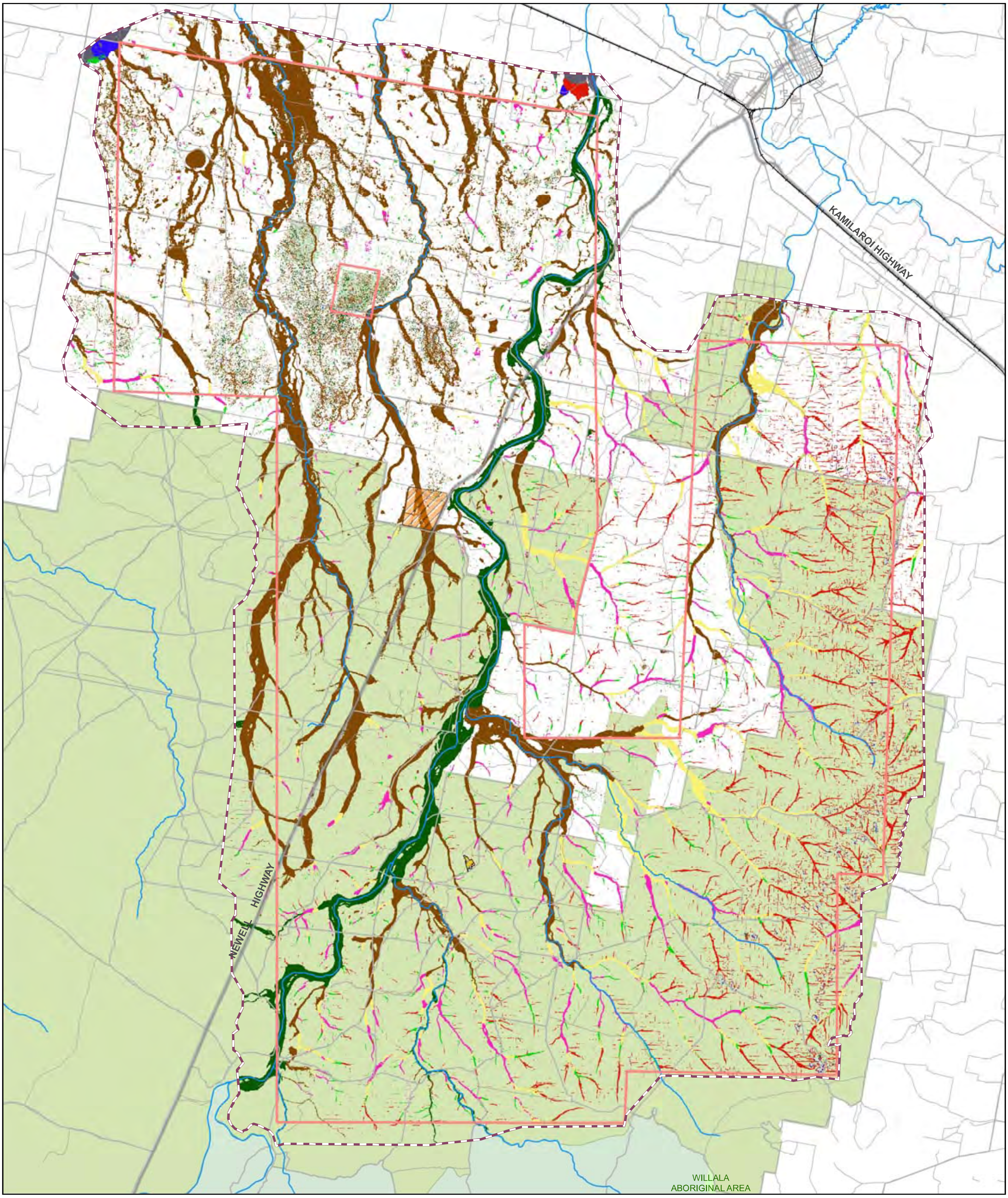
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

- Project area
- Leewood
- Bibblewindi
- Parks and reserves
- State forest
- Aboriginal areas
- Lakes and dams
- Watercourses
- TUFLOW model extent

Critical duration

10min	180min
20min	360min
30min	720min
60min	1440min
90min	2160min
	2880min

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Spatial Variation in Critical Storm Duration 10% AEP

