Chapter 13

Hydrology and geomorphology

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Chapter 13 Hydrology and geomorphology

The Secretary's environmental assessment requirements for the Narrabri Gas Project include a requirement to assess potential impacts on surface water quantity, water courses and flooding. Aspects of the assessment are summarised from the hydrology and geomorphology assessment provided in Appendix H, the Managed Release Study (Bohena Creek) in Appendix G1 and the Groundwater Impact Assessment in Appendix F. Hydrology refers to the movement, volume and distribution of surface water. Geomorphology refers to landforms and topography and in this assessment focuses on watercourse and drainage patterns.

Key aspects of these assessments that relate to hydrology and geomorphology are summarised in this chapter. Potential impacts on surface water quality are discussed in Chapter 12 (Surface water quality). Potential impacts on aquatic ecology are discussed in Chapter 16 (Aquatic ecology), while potential impacts on soils are discussed in Chapter 14 (Soils and land contamination).

The project is located within the Namoi River catchment. The major watercourses through the project area are Bohena Creek and tributaries, Bundock Creek, Mollee Creek and Jacks Creek. Drainage within the project area can be sub-divided into three main areas: Bohena Creek, western drainage and eastern drainage (refer to Figure 13-5). The watercourses in the project area are ephemeral and most have been degraded through human impacts such as clearing and the introduction of hard-hooved animals, all of which occurred prior to the commencement of the proponent's activities in the project area.

The key findings of the impact assessment in relation to hydrology and geomorphology were:

- potential impacts in and surrounding the project area would be negligible with the implementation of the Field Development Protocol and appropriate management and monitoring
- localised increases in flood depth and extent would occur near Leewood, but the impact would be negligible
- there are no anticipated changes to flooding at Bibblewindi
- localised flooding impacts would be negligible as a result of the placement of linear and non-linear infrastructure
- negligible impacts, are anticipated from the construction of linear infrastructure watercourse crossings
- negligible flooding and geomorphic impacts would result from the managed release in to Bohena Creek.

During operation, the key potential impact on hydrology and geomorphology would be associated with the managed release of treated water to Bohena Creek. Modelling of the proposed release was undertaken which concluded there would be no impacts associated with flood levels or water volumes during managed release under appropriate flow conditions within Bohena Creek (surface water quality impacts are addressed in Chapter 12 – Surface water quality). It is likely that there would be localised geomorphic impacts, such as erosion or deposition, associated with the managed release structure; however, with the implementation of suitable construction and mitigation measures, potential impacts were assessed to be negligible.

It is important to note that the Field Development Protocol would inform the selection of crossing locations for surface water drainage lines and the placement of infrastructure to minimise impacts, where practicable. The implementation of erosion and sediment controls would further reduce potential impacts. Suitable bed and bank protection would be provided in the vicinity of the managed release structure at Bohena Creek. A Water Monitoring Plan would be implemented to identify changes in water volumes and / or quality as a result of this project (refer to Appendix G3).

Due to the use of appropriate design and implementation of the Field Development Protocol and appropriate management and monitoring, it is concluded that the potential impacts on the hydrology and geomorphology in and surrounding the project would be negligible.

13.1 Methodology

A number of studies were undertaken to inform the hydrology and geomorphological assessment including:

- flood modelling to identity hydrology and hydraulics for a 10 per cent annual exceedance probability (AEP), one per cent AEP event, and probable maximum flood across the project area including Leewood and Bibblewindi
- classification and assessment of flood risk on flood prone land in accordance with the NSW Government *Floodplain Development Manual*
- geomorphological mapping for the project area and targeted field survey
- localised hydraulic and geomorphological assessment of Bohena Creek near the managed release discharge location
- regional groundwater modelling to assess the potential for interaction between surface water and groundwater.

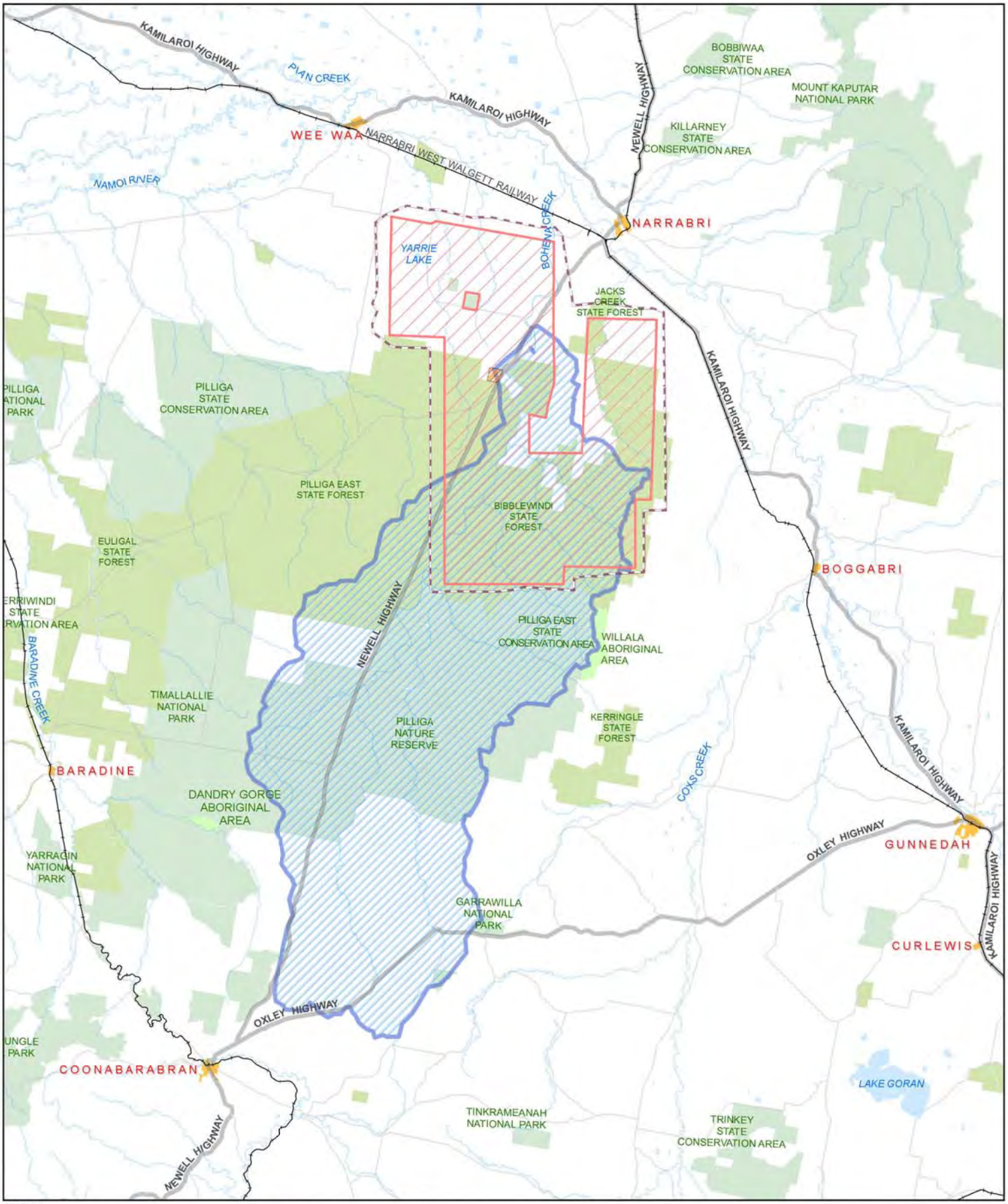
The different study areas and methodologies for each study are documented below.

13.1.1 Hydrology and hydraulics in the project area

A project wide study of hydrology and hydraulics was undertaken across the project area (Appendix H). Figure 13-1 shows the catchment area for the flood modelling that informs the hydraulic and hydrology assessment and the extent of the modelling undertaken.

To assess catchment hydrology and hydraulics, the following steps were undertaken:

- A desktop assessment of existing geographic information system (GIS) data, aerial imagery and climatic data to develop an understanding of existing catchment conditions.
- Hydrologic and hydraulic flood modelling of the study area for flood events with varied annual exceedance probability (AEP) including the 10 per cent AEP, 1 per cent AEP event, and probable maximum flood event and definite of flood risk to people and property in accordance with the NSW Government *Floodplain Development Manual* (2005).
- 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
- Site-specific assessment of post construction flood impacts at Leewood as the site of major facilities including the central gas processing facility, water management infrastructure and power generation.



LEGEND

- Project area
- Leewood
- Urban Areas
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Hydrological catchment
- 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
Environmental Impact Statement

Upstream catchment area and model extent for hydrological assessment

Job Number 21-22463
Revision A
Date 06 May 2015

Figure 13-1

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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

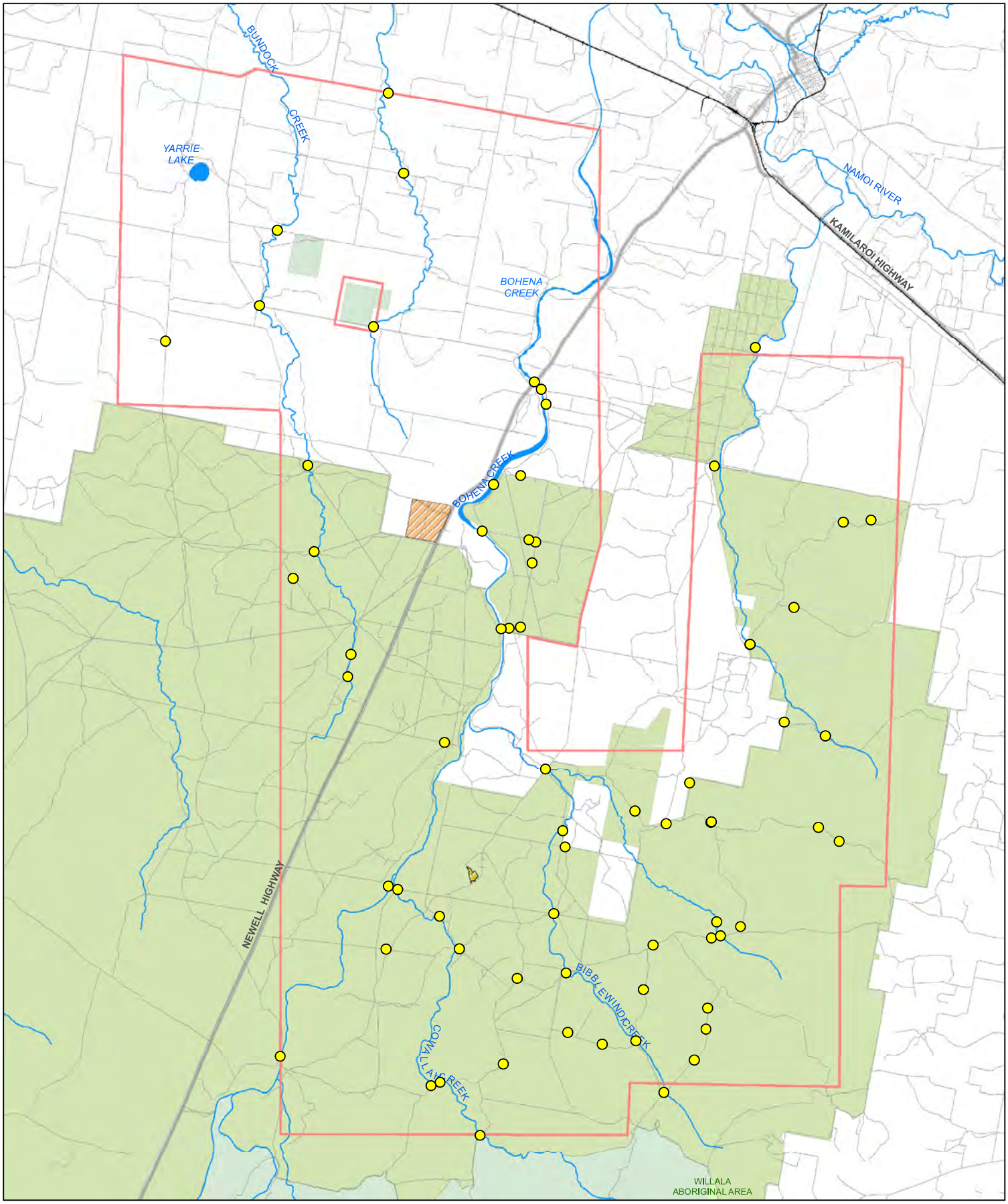
13.1.2 Project area watercourse geomorphology

To determine the existing geomorphology of the project area the following was undertaken:

- a desktop assessment of existing information to:
  - develop a preliminarily map of the watercourses
  - identify the watercourse types
  - understand the geomorphic condition and stream order of the watercourses
- a site investigation to identify the baseline physical characteristics and geomorphic condition of the watercourses within the project area (this was completed in February 2014).

