Modification Application – Regulation 23

Interest Holder	Santos QNT Pty Ltd	EMP Title	McArthur Basin 2019 Hydraulic Fracturing Program	Unique EMP ID No.	STO3-4	Mod No.	2	Date	18/08/2020
Brief Description	The Water Resources Division Technical Report 20/2020 confirms the presence of a newly discovered aquifer, referred to as the Inacumba aquifer. Identification of the new Inacumba aquifer at Tanumbirini Station has subsequently triggered a change in the existing environment relevant to this EMP. This EMP modification application is required under Regulation 23 to give the Minister a notice that specifies details of the changes to the EMP.								
Geospatial Files Included?	No								

Does the change in existing environment result in a new, or increased, potential or actual environmental impact or risk?	If a NEW potential or actual environmental impact or risk, is it provided for in the approved EMP?	If an INCREASE in an existing potential or actual environmental impact or risk, is it provided for in the approved EMP?	Does the change in the existing environment require additional mitigation measures to be included?	Has additional stakeholder engagement been conducted?	Does it require additional environmental performance standards and measurement criteria?	Does it affect compliance with Sacred Site Authority Certificates?	Does it affect current rehabilitation, weed, fire, wastewater, erosion and sediment control, spill or emergency response plans?	Will the environmental outcome continue to be achieved and will the impacts and risks be managed to ALARP and acceptable?
No	N/A	N/A	No	No	No	No	No	Yes

Current EMP Text	Amended EMP Text
Table ES-1: Summary of Environmental Values and Sensitivities	**Table ES-1: Summary of Environmental Values and Sensitivities**

Environmental Factors	Environmental Values and Sensitivities	Summary
Inland water environmental quality	Groundwater	The Cambrian Limestone Aquifer is a regional scale aquifer that provides groundwater resources for pastoral enterprises, domestic bores at homesteads and town water supplies at a number of small communities across the region. The groundwater resource in this area is understood to connect to the Roper River, where groundwater discharge supports aquatic, riparian and floodplain ecosystem function.

Environmental Factors	Environmental Values and Sensitivities	Summary
Inland water environmental quality	Groundwater	The Cambrian Limestone Aquifer is a regional scale aquifer that provides groundwater resources for pastoral enterprises, domestic bores at homesteads and town water supplies at a number of small communities across the region. In addition, the Water Resources Division Technical Report 20/2020 confirms the presence of a newly discovered aquifer, referred to as the Inacumba aquifer. Presently, there is limited information available regarding the regional and stratigraphic extent of the Inacumba aquifer. Its productivity as a water resource aquifer is only confirmed in a few bores within the vicinity of the Inacumba 1 well lease. The value of this aquifer as a groundwater resource is limited due to presence of overlying and highly productive water bearing formations of the Gum Ridge Formation (Cambrian Limestone Aquifer). The Gum Ridge Formation groundwater resource in this area is understood to connect to the Roper River, where groundwater discharge supports aquatic, riparian and floodplain ecosystem function.