Figure 5-10

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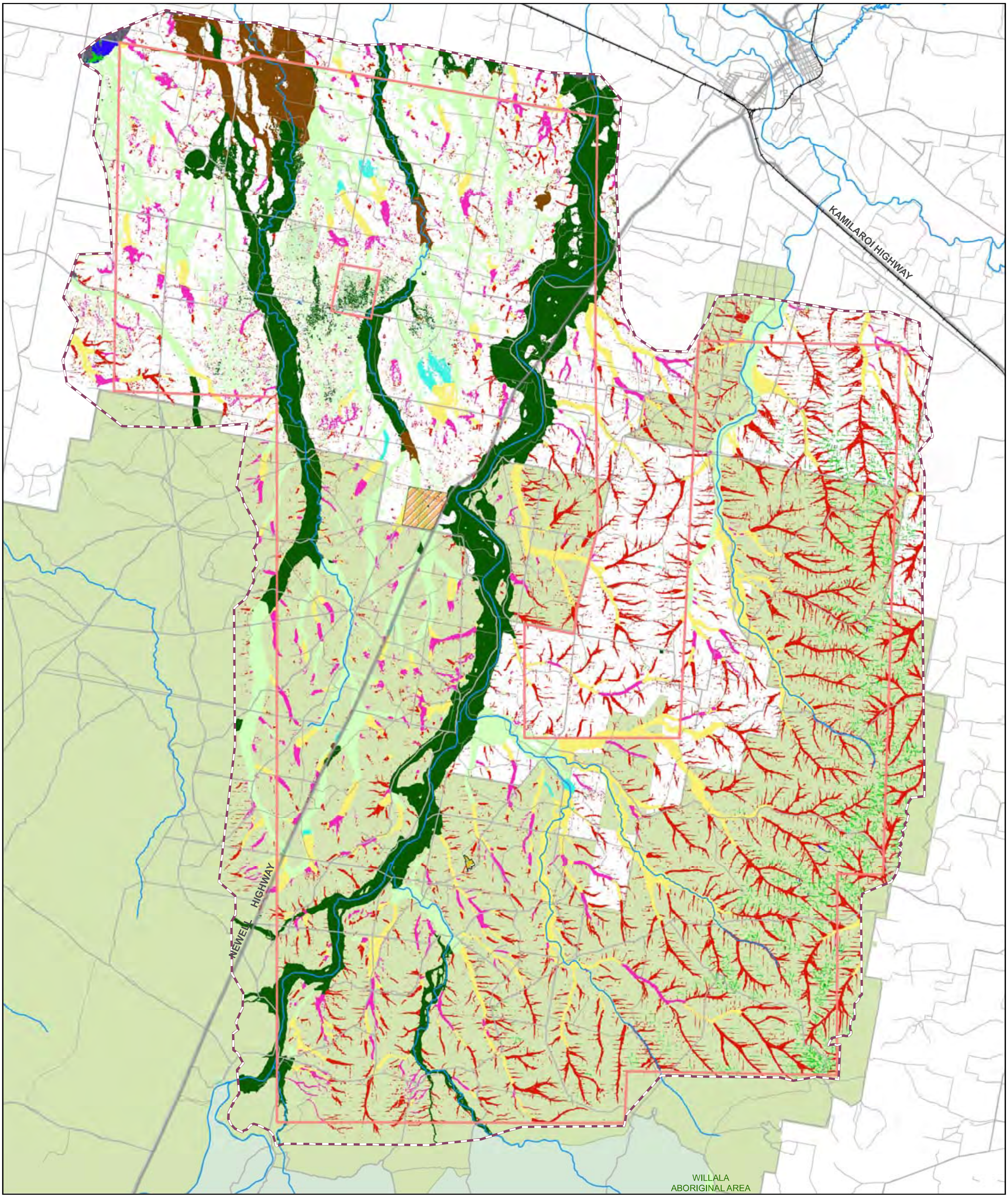
Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy



LEGEND

Project area	Watercourses	**Critical duration**	
Leewood	TUFLOW model extent	10min	180min
Bibblewindi		20min	360min
Parks and reserves		30min	720min
State forest		60min	1440min
Aboriginal areas		90min	2160min
Lakes and dams			2880min

0 1.75 3.5 7
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Narrabri Gas Project
EIS Technical Appendix Flood Study

Job Number 21-22463
Revision A
Date 12 Dec 2016

Spatial Variation in Critical Storm Duration 1% AEP

Figure 5-11

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Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:afoddy

5.1 Discussion of Results

Taking into consideration the quality of the hydrological analysis and the data underlying this analysis as well as the extent of the project area (some 45 kilometres in the north to south direction and 35 kilometres in the east to west direction), it is estimated that the current hydraulic model provides a reasonable broad-scale estimate of the one per cent AEP flooding in the area.

If additional fine-scale detail of flooding in small watercourses and channels (particularly in the upper reaches near the project area boundaries) is required, additional 1D channel sections could improve the estimation of flow characteristics in these areas. Sensitivity analysis prior to the implementation of the current 1D sections indicated that using additional breaklines to define gullies is not effective at the 10 metre grid size.

5.2 Qualifications

It should also be noted that the flood results are only valid within the project area (refer Figure 1-1). Flood results located between the project area and the TUFLOW model boundary (refer Figure 4-3) should not be used.