A targeted geomorphological field survey was undertaken across the project area at locations as shown in Figure 13-2. Watercourses within the project area were allocated an order following the Strahler stream classification system. Under the Strahler classification, watercourses are given an 'order' according to the number of additional tributaries associated with each watercourse (Strahler 1952). Figure 13-3 indicates the Strahler stream ordering process for a generic catchment. Numbering begins at the top of a catchment with headwater, or '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.



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

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
Environmental Impact Statement

Field survey locations for geomorphological investigation

Job Number 21-22463
Revision A
Date 12 Dec 2016

Figure 13-2

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Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy

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

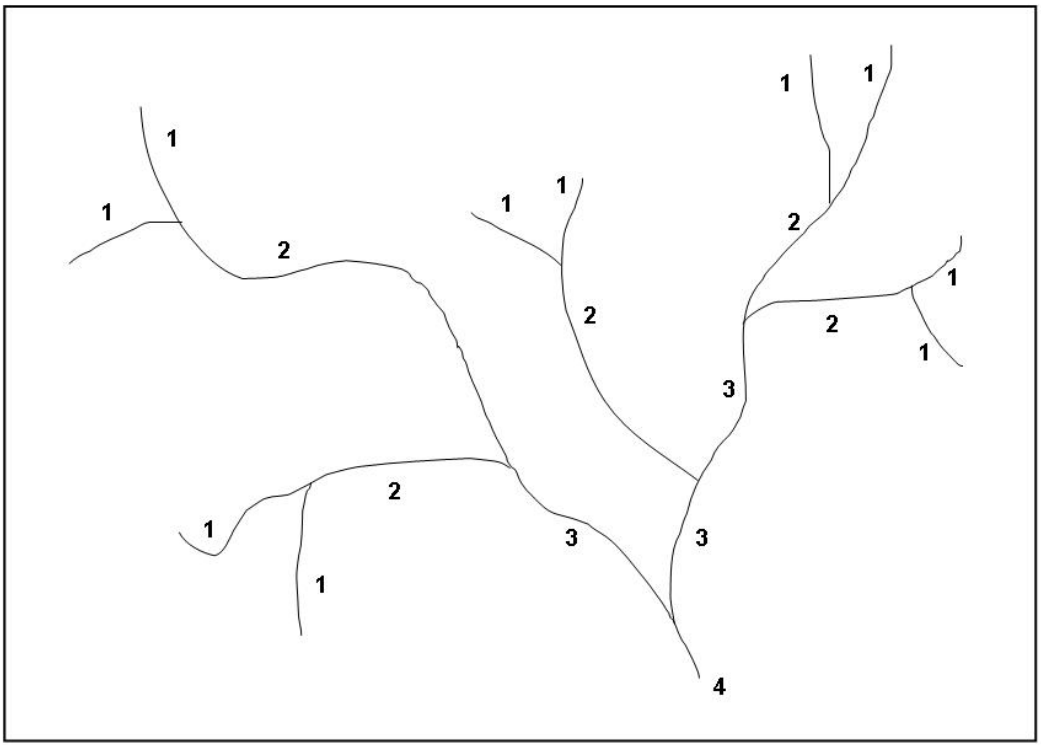

Figure 13-3 Stream order for a generic catchment (after Strahler 1952)

13.1.3 Localised hydrology, hydraulics and geomorphology of Bohena Creek

A localised flood model was developed to identify the potential flow and geomorphological impacts on Bohena Creek from the proposed managed release of treated water under flow conditions. The study area for the Bohena Creek managed release scheme and the approximate location of the managed release is shown in Figure 13-4. The conservative flood model assumed a constant treated water flow of 12 megalitres per day from the Leewood water treatment plant, with flows in Bohena Creek varying according to various weather scenarios. Managed release would only occur to Bohena Creek when daily flow is greater than, or equal to, 100 megalitres per day as measured at the Newell Highway gauging station. Appendix G1 provides further detail on the modelling methodology.

To identify potential geomorphic impacts associated with the managed release, key geomorphic features were mapped along the reach of Bohena Creek applicable to the managed release. This work involved:

- desktop mapping using a combination of aerial imagery and surface elevation data
- site inspection to ‘ground truth’ desktop findings
- assessment of natural geomorphic adjustment over time by analysing historic planform change within Bohena Creek using aerial imagery and Cadastral data
- assessment of the interaction between surface water and groundwater between Bohena Creek and shallow aquifers
- prediction of potential sediment transport by using flood modelling to obtain an estimate of average channel velocity for Bohena Creek.

LEGEND

- Study area
- Provisional managed release location
- Leewood
- State forest
- Watercourses
- Roads

0 0.325 0.65 1.3
Kilometers

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

N

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Narrabri Gas Project
Environmental Impact Statement

Job Number 21-22463
Revision A
Date 09 Dec 2016

Bohena Creek managed release provisional location and study area

Figure 13-4

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

13.1.4 Interaction between surface water and groundwater

The potential effects of depressurisation of coal seams and other geological layers on surface water bodies were assessed as part of the Groundwater Impact Assessment (refer to Chapter 11 – Groundwater and geology, and Appendix F).

A hydrogeological conceptual model was prepared to consolidate current understanding of the groundwater systems within the region (refer to Appendix F). The conceptual model is a simplified representation of the key features of groundwater systems, based on interpretation of available data and information. The conceptual model forms the basis for establishing the environmental values for groundwater, and provides the framework for assessing and managing potential groundwater related impacts from the project. It also provides the framework for assessing and managing potential surface water impacts resulting from changes to groundwater.

A regional-scale numerical groundwater flow model of the Gunnedah Basin was then developed based on the hydrogeological conceptual model referred to above. The groundwater model was used to predict the potential impacts on groundwater sources within the region due to water extraction from the coal seams that would be targeted for gas production. Simulations of water extraction from the coal seams provide regional-scale predictions of depressurisation and drawdown of hydraulic head within the Gunnedah Basin, and the associated induced flows between these and other groundwater sources. It therefore, identifies potential impacts with regard to surface water volumes.

A number of studies have been undertaken to assess the surface water-groundwater connectivity and interaction within the Namoi Catchment (Ivkovic 2006). These studies, as well as the model referred to above, were drawn on to inform the assessment of surface-groundwater interaction.

13.1.5 Flood planning

The assessment of hydrology in the project area has been undertaken pursuant to a series of guidelines including the flood planning provisions of the Narrabri Shire Council *Narrabri Local Environmental Plan 2012* and the NSW Government *Floodplain Development Manual*.

Narrabri Local Environmental Plan 2012

Clause 6.2 of the *Narrabri Local Environmental Plan 2012* prescribes requirements for development in a flood planning area. The plan states that development in a flood planning area should not “significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties”. The flood planning area includes land at or below the flood planning level of a 1 in 100 year ARI flood event plus freeboard.

In consideration of the proposed land use for the project, the one per cent AEP event has been adopted as an appropriate flood planning level for the design of the project and has been modelled through the hydrology assessment.

The Field Development Protocol would ensure large dams and ponds are outside this flood planning level, while other infrastructure sited in accordance with the Field Development Protocol and within this flood planning level would be designed and installed for negligible modification of flows.

The layout of major infrastructure at Leewood and Bibblewindi has been designed in consideration of the flood planning level. The flood assessment indicates that flooding at these locations in the one per cent AEP event would not significantly affect other development or properties.

Floodplain Development Manual

The primary objective of the NSW Government *Floodplain Development Manual* is to reduce the impact of flooding on flood prone land. A key part of the *Floodplain Development Manual* is the Flood Prone Land Policy to be implemented by local councils with support from the NSW Government to achieve this objective. The policy provides that local councils are responsible to determine flood controls including flood planning levels such as that under the *Narrabri Local Environmental Plan 2012*.

This hydrology assessment considered a number of matters described in the manual including:

- flood prone land – defined by the extent of the probable maximum flood
- flood planning area – defined by the extent of the one per cent AEP flood
- flood hazard – defined as a product of flood depth and velocity
- hydraulic category – flood prone land categorised by potential impacts of development.

These matters are considered in Sections 13.3 and 13.5.

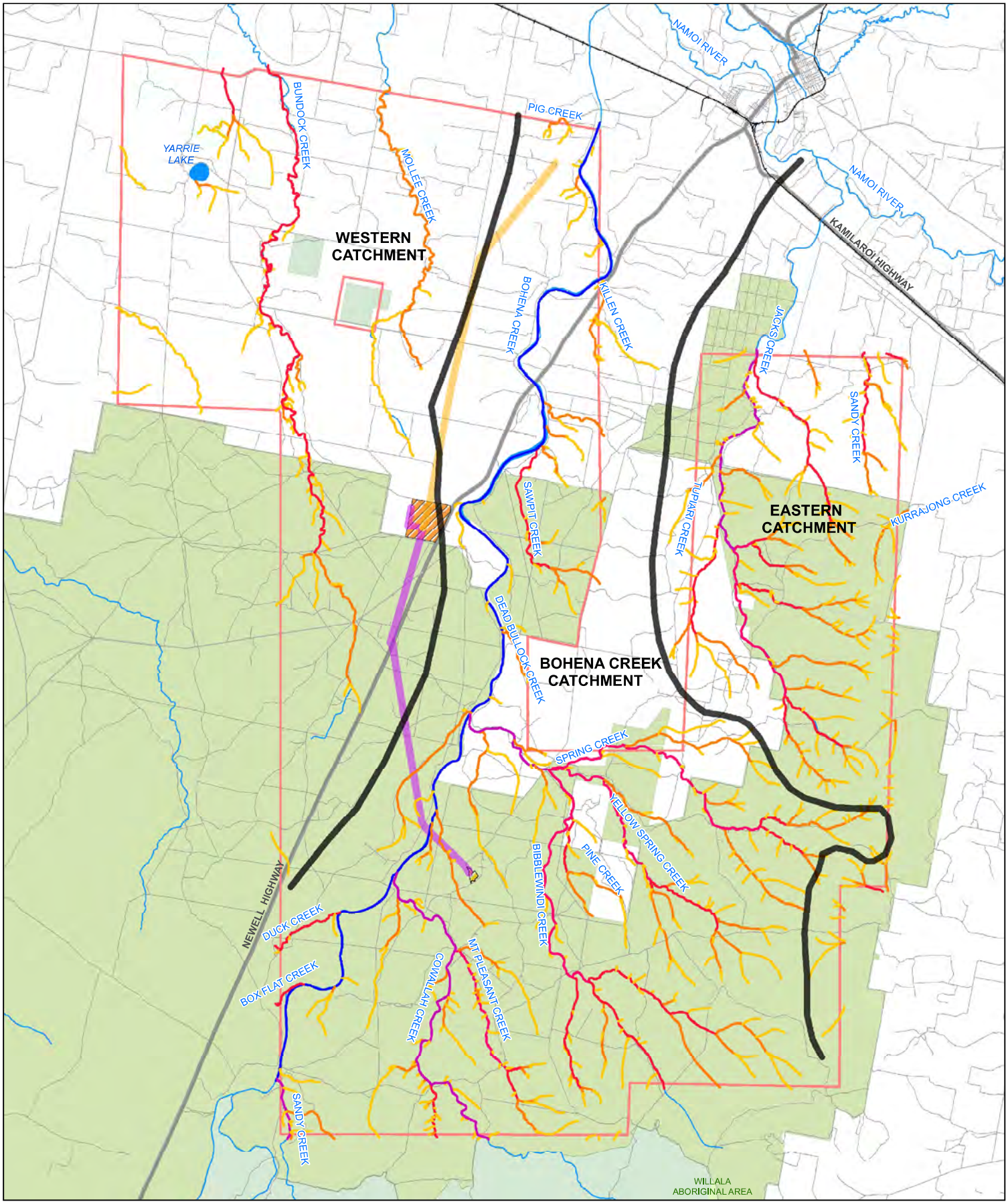
13.2 Existing environment

13.2.1 Project region

The project is located in the Namoi catchment in the central north of NSW within the Murray Darling Basin. The headwaters of the Namoi River rise on the western slopes of the Great Dividing Range north of Tamworth and flows north-west for approximately 350 kilometres before joining the Barwon River near Walgett. The Namoi River is a perennial system, with highly variable flows, and is regulated below Keepit Dam (upstream of Narrabri) by releases from the dam. Many of the tributaries of the Namoi River are intermittent or ephemeral with flow only observed following significant rainfall events (Schlumberger 2012).