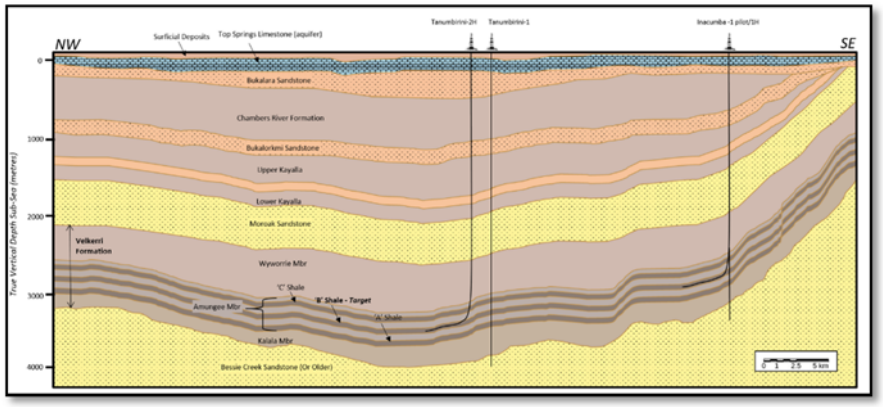
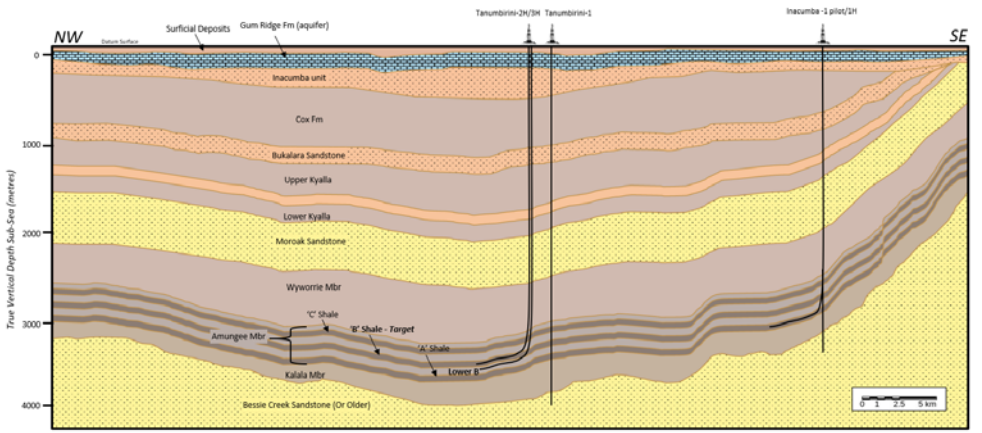


Figure 3-4



3.3.1 Inacumba 1/1H

Following completion of the well drilling operations, the operator proposes to conduct a program of hydraulic fracture stimulations in the horizontal section of the Inacumba 1H well bore, and subsequently flow test the well. The precise interval targeted by the horizontal section of the well will be confirmed once the results of the vertical pilot well are known, but the shallowest possible target is considered to be the Amungee Member C Shale (of the Velkerri Formation). The top of this unit is prognosed to be intersected at 2,462m TVD in the vertical pilot well. The deepest aquifer at this location, based on offset well data (including water bores), is expected to be the Bukalara Sandstone. The base of this unit is prognosed to be intersected at 477m TVD. Therefore a minimum offset of 1,985m is expected between the base of the deepest aquifer and the top of the shallowest primary target of the horizontal section of the well. This significantly exceeds the minimum offset, of more than 600m, between top target zone and base aquifer as mandated by the Code of Practice.

The Bukalara Sandstone, which is stratigraphically deeper than the Top Springs Limestone was penetrated by RN040939 and RN041242 and completed as water supply and monitoring bores. The waterbores did not drill to the base of the Bukalara Sandstone.

3.3.1 Inacumba 1/1H

Following completion of the well drilling operations, the operator proposes to conduct a program of hydraulic fracture stimulations in the horizontal section of the Inacumba 1H well bore, and subsequently flow test the well. The precise interval targeted by the horizontal section of the well will be confirmed once the results of the vertical pilot well are known, but the shallowest possible target is considered to be the Amungee Member C Shale (of the Velkerri Formation). The top of this unit is prognosed to be intersected at 2,462m TVD in the vertical pilot well. The deepest aquifer at this location, based on offset well data (including water bores), is expected to be within the Inacumba unit. The base of this unit is prognosed to be intersected at approximately 305m TVD. Therefore, a minimum offset of 2,157m is expected between the base of the deepest aquifer and the top of the shallowest primary target of the horizontal section of the well. This significantly exceeds the minimum offset of more than 600m, between top target zone and base aquifer as mandated by the Code of Practice.

The Inacumba unit, which is stratigraphically deeper than the Gum Ridge Formation was penetrated by RN040939 and RN041242 and completed as water supply and monitoring bores. The waterbores did not drill to the base of the Inacumba unit, which comprises the Inacumba aquifer. However using isopach data from Tanumbirini 1, the base of the Inacumba unit is expected to be at approximately 305mTVD.