The results of the analysis are primarily subject to the accuracy of rendering in the model of the topography of the study area, the schematisation adopted in the hydrological and hydraulic modelling processes and the quality of the data available for model calibration.

In addition, the results are most sensitive to changes in land use (and the corresponding representation in the model in terms of bed roughness), the accuracy in assessing inflows from the contributing catchments, floodplain geometry, grid resolution, etc. None of the existing hydraulic structures in the project (i.e. culverts, bridges, weirs) have been considered in the analysis.

6. Conclusions

Flood analysis has been carried out for a 10 per cent AEP, one per cent AEP and the PMF events. This flood study identified the maximum flood extent, level, depth and velocity associated with these events under existing conditions.

The outputs provide information regarding the extent of flood prone land across the entire project area and will be used as inputs into future siting of project infrastructure.

The findings of the study were used to inform the assessment of the existing flooding environment for the Narrabri Gas Project - Environmental Impact Statement Hydrology and Geomorphology Study. The hydraulic model developed in this study was also used as the basis for further modelling and analysis of floodplain characteristics and the impacts of development on flooding which are further described in the Hydrology and Geomorphology Study.

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Appendix B – Table of Sensitive Receivers

Receiver ID	Flood Depth (m)	Receiver ID	1% Flood Depth (m)	Receiver ID	1% Flood Depth (m)	Receiver ID	Flood Depth (m)
1	N/A	56	N/A	111	N/A	166	1.35
2	N/A	57	N/A	112	N/A	167	N/A
3	N/A	58	0.58	113	N/A	168	N/A
4	N/A	59	N/A	114	N/A	169	0.06
5	N/A	60	N/A	115	N/A	170	N/A
6	N/A	61	N/A	116	N/A	171	1.43
7	N/A	62	0.33	117	N/A	172	N/A
8	N/A	63	N/A	118	N/A	173	0.86
9	N/A	64	0.64	119	N/A	174	0.62
10	N/A	65	N/A	120	N/A	175	N/A
11	0.69	66	N/A	121	0.13	176	N/A
12	N/A	67	N/A	122	N/A	177	N/A
13	N/A	68	N/A	123	0.62	178	0.15
14	N/A	69	N/A	124	N/A	179	N/A
15	0.10	70	N/A	125	N/A	180	N/A
16	N/A	71	N/A	126	N/A	181	N/A
17	N/A	72	N/A	127	0.38	182	N/A
18	N/A	73	N/A	128	N/A	183	1.31
19	N/A	74	N/A	129	N/A	184	N/A
20	N/A	75	N/A	130	N/A	185	N/A
21	0.10	76	N/A	131	N/A	186	0.13
22	N/A	77	N/A	132	N/A	187	N/A
23	N/A	78	1.08	133	0.10	188	N/A
24	N/A	79	N/A	134	0.15	189	1.83
25	N/A	80	0.15	135	N/A	190	N/A
26	N/A	81	N/A	136	N/A	191	0.57
27	N/A	82	N/A	137	N/A	192	N/A
28	N/A	83	N/A	138	N/A	193	N/A
29	N/A	84	N/A	139	0.54	194	N/A
30	N/A	85	N/A	140	N/A	195	N/A
31	N/A	86	0.70	141	N/A	196	N/A
32	N/A	87	N/A	142	0.21	197	N/A
33	N/A	88	N/A	143	1.30	198	N/A
34	N/A	89	N/A	144	0.06	199	N/A
35	N/A	90	N/A	145	N/A	200	0.09

Receiver ID	Flood Depth (m)	Receiver ID	1% Flood Depth (m)	Receiver ID	1% Flood Depth (m)	Receiver ID	Flood Depth (m)
36	N/A	91	N/A	146	N/A	201	N/A
37	0.32	92	N/A	147	1.64	202	0.11
38	N/A	93	N/A	148	0.06	203	N/A
39	0.15	94	N/A	149	N/A	204	0.29
40	N/A	95	N/A	150	0.07	205	N/A
41	N/A	96	N/A	151	N/A	206	0.27
42	N/A	97	N/A	152	0.15	207	N/A
43	0.84	98	N/A	153	N/A	208	0.05
44	N/A	99	N/A	154	0.07	209	N/A
45	N/A	100	0.12	155	N/A	210	N/A
46	N/A	101	0.13	156	N/A	211	N/A
47	N/A	102	2.14	157	0.40	212	1.18
48	N/A	103	N/A	158	N/A	213	N/A
49	N/A	104	N/A	159	N/A	214	N/A
50	N/A	105	0.12	160	0.44	215	N/A
51	N/A	106	N/A	161	N/A	216	N/A
52	N/A	107	0.09	162	0.89	217	N/A
53	N/A	108	N/A	163	N/A		
54	N/A	109	0.56	164	N/A		
55	N/A	110	1.14	165	N/A		

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