Drainage within the project area can be sub-divided into three main areas: Bohena Creek, western drainage and eastern drainage (refer to Figure 13-5).

Bohena Creek is the main watercourse system flowing through the project area and generally flows in a northerly direction from its tributaries in the footslopes of the Warrumbungle Ranges to the Namoi River approximately 10 kilometres downstream of Narrabri. Bohena Creek is considered a sixth order stream and is classified as intermittent, flowing predominantly during heavy rainfall, and also after protracted periods of rainfall.



LEGEND

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

Stream order

- 1
- 2
- 3
- 4
- 5
- 6

- 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

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Narrabri Gas Project
Environmental Impact Statement

Job Number 21-22463
Revision A
Date 09 Dec 2016

Catchments and stream order within the project area

Figure 13-5

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Bohena Creek remains dry for extended periods between runoff events, sometimes for more than 12 months. It is understood that Bohena Creek contributes little inflow to the Namoi River under normal conditions but can generate significant flood inflows during protracted wet conditions.

The largest tributaries that drain into Bohena Creek are shown in Figure 13-5. They are:

- Spring Creek, which is an undisturbed watercourse that joins Bibblewindi Creek
- Yellow Spring Creek, which runs south-east to north-west to join Bibblewindi Creek
- Bibblewindi Creek, which runs north westwards to Bohena Creek
- Mt Pleasant Creek, which runs north west to Cowallah Creek
- Cowallah Creek, which runs northwards to join Bohena Creek.

Watercourses in the western drainage area typically flow north through the project area before trending more westerly. Downstream of the project area, these watercourses flow into the Namoi River either directly or via a number of creeks including:

- 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.

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

- 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 (east of the project area) before joining the Namoi River.

13.2.2 Rainfall and evaporation

Rainfall in the project area is highly variable; the warmer months are generally wetter than the cooler months. Relevant data (1900 to 2013) are as follows:

- 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 average annual evaporation total is 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. Evaporation is highest in the warmer months and lowest in the cooler months.

13.2.3 Watercourse geomorphology

Most watercourses in the project area comprise a Strahler stream order of minor (first to third order) (refer to Figure 13-5). The exceptions are:

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

There are four main watercourse groups, and seven different stream types in the project area as summarised in Table 13-1. Further detail, including schematics and photographs are included in Section 4.6 of Appendix H.

Table 13-1 Summary of watercourse group and stream types in the project area

Watercourse group	Stream type	Description
Unchannelised systems Relatively flat, unincised valley floor surface with substrates comprised of alluvial fine silts, sands and muds.	Valley fill systems	Flat valley floor with no defined channel such that the whole valley floor acts as a channel with valley margins as the banks. Valley fill systems are located throughout the project area along first to fourth order streamlines.
	Chain of pond systems	Display a series of symmetrical (occasionally irregular) ponds that occur at irregular intervals along a poorly defined drainage line set within an alluvial valley floor. Chain of ponds systems occupy lower catchment positions along streamlines set within Pilliga outwash sediments, namely Bohena, Mollee, Bundock and Oakyhole creeks.
Confined systems Single, symmetrical channel often in bedrock controlled, irregular V- or U-shaped valleys. Confined systems in the project area included headwater systems and confined valley sand systems.	Headwater systems	Steep gradient channels in a narrow valley (less than 5 metres wide). Headwater systems are largely located in upper catchment positions along first and second order tributaries feeding the eastern drainage streamlines.
	Confined valley sand systems	Low sinuosity channel set within narrow bedrock or terrace bound valley. Confined valley sand systems are located in middle to upper catchment positions, typically along second to third order streamlines.
Partly confined valley systems Dictated largely by the confinement of the valley that can control between 10 and 90 per cent of the length of the channel.	Platform controlled, low sinuosity sand systems	Slightly irregular valley with valley margins which may be bedrock or terrace that limit lateral migration of the channel. Discontinuous floodplains are formed as the channel crosses the valley floor from one valley margin to the other. Located in middle to lower catchment positions typically along third to sixth order streamlines. The majority of Bohena Creek through the project area consists of this system.

Watercourse group	Stream type	Description
Laterally Unconfined Valley Systems Limited or no valley influence on the channel and exhibit floodplains bounding both sides of the channel.	Low sinuosity sand systems	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. Low sinuosity sand systems are located in middle to lower catchment positions on third to fourth order segments of Bibblewindi, Pine and Sawpit creeks.
	Channelised fill systems	Continuous channel that has incised, probably since European settlement, into valley fill or chain of ponds through headcut retreat and channel expansion. Located throughout the project area in middle to upper catchment positions, typically along first to third order streamlines.

Despite the project area being largely vegetated, the geomorphic condition of many of the streamlines is moderate to poor due to past channel incision and enlargement. It is likely most of these 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 – for example, construction of tracks across watercourses resulting in channel bed disturbance, leading to scour and incision
- indirect disturbances – for example, clearing and altered fire frequencies leading to increased runoff 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 is also still evident across the project area.

Good condition watercourses make up approximately half of the assessed stream length. Good condition reaches are primarily located on first order streamlines and are largely valley fill and headwater stream types. The condition of watercourses generally decreases with increasing stream order, with no fifth order streamlines assessed to be in good condition. Figure 13-6 provides a comparison of watercourse geomorphic condition against stream order.

The fragility of watercourse geomorphic types in the project area was assessed based on the potential for the watercourse type to adjust. The application of a geomorphic disturbance risk framework to watercourses within the project area is shown in Figure 13-7. Further information on this assessment is provided in Section 4.6.4 of Appendix H.

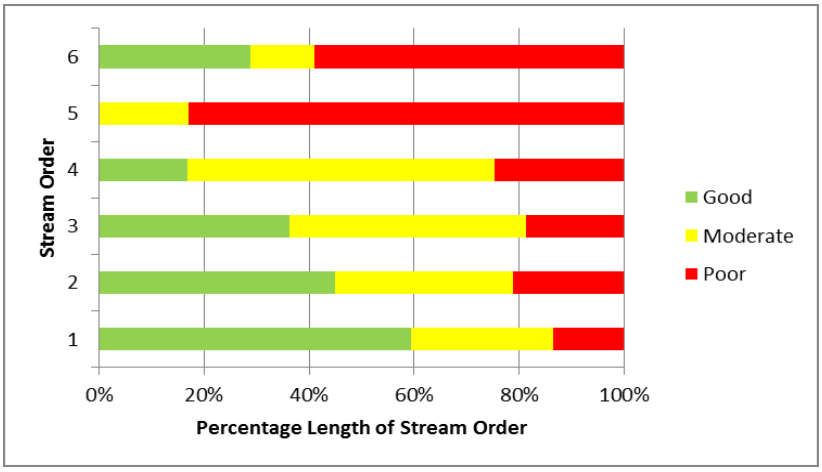
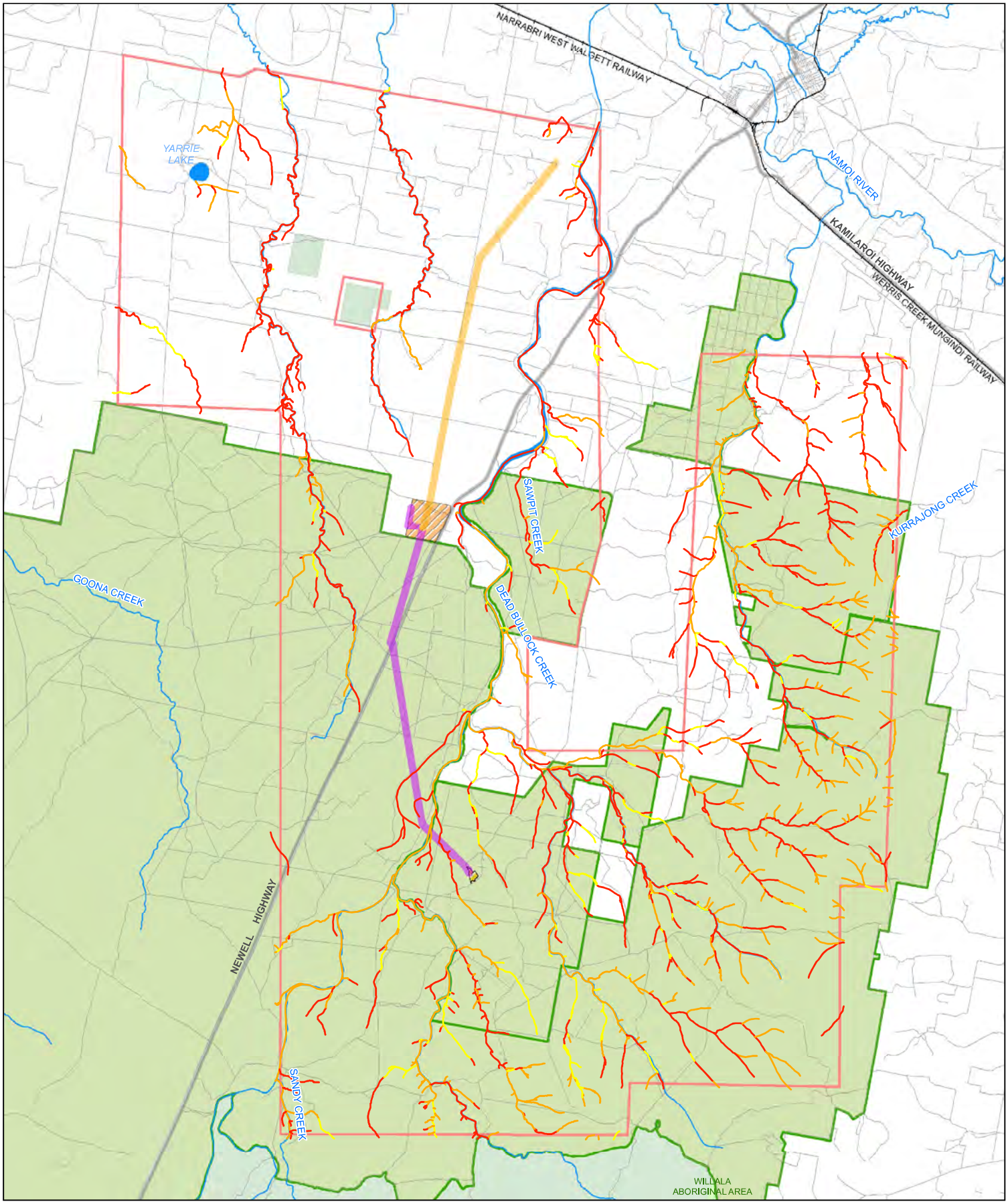


Figure 13-6 Geomorphic condition of watercourses by stream order



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

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Narrabri Gas Project
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Job Number 21-22463
Revision A
Date 09 Dec 2016

Watercourse disturbance risk

Figure 13-7

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

13.2.4 Bohena Creek managed release reach

The reach of Bohena Creek identified for the managed release of treated water is located on the Pilliga Outwash—a geomorphic term for the aggradational landscape with deposition of sediment. The sediment was sourced from the erosion of the Pilliga Sandstone plateau. The area in question is a low-lying landscape of undulating alluvial sediments, where local relief does not exceed 10 metres. It is traversed by numerous drainage lines; many being abandoned paleo-channels reflecting changes in climatic conditions during the Quaternary period. Most sediment within the streams of this area is derived from upstream or as a result of reworking of the broad outwash plain.