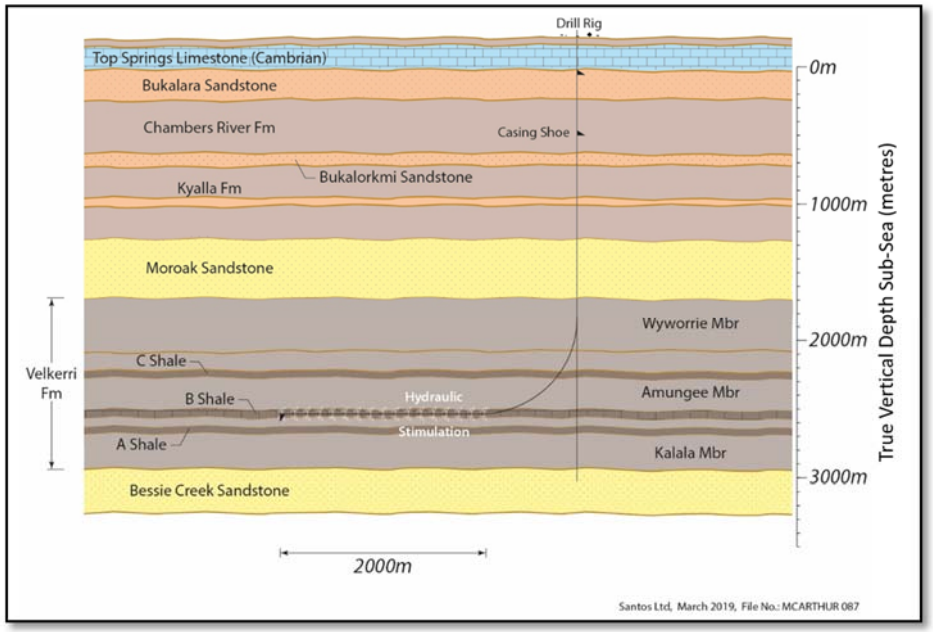


Figure 3-5

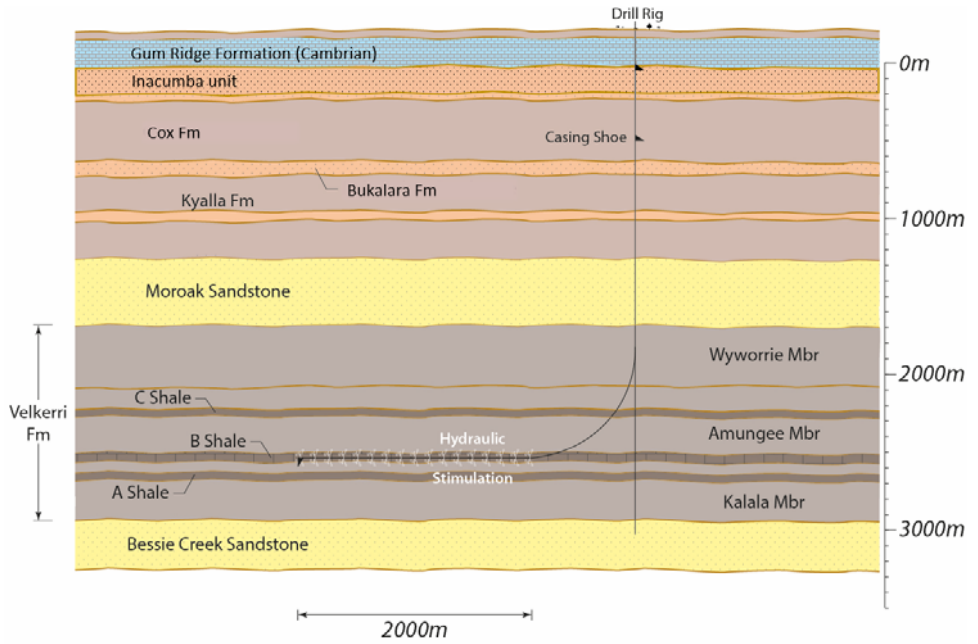


Figure 3-5

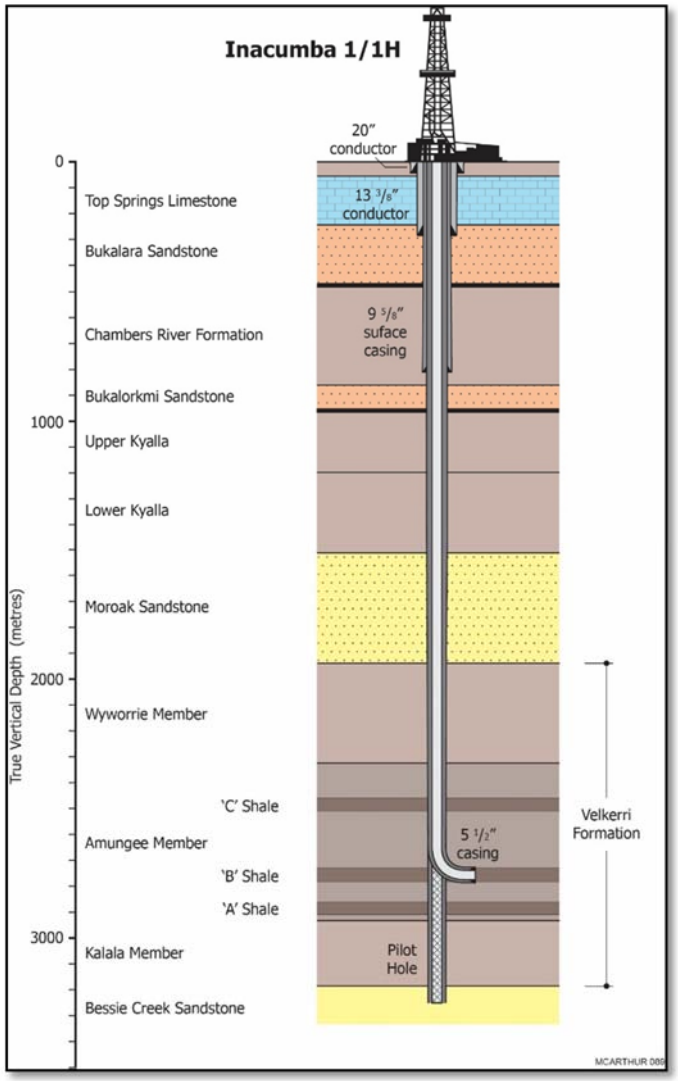


Figure 3-6

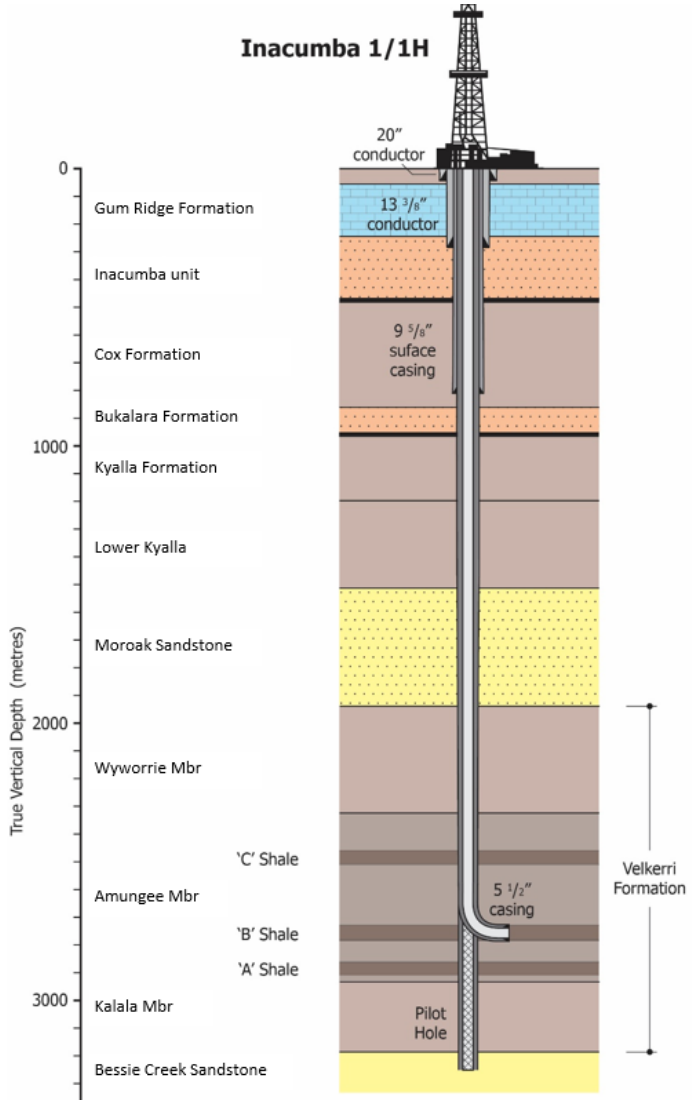


Figure 3-6

3.3.2 Tanumbirini 2H Following completion of the well drilling operations, the operator proposes to conduct a program of hydraulic fracture stimulations in the horizontal section of the Tanumbirini 2H well, and subsequent flow testing. The primary target for the horizontal section of the well comprises the Amungee Member B Shale (of the Velkerri Formation). The top of this unit is prognosed to be intersected at 3,425m TVD. The deepest aquifer expected at this location is the Top Springs Limestone (Gum Ridge Formation). The base of this unit is prognosed to be intersected at 202m TVD. Therefore a minimum offset of 3,223m is expected between the base of the deepest aquifer and the top of the primary target of the horizontal section of the well. This significantly exceeds the minimum offset, of more than 600m, between top target zone and base aquifer as mandated by the Code of Practice. The Bukalara Sandstone, which is stratigraphically deeper than the Top Springs Limestone, is recognised as an aquifer on a regional basis. However, based available data acquired during drilling of offset wells (including water bores) the Bukalara Sandstone is not considered to be of sufficient quality (porosity and permeability) to constitute an aquifer at this location. The base of the Bukalara Sandstone is prognosed to be intersected 582m TVD. Thus even if the Bukalara Sandstone were regarded as an aquifer at this location, the offset to the top of the target interval (3,425m TVD) would still be 2,843m; which far exceeds the minimum offset required under the Code of 600m.	**3.3.2 Tanumbirini 2H** Following completion of the well drilling operations, the operator proposes to conduct a program of hydraulic fracture stimulations in the horizontal section of the Tanumbirini 2H well, and subsequent flow testing. The primary target for the horizontal section of the well comprises the Amungee Member B Shale (of the Velkerri Formation). The top of this unit is prognosed to be intersected at 3,425m TVD. The deepestaquifer at this location is recognised as the Gum Ridge Formation. The base of this unit is prognosed to be intersected at 202m TVD. Therefore, a minimum offset of 3,223m is expected between the base of the this aquifer and the top of the primary target of the horizontal section of the well. This significantly exceeds the minimum offset of more than 600m, between top target zone and base aquifer as mandated by the Code of Practice. The Inacumba unit, which is stratigraphically deeper than the Gum Ridge Formation, is recognised as hosting an aquifer on a local basis. However, based on available data acquired during drilling of offset wells (including water bores) the Inacumba unit is not considered to be of sufficient quality to support high-yielding water supply in the vicinity of Tanumbirini 2H (inferred moderate porosity from cuttings analysis) and may not constitute an aquifer at this location. Furthermore, the availability of reliable groundwater supply from the overlying Gum Ridge Formation and the depth of the Inacumba unit comprising the Inacumba aquifer reduces its potential value as a water supply aquifer. The base of the Inacumba unit is prognosed to be intersected 582m TVD. Thus even if the Inacumba unit were regarded as a viable aquifer at this location, the offset to the top of the target interval (3,425m TVD) would still be 2,843m; which far exceeds the minimum offset required under the Code of 600m.