Within the vicinity of the proposed managed release area, Bohena Creek is braided, within a wide and stable channel planform. The braided channel is composed of mobile sand bars (high points in the channel bed) and a series of depressions (low points in the channel bed) creating low-flow channels. In-channel sediments are highly mobile under high flow conditions. Within the managed release area, Bohena Creek is in a moderate condition and is considered at high risk of disturbance.

Data from the Newell Highway gauging station for the period between 1995 to 2005 show that Bohena Creek flows only about 15 per cent of the time in the vicinity of the proposed managed release point, and around 12 per cent of the time over 100 megalitres per day. On average, monthly flows between January and June are lower than from July to December. Refer to Appendix G1 for modelled flows in Bohena Creek in the vicinity of the managed release area.

13.2.5 Watercourses near major project infrastructure

Watercourses near major infrastructure were identified to assist with the impact assessment presented in Sections 13.4 and 13.5. They are as follows:

- Leewood is located approximately 380 metres west of Bohena Creek at its nearest point. There are no other watercourses in the vicinity of Leewood, however the site is crossed by overland flow.
- Bibblewindi is not located near defined watercourses. Bohena Creek is approximately two kilometres to the west and Bibblewindi Creek approximately two kilometres to the east. There are also un-named first order watercourses approximately 650 metres east and west of Bibblewindi. The infrastructure at Bibblewindi is subject to minor flooding of less than 100 millimetres during the one per cent AEP flood event.
- The Bibblewindi to Leewood infrastructure corridor crosses Bohena Creek and a number of un-named first order watercourses that are tributaries to Bohena Creek. Bohena Creek is defined as being in poor condition and at moderate risk of disturbance at the crossing location. The un-named watercourses are classified as being in good condition and at high risk of disturbance. The infrastructure corridor also crosses several overland flow paths which flood during the one per cent AEP flood event.
- There are no watercourse crossings along the Leewood to Wilga Park underground power line corridor. The corridor would cross potential overland flow paths which flood during the one per cent AEP flood event.

13.2.6 Interaction between surface water and groundwater in the project area

The interaction between surface water and groundwater can be described in the following ways:

- streams gain water from inflow of groundwater through the streambed (a gaining stream)

- streams lose water to groundwater by outflow through the streambed (a losing stream)
- they do both at different locations and times (a gaining and losing stream).

Additionally, surface water systems may be connected or disconnected to the groundwater system. A connected surface water system is defined as having a length of river in direct contact with the underlying transmissive unit through a zone of saturated material or by a narrow unsaturated zone (Bouwer and Maddock 1997). A disconnected surface water system is characterised by the presence of an unsaturated zone between the surface water system and the underlying transmissive unit (refer to Table 13-2).

Table 13-2 Surface water system connectivity

Connection	Interaction	Unsaturated zone
Connected	Gaining	None
Connected	Losing	Narrow
Connected	Gaining and losing	None to Narrow
Disconnected	Losing	Broad

As discussed in Chapter 11, the Namoi River in the vicinity of the project is a losing stream. Whilst there is connectivity between the Namoi River and Namoi alluvium, there is no direct connection between the Namoi River and the Great Artesian Basin or Gunnedah Basin. The Bohena Creek managed release study also assessed the interaction between Bohena Creek and the underlying alluvial aquifer and Pilliga Sandstone aquifer. The model determined that Bohena Creek loses water to the perched alluvial aquifer but not to the Pilliga Sandstone aquifer (refer to Section 6.3.4 of Appendix G1). Bohena Creek is therefore a losing stream.

13.3 Catchment hydrology and hydraulics flood model

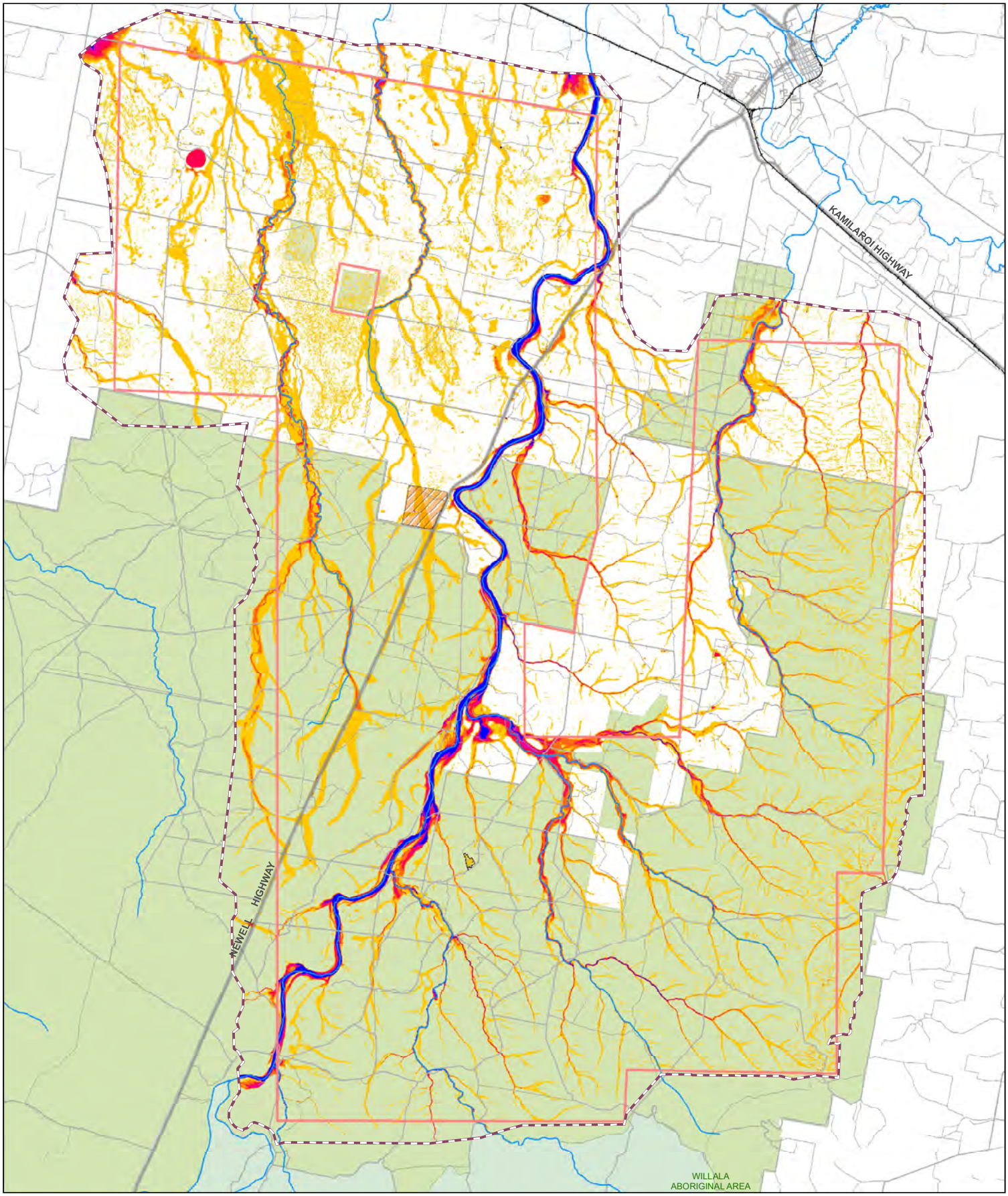
The results of the flood study informed the assessment of existing flooding conditions.

Although the study area is usually dry it contains a network of ephemeral streams and drainage lines that flow during flood events. The predicted extent and depth of the 10 per cent AEP event, one per cent AEP event and the probable maximum flood event are shown in Figure 13-8, Figure 13-9 and Figure 13-10.

As shown, flooding is concentrated around the mapped watercourses in the study area. The flows extend onto floodplains in the northern part of the study area particularly in the probable maximum flood event. With regard to the *Floodplain Development Manual* (NSW Government 2005), it is noted that the extent of the one per cent AEP event represents the flood planning area while the extent of the probable maximum flood event represents flood prone land.

The deepest flooding and highest flow velocities occur along Bohena Creek as the highest order 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.

Flood hazard posed to people and property in accordance with the *Floodplain Development Manual* (NSW Government 2005) are shown in Figure 13-11, Figure 13-12 and Figure 13-13. As shown, levels of risk are elevated in proximity to mapped watercourses in the study area except for the probable maximum flood where elevated risks extend across some drainage lines and floodplains.



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

Narrabri Gas Project
Environmental Impact Statement

Existing maximum flood depth for 10 per cent AEP event

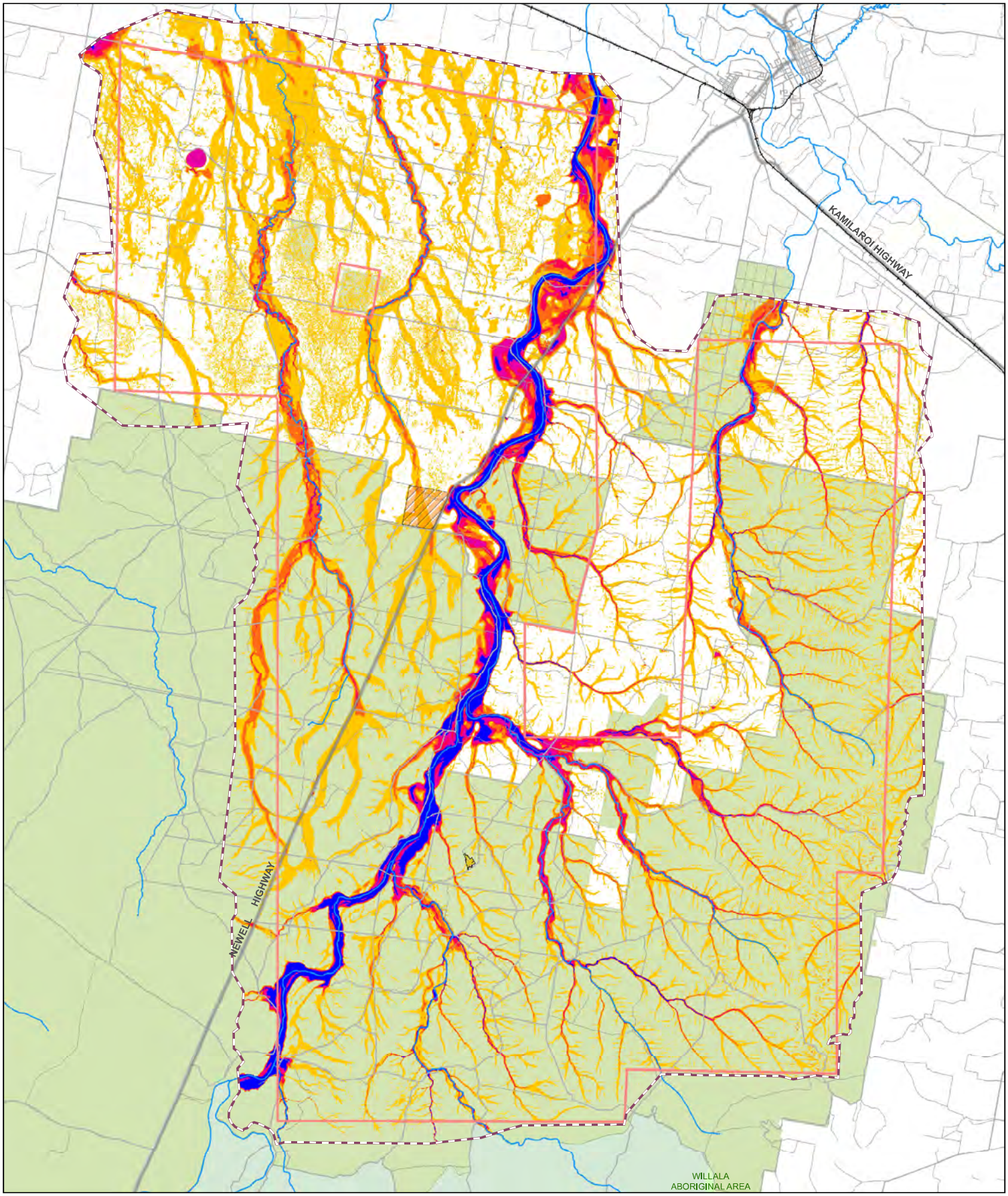
Job Number 21-22463
Revision A
Date 10 Dec 2016

Figure 13-8

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 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

Narrabri Gas Project
Environmental Impact Statement

Existing maximum flood depth for one per cent AEP event

Job Number 21-22463
Revision A
Date 10 Dec 2016

Figure 13-9

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

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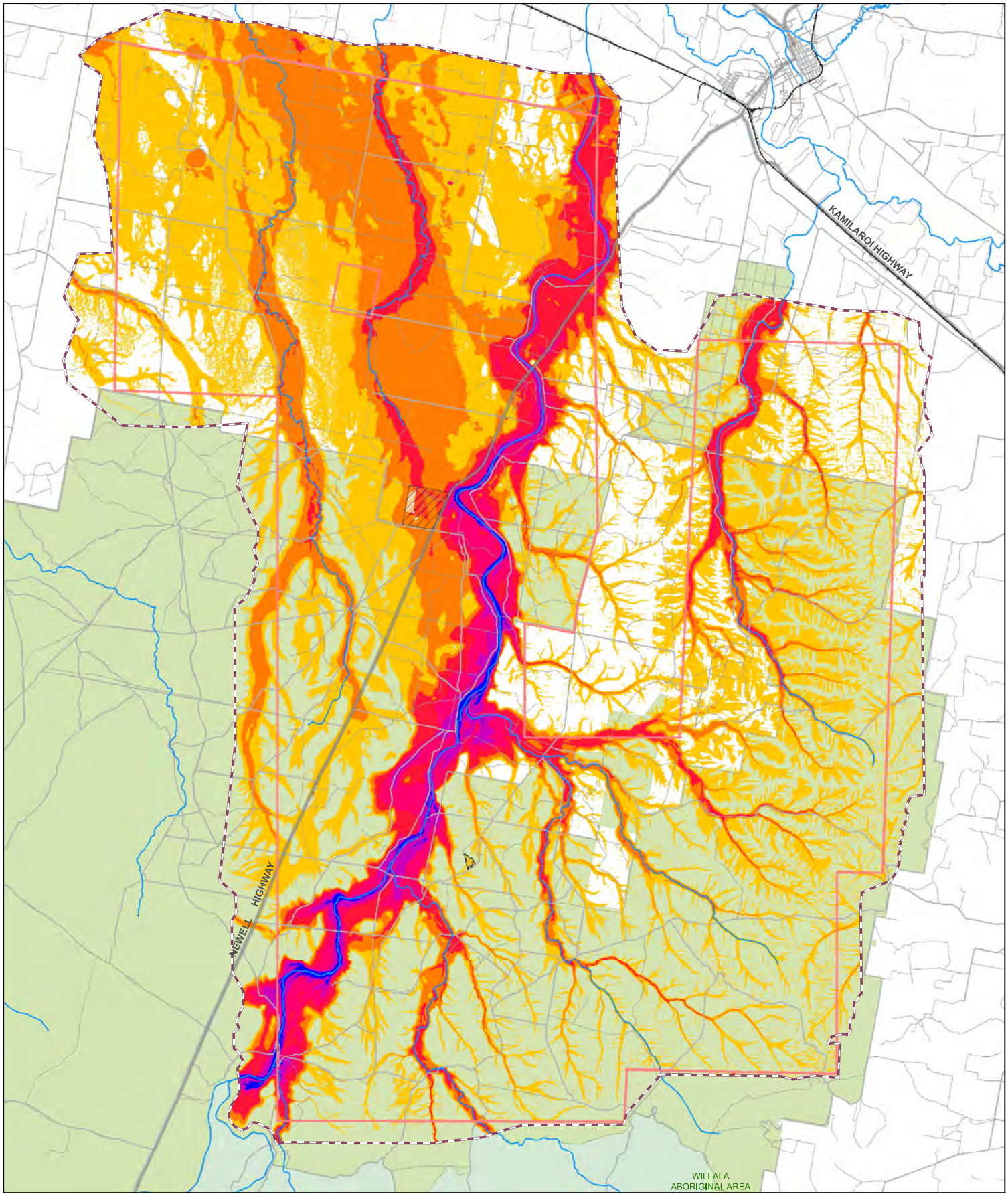

LEGEND

- 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

N

GHD

Narrabri Gas Project
Environmental Impact Statement

Job Number 21-22463
Revision A
Date 10 Dec 2016

Existing maximum flood depth for probable maximum flood event

Figure 13-10

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

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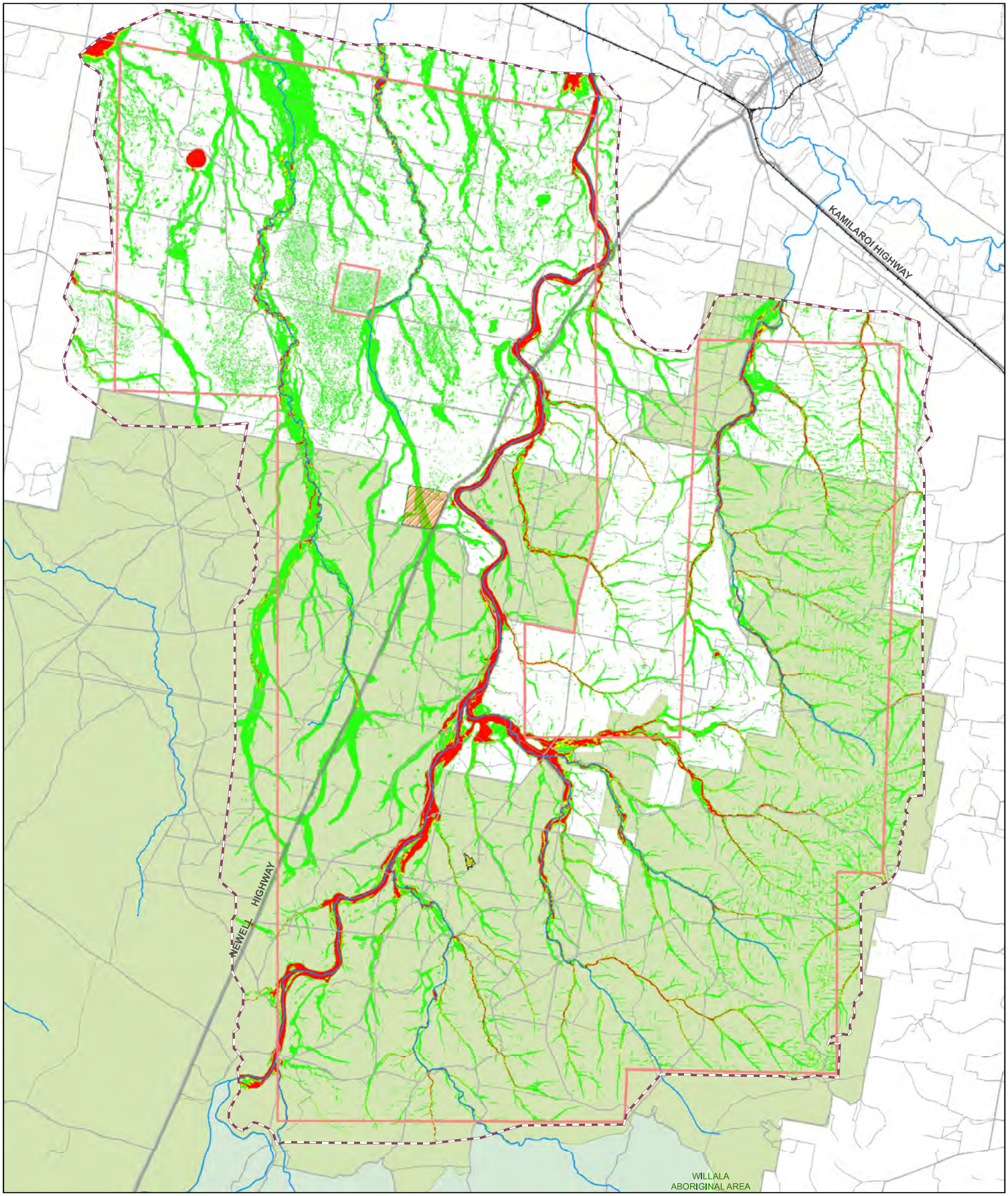


LEGEND

- 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
Environmental Impact Statement

Existing level of hazard for 10 per cent AEP event

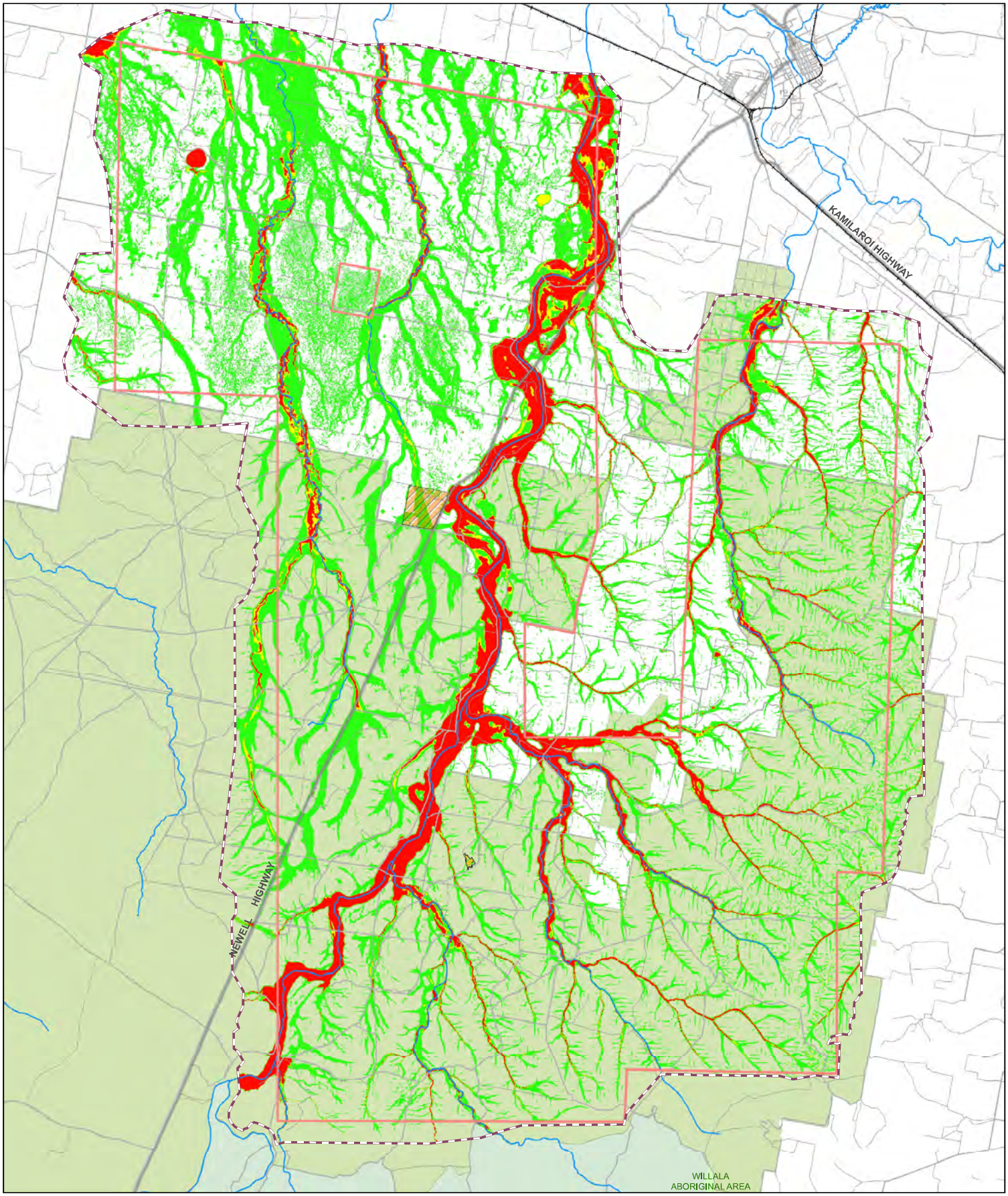
Job Number 21-22463
Revision A
Date 10 Dec 2016

Figure 13-11

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

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
Environmental Impact Statement

Existing level of hazard
for one per cent AEP event

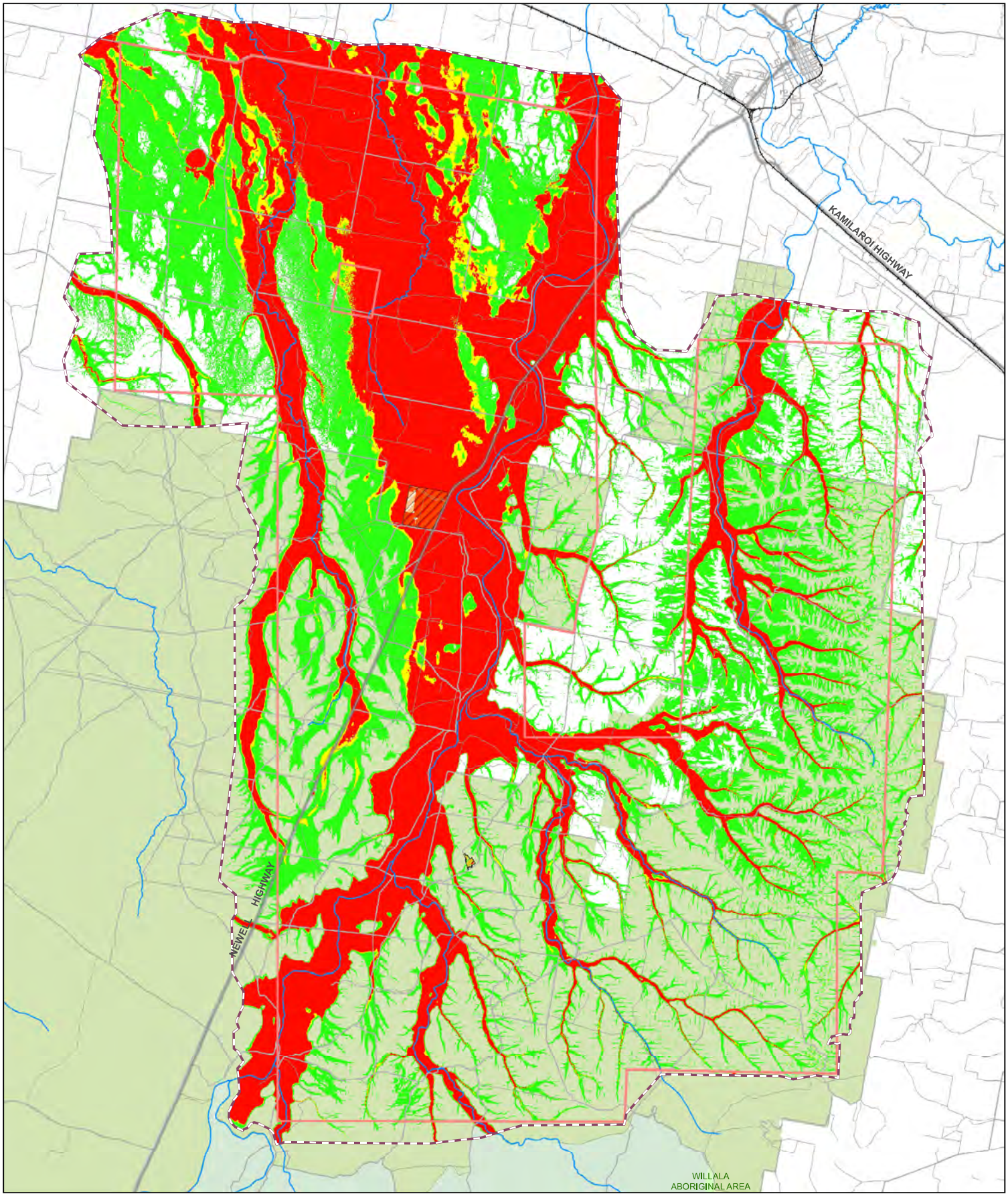
Job Number 21-22463
Revision A
Date 10 Dec 2016

Figure 13-12

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

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

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



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
Environmental Impact Statement

Job Number 21-22463
Revision A
Date 10 Dec 2016

Existing level of hazard for probable maximum flood event

Figure 13-13

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

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

13.4 Potential impacts – construction

This section provides an overview of potential construction impacts. Impacts associated with the presence of the proposed infrastructure during operation of the project are assessed in Section 13.5. A location-specific assessment was undertaken for the major infrastructure including at Leewood, Bibblewindi, Westport and the infrastructure corridors.

The amount of impact, in part, would depend on the siting of field infrastructure, which would be governed by the Field Development Protocol. The Field Development Protocol minimises potential impacts on watercourses and hydrology through the following conditions:

- Field infrastructure would be sited, designed and constructed to ensure
  - Negligible modification of flood flows
  - No ongoing impacts to geomorphology
  - Necessary erosion and sedimentation controls
- Non-linear infrastructure would be separated from riparian corridors
- Large ponds or dams would be located outside the one per cent AEP event flood extent

Additionally, project components would be established in accordance with the mitigation and management measures discussed in Section 13.6.

13.4.1 Leewood

The potential impacts at Leewood during construction would be mainly associated with the risk of flooding as there are no watercourses located on the property.

Parts of Leewood are predicted to be inundated during a 10 per cent AEP flood event, one per cent AEP flood event and probable maximum flood event. The flood flow paths traversing Leewood from south to north, and also from south-west to north.

Flooding at Leewood would represent a low level of hazard during the 10 per cent AEP flood event and one per cent AEP flood event, but with flow depths of up to 400 millimetres. During the probable maximum flood, flooding at Leewood would represent a high level of hazard.

In the event of a flood event, there is potential for flow paths to be altered due to stockpiles, machinery, equipment and structures. However, these impacts would be localised and are not anticipated to result in changes to flood levels. Long term impacts to flooding as a result of the fully constructed and operational project are discussed in Section 13.5.1.

13.4.2 Bibblewindi

Bibblewindi is subject to minor flooding of less than 100 millimetres during the one per cent AEP event. The northern extent of the site remains largely flood free even during the probable maximum flood event, with some ponding in the southern extent. It is not expected that construction at Bibblewindi would substantially impact flood flows.

There are no anticipated hydrological or geomorphological impacts of construction at Bibblewindi due to the two kilometre distance to the nearest watercourse.

13.4.3 Bibblewindi to Leewood infrastructure corridor

The Bibblewindi to Leewood infrastructure corridor crosses Bohena Creek and some associated tributaries. Construction of the corridor would involve trenching and installation of infrastructure which would require short term disturbance of the bed and banks of these watercourses. The disturbance would be short term, localised and would occur during periods of no flow.

Stormwater runoff would be readily controlled by the proposed erosion and sediment controls. Furthermore, the corridor would be subject to rehabilitation measures following construction. The potential impacts of construction of the corridor are therefore considered minor.

13.4.4 Leewood to Wilga Park infrastructure corridor

The Leewood to Wilga Park infrastructure corridor would not cross creeks, and therefore, 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 appropriate erosion and sediment controls.

13.4.5 Gas field

Hydrology and hydraulics

Construction activities in the gas field would predominately consist of well pad preparation, the drilling of wells, installation of gas and water gathering lines through plough-in or trenching, and the clearing of access tracks. Construction methodologies are described in Chapter 6.

An increase in impermeable area (such as hardstand, laydown area or associated clearing) as a result of the project could result in minor and localised increases in flows. The total increase in impervious area would be less than one per cent of the project area and regional impacts on flooding are therefore not predicted.

Potential impacts to hydrology and hydraulics are minor, highly localised and dispersed across the project area. With the implementation of the Field Development Protocol and erosion and sediment controls, impacts to hydrology and hydraulics are anticipated to be negligible.

Geomorphology

Impacts on watercourse geomorphology associated with construction of field infrastructure may include:

- disturbance of floodplains from vegetation clearing, trenching and access track construction
- alteration of watercourse bed from trenching and access track construction
- erosion of watercourse banks in areas disturbed by construction activities
- scour within a watercourse from pipeline construction.

These impacts would be localised. Due to the dispersed nature of the project, overall geomorphological impacts are anticipated to be negligible with the implementation of the Field Development Protocol and erosion and sediment controls.

Water extraction

Depressurisation of targeted coal seams from water extraction would not have a direct effect on surface hydrology. Surface water-groundwater connectivity between the targeted coal seams and surface flows is extremely limited with depressurisation highly unlikely to be expressed at the surface. Potential groundwater impacts are discussed in detail in Chapter 11.

13.4.6 Westport workers' accommodation

The expansion of Westport workers' accommodation would not occur in or near a watercourse or within areas affected by the 10 per cent AEP or one per cent AEP events. Construction of Westport workers' accommodation is therefore not expected to impact hydrology or geomorphology.

13.4.7 Bohena Creek managed release

Construction of the Bohena Creek managed release pipeline and diffuser would be undertaken during a no-flow event when no rainfall is predicted, as this would minimise the potential for impacts. However, rainfall and flow either during construction or immediately post-construction would potentially result in the following impacts:

- localised bank erosion
- localised channel bed scour / erosion.

The impacts on Bohena Creek can be minimised by implementing erosion and sediment controls and rehabilitating the banks as soon as practical following construction.

13.5 Potential impacts – operation

This section provides an overview of potential impacts during the operation of the project, including major infrastructure and infrastructure corridors, field infrastructure and ancillary infrastructure. Field infrastructure would be sited in accordance with the Field Development Protocol, with regard to potential impacts to hydrology and geomorphology as described in Section 13.4. Potential impacts include:

- Modification of watercourse hydrology at crossings
- Modification of watercourse geomorphology at crossings
- Modification of flood plain hydrology including extent, depth and velocity
- Modification of flood characteristics on adjoining properties
- Potential hydrological and geomorphological impacts of Bohena Creek managed release.

13.5.1 Leewood

To assess the operational flooding risk at Leewood, a site-specific, hydraulic modelling assessment of the existing and proposed Leewood infrastructure was carried out.

The change in flood depths (afflux) during the 10 per cent and one per cent AEP events at Leewood are shown in Figure 13-14 and Figure 13-15 respectively. As shown, predicted afflux is localised to the Leewood site and the immediately surrounding area. 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.

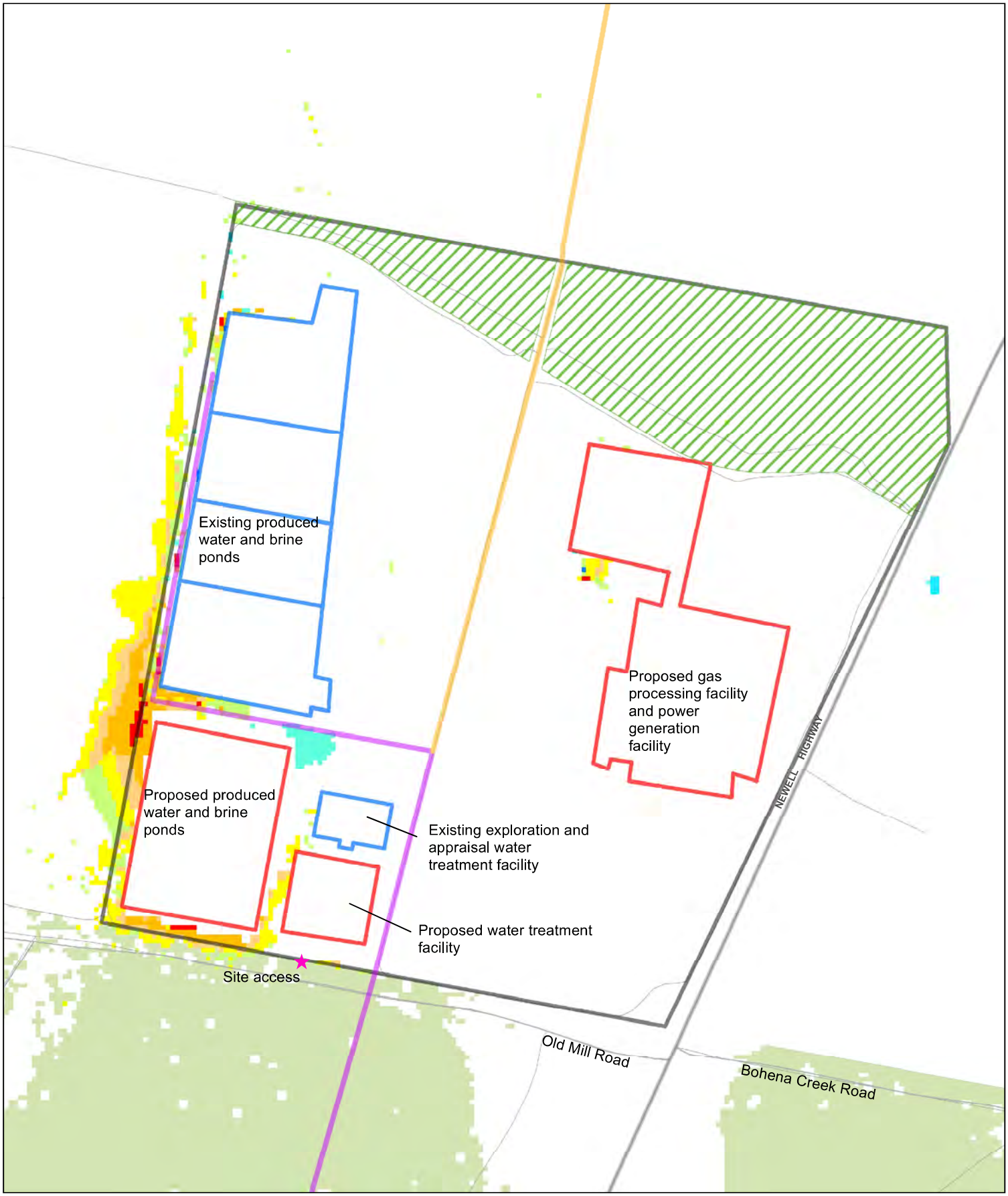
Regional flood impact from the project infrastructure at Leewood is considered to be minimal, with changes in flood levels having dissipated to less than 50 mm in some isolated areas downstream of the Leewood site.

Localised afflux is concentrated along the western boundary of Leewood and is generally less than 250 millimetres but up to 330 millimetres in some places. Afflux during the smaller 10 per cent AEP is similar but less pronounced. Afflux is not predicted to affect residences or access to properties.

Flood conditions and associated levels of hazard posed to people and property surrounding Leewood are not substantially different to existing conditions. The levels of hazard in and around Leewood for the 10 per cent and one per cent AEP events are shown in Figure 13-16 and Figure 13-17.

In the unlikely event of a very large flood in the order of a probable maximum flood event, Leewood would be affected with the majority of the site constituting a floodway constituting a high level of hazard. The nearest property to Leewood would also be affected by flooding with a high level of hazard during a flood event of this magnitude regardless of the influence of Leewood. Furthermore, the hydraulic categorisation flood prone land under the *Floodplain Development Manual* would be largely unchanged from existing conditions. The hydraulic categorisation of land at Leewood under existing and developed conditions is mapped in Appendix H.

As changes in flood depth and extent are localised and not materially different from existing conditions in terms of level of hazard or hydraulic categorisation, the hydrological impacts of the operation of Leewood are considered minor and compatible with the flood planning provisions outlined in Section 13.1.5.



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
Environmental Impact Statement

Afflux at Leewood
for 10 per cent AEP event

Job Number 21-22463
Revision A
Date 08 Dec 2016

Figure 13-14

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

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

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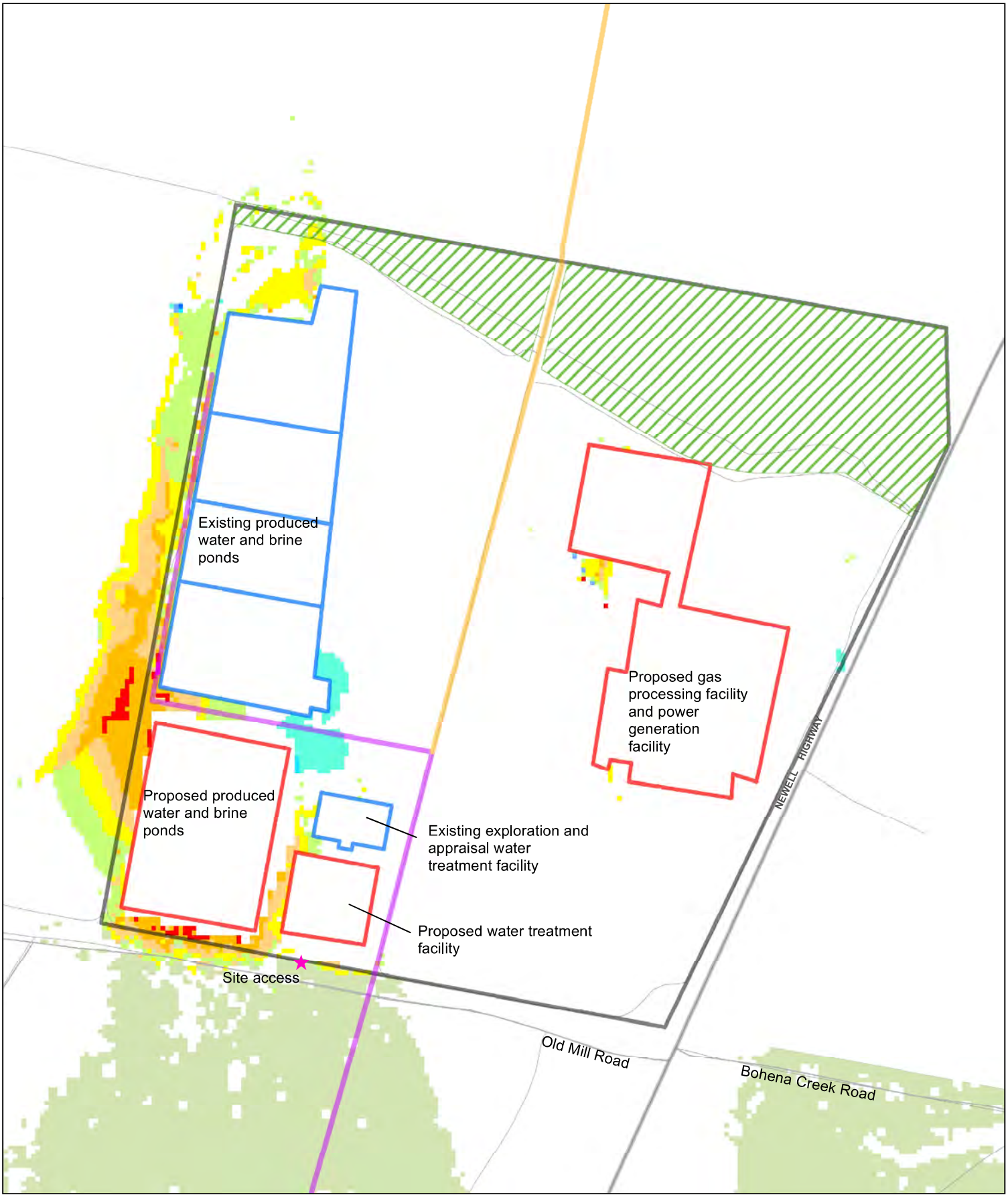

LEGEND

- 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

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Narrabri Gas Project
Environmental Impact Statement

Afflux at Leewood for one per cent AEP event

Job Number 21-22463
Revision A
Date 08 Dec 2016

Figure 13-15

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

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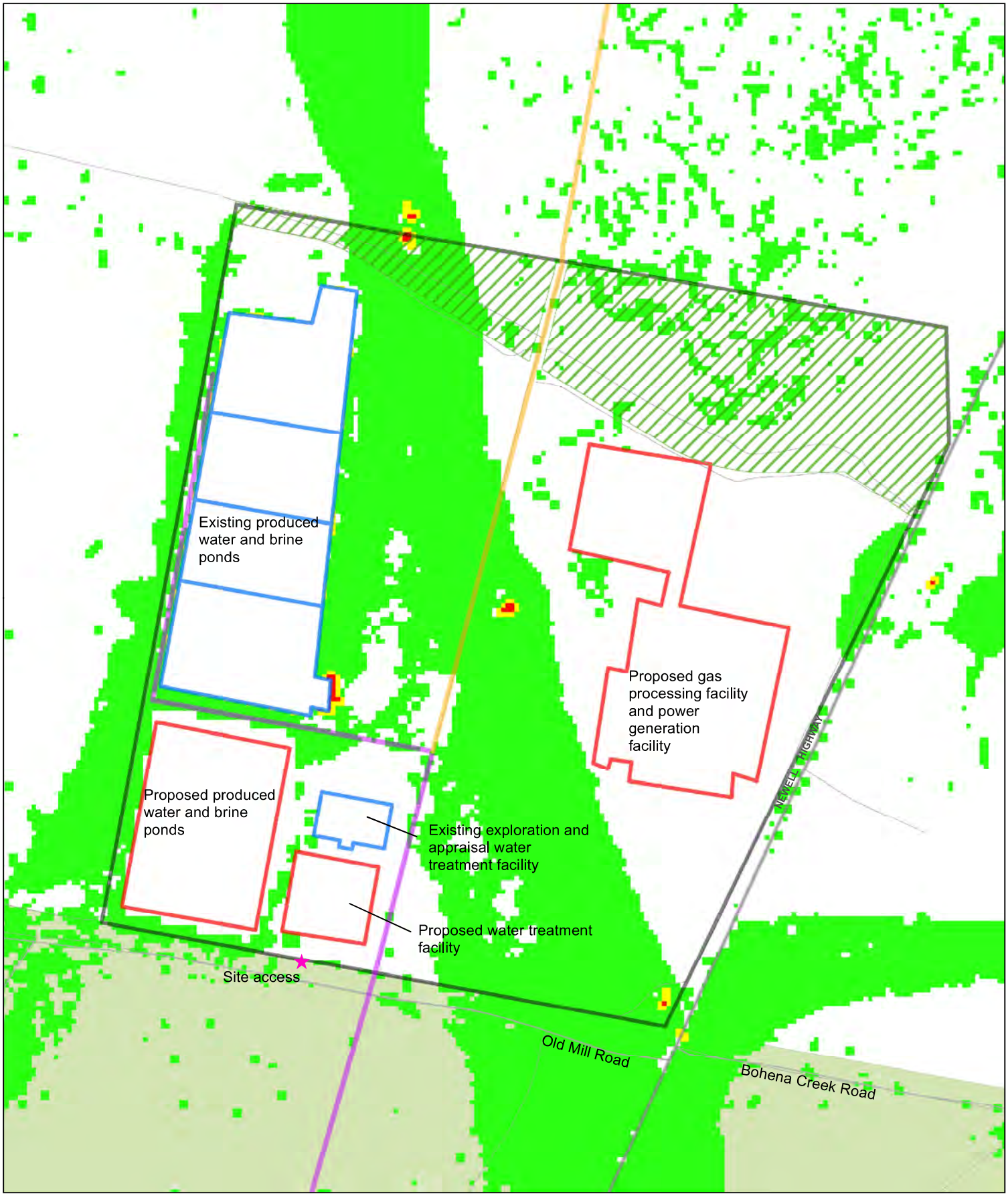

LEGEND

- 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

GHD

Narrabri Gas Project
Environmental Impact Statement

Level of hazard at Leewood for 10 per cent AEP event

Job Number 21-22463
Revision A
Date 08 Dec 2016

Figure 13-16

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

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

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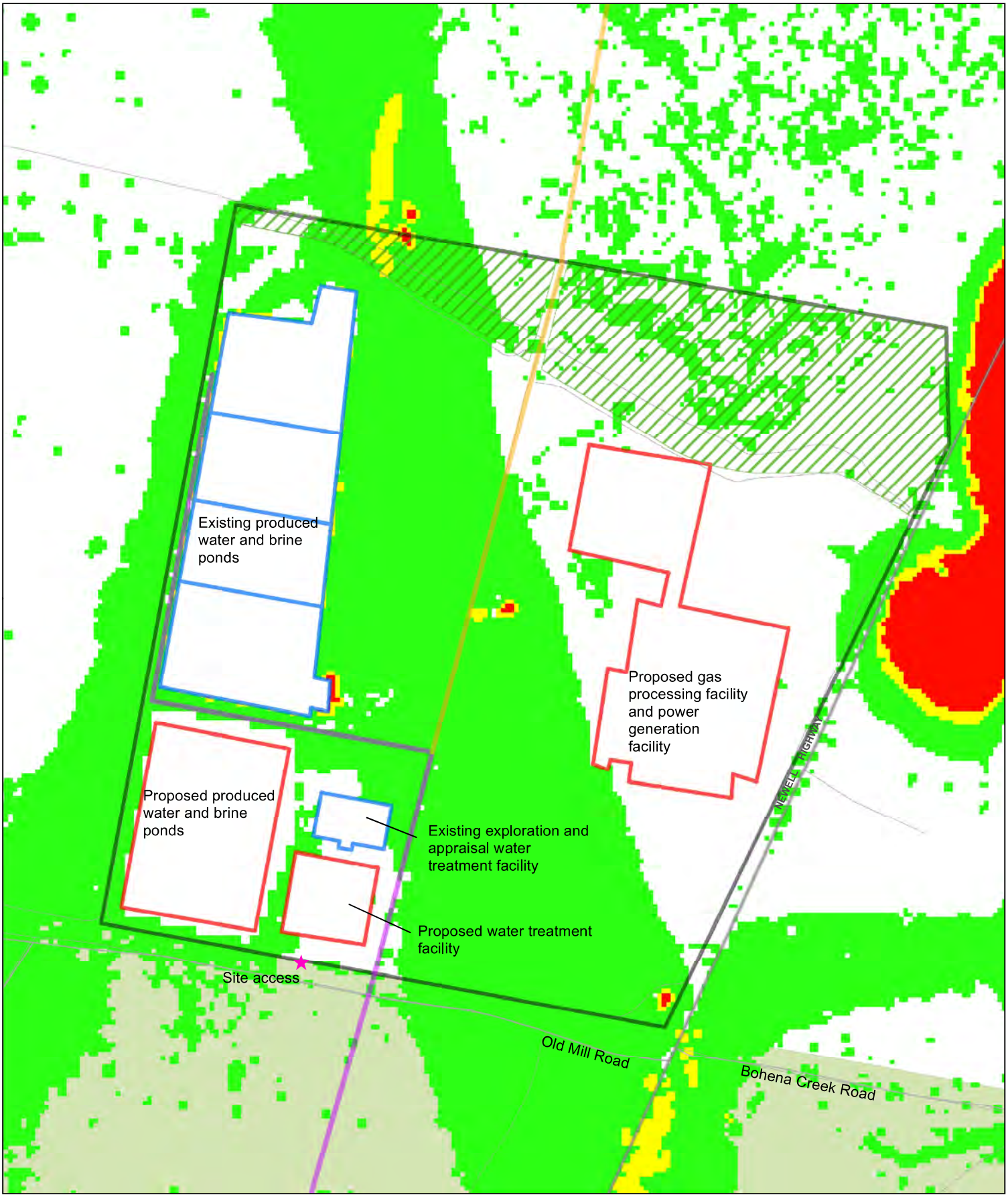

LEGEND

- 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
Environmental Impact Statement

Level of hazard at Leewood for one per cent AEP event

Job Number 21-22463
Revision A
Date 08 Dec 2016

Figure 13-17

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

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

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

13.5.2 Bibblewindi

Bibblewindi is subject to minor flooding of less than 100 millimetres during the one per cent AEP event. The northern extent of the site remains largely flood free even during the probable maximum flood event, with some ponding in the southern extent. As such, it is not expected that the project would materially affect flood flows at Bibblewindi or surrounding land.

13.5.3 Bibblewindi to Leewood infrastructure corridor

There are no anticipated impacts on Bohena Creek or tributaries during operation of the Bibblewindi to Leewood infrastructure corridor as all infrastructure would be buried and the corridor would be subject to rehabilitation measures following construction.

13.5.4 Leewood to Wilga Park underground power line

There are no anticipated operational impacts on hydrology and geomorphology during operation as all infrastructure would be located underground and no watercourses would be crossed by the corridor.

13.5.5 Gas field

Hydrology and hydraulics

Gas field infrastructure would have a limited effect on flood conditions. Potential for impacts would be greater in areas that areas that are flat, low-lying or otherwise susceptible to flood. Flood impacts would be avoided by minimising topographic change in planning and design of field infrastructure.

Well pads would be at-grade in flood vulnerable areas and would therefore not be expected to increase flood levels. Access tracks would typically follow existing topography while gas and water gathering lines would be buried and as a result would also not be expected to increase flood levels.

Where field infrastructure is positioned in areas susceptible to flood there would be potential for localised increases in flood levels. There would also be potential for localised increases in flood levels where access tracks are built on an embankment.

Potential impacts of field infrastructure would be minimised through detailed design to ensure negligible modification of flood flows including incorporation of cross-drainage as appropriate.

Geomorphology

Potential impacts of field infrastructure on geomorphology during operation would be localised to watercourse crossings for access tracks and gas and water gathering lines. If inappropriately designed or constructed, watercourse crossings can affect watercourse hydrology and consequently increase erosion and sedimentation of the watercourse bed and banks.

It is considered that the above impacts would be highly localised and negligible with the implementation of the Field Development Protocol for locating access tracks and gas and water gathering lines at watercourse crossings, the application of erosion and sediment controls, and appropriate design of vehicular crossings.

Water extraction

Depressurisation of target coal seams from water extraction would not have a direct effect on surface hydrology. Surface water-groundwater connectivity between the targeted coal seams and surface flows is extremely limited with depressurisation highly unlikely to be expressed at the surface. Potential groundwater impacts are discussed in detail in Chapter 11.

13.5.6 Westport workers' accommodation

Westport workers' accommodation would not be near a watercourse or within areas affected by the 10 per cent AEP or one per cent AEP events. A portion of Westport workers' accommodation would be affected by the probably maximum flood, however the site as a whole is predicted to be a "flood island". Westport workers' accommodation is therefore not expected to cause material impacts to hydrology or geomorphology during the operation of the project.

13.5.7 Bohena Creek managed release

The managed release of treated water into Bohena Creek may potentially result in a change to the existing surface flow regime, with the magnitude of predicted impacts be influenced by the managed release regime. The assessment of this potential impact focused on the first four years of the project when water production would be at its highest. Therefore, the assessment is highly conservative.

The study estimated that during years zero to four of the project, the increase in median flow volumes in Bohena Creek as a result of the managed release of treated water would be 0.49 per cent. This estimate is based on the rolling four-year sum of water volume under managed release relative to streamflow as based on the assessment period 1995 to 2005 when streamflow data was recorded (refer to Appendix G1). To ensure the potential for impact is minimised, managed release would only occur when the flow is equal to, or is greater than, 100 megalitres per day as measured at the Newell Highway gauging station.

As such, there is no anticipated impact on surface water quantity during years zero to four. Given that the chance of managed release in subsequent years of the project would be much lower and potentially zero, it is concluded that surface water quantity impacts in later years of the project (years five to 25) are negligible.

Whilst it is possible that managed release during streamflow events may marginally extend the period of time the creek would take to dry, the effect is considered too small to be measureable and this potential impact would diminish as water production reduces over the course of the project.

The impact of the managed release structure was assessed. It found that the structure has the potential to result in:

- localised scour of bed and banks particularly during low flow conditions
- localised scour / erosion around the managed release structure caused by lateral channel change
- being buried by sediment from upstream and blockage of the managed release structure by large woody debris from upstream
- the development of a scour pool in the channel bed at the release location
- the managed release structure encouraging sedimentation around it.

All of these impacts are considered localised and the environmental risk is considered negligible given that managed release would occur only when daily flow in Bohena Creek was equal to, or greater than, 100 megalitres per day as measured at the Newell Highway gauging station. Refer to Appendix G1 for further information and Chapter 12 (Surface water quality) for water quality impacts.

13.6 Risk assessment

The environmental risk assessment and the mitigation and management measures proposed to minimise the potential impacts on hydrology and geomorphology are presented in Table 13-3. As shown in Table 13-3, the identified risks are considered low to negligible with mitigation and management measures in place.

Table 13-3 Environmental risk assessment

Issue	Phase	Pre-mitigated risk			Mitigation and management measures	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
Increased localised flooding	Construction	Unlikely	Moderate	Medium	Crossings within the one in 100-year flood zone will be designed for negligible modification of flood flows.	Unlikely	Minor	Low
	Operation	Unlikely	Moderate	Medium	Infrastructure within the one in 100 year flood zone in the vicinity of residential dwellings will be designed for negligible modification of flood flows.	Unlikely	Minor	Low
	Decommissioning	Unlikely	Moderate	Medium		Unlikely	Minor	Low
Watercourse crossings leading to substantial alteration of hydrology and geomorphology including bank stability	Construction	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 crossings will be designed and constructed to include appropriate stabilisation.	Unlikely	Minor	Low
	Operation	Unlikely	Moderate	Medium		Unlikely	Minor	Low
	Decommissioning	Unlikely	Moderate	Medium		Unlikely	Minor	Low

Issue	Phase	Pre-mitigated risk			Mitigation and management measures	Residual risk		
		Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
Localised scour of bed and banks (Bohena Creek)	Construction	Unlikely	Moderate	Medium	As above. 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
	Operation	Likely	Moderate	Medium		Unlikely	Minor	Low
	Decommissioning	Unlikely	Moderate	Medium		Unlikely	Minor	Low

13.7 Conclusion

The assessment found that potential impacts to hydrology and geomorphology would be localised and dispersed with a low to negligible residual risk when considering the planned outcomes of the Field Development Protocol and the proposed mitigation and management measures.

Potential impacts of major facilities at Leewood on hydrology would be localised and not predicted to affect residences or access to properties while existing flooding at Bibblewindi is minor and therefore would not be materially affected by the establishment of infrastructure.

Potential impacts of the Bibblewindi to Leewood infrastructure corridor and Leewood to Wilga Park underground power line on hydrology would be negligible as the infrastructure would be buried.

Potential impacts from field infrastructure would be avoided in most cases as the infrastructure would follow the existing topography or would be buried. Potential impacts from field infrastructure would otherwise be minimised through detailed design to ensure negligible modification of flood flows.

Impacts on geomorphology have the potential to occur at watercourse crossings for linear infrastructure and the Bohena Creek managed release, however impacts would be avoided or minimised by use of existing crossings where practicable, construction of crossings during periods of no flow, and implementation of appropriate erosion and sedimentation controls.

Impacts of the Bohena Creek managed release during operation would be localised and negligible in the context of the required flow of 100 megalitres per day.

The residual risk of the potential impacts of the project on hydrology and geomorphology are presented in Table 13-4. With the implementation of appropriate mitigation measures, the identified hydrological and geomorphological impacts are considered to have a low to negligible residual risk.

Table 13-4 Hydrology and geomorphology residual risks

Potential Impact	Construction	Operations	Decommissioning
Increased localised flooding	Low	Low	Low
Degradation of watercourse geomorphic form, processes and stability	Low	Low	Low
Localised scour of bed and banks (Bohena Creek)	Low	Low	Low