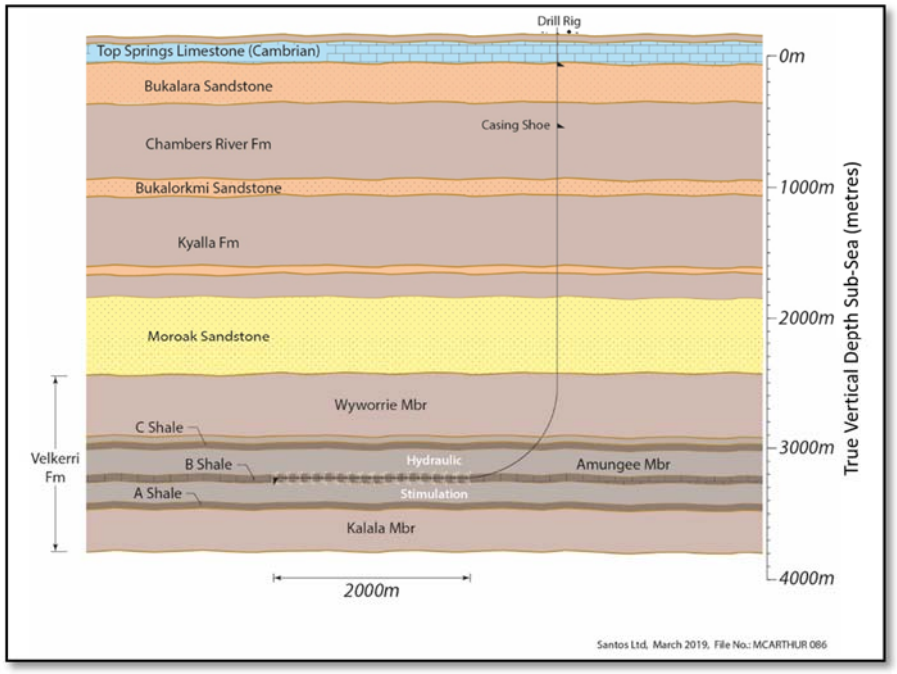


Figure 3-7

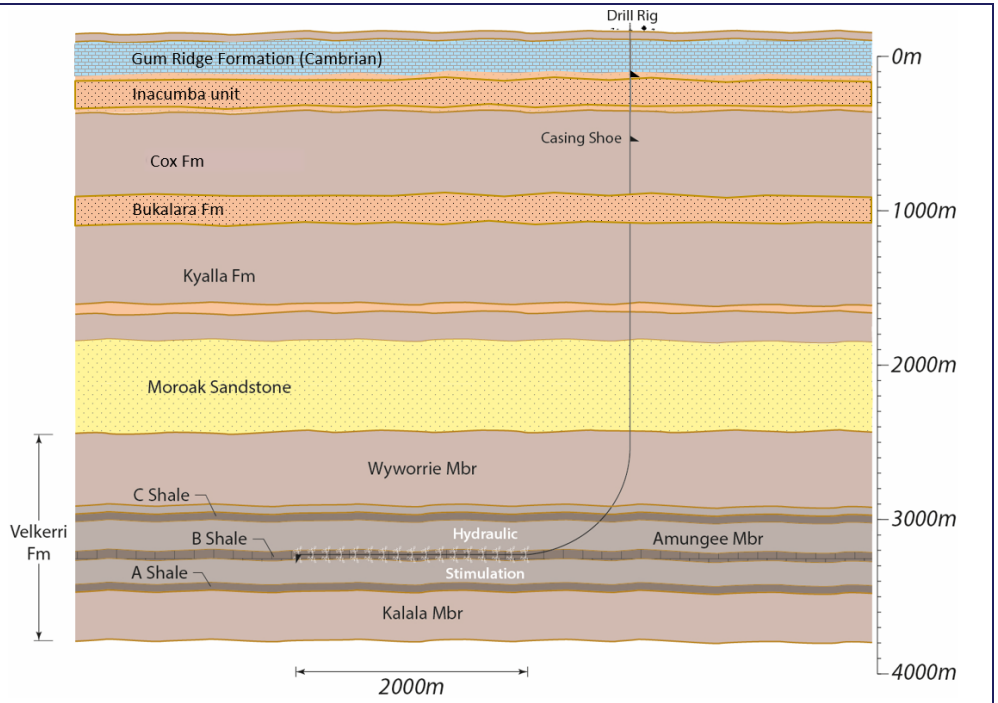


Figure 3-7

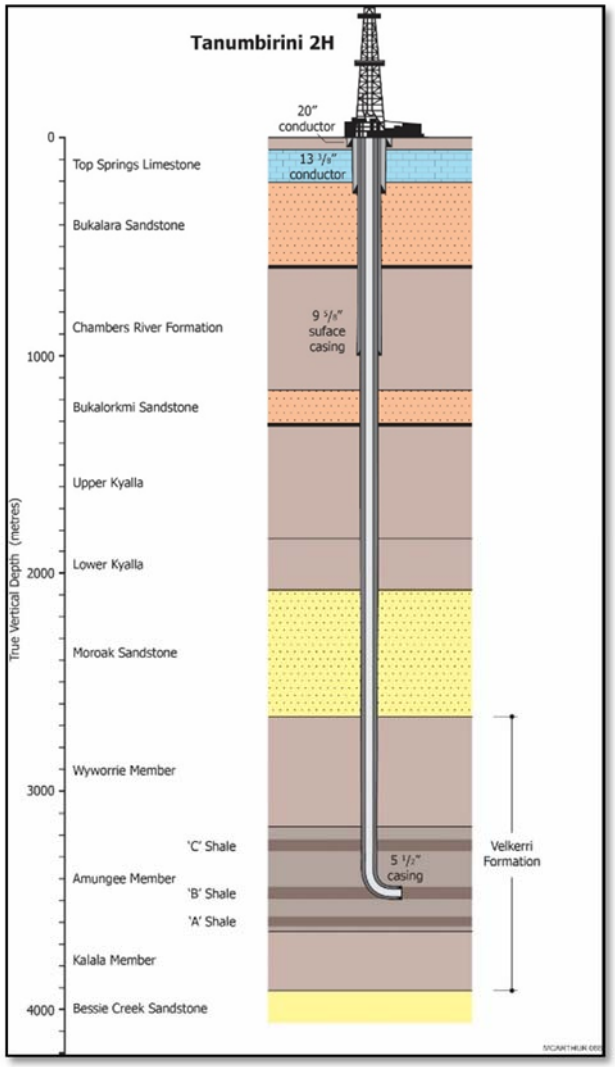


Figure 3-8

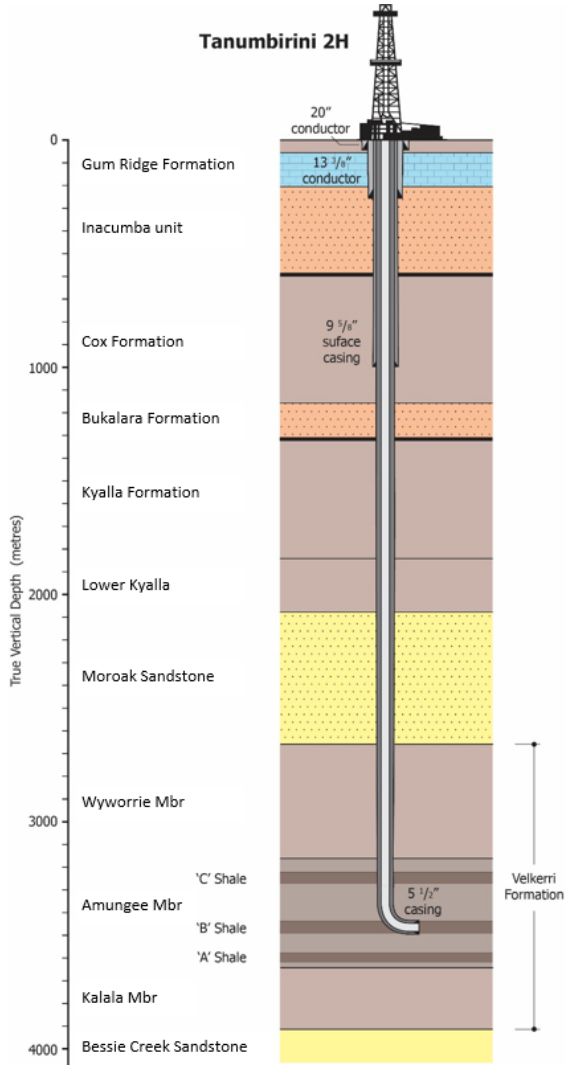


Figure 3-8

3.3.3 Tanumbirini 1 The Tanumbirini 1 well was drilled to a total depth of 3946m (MD & TVD) and drilled through the Velkerri formation, which is the target for appraisal. The operator proposes to conduct a program of hydraulic fracture stimulations in various targets of the Velkerri formation, fracturing and testing the A, B, and C shales. The top of the Velkerri unit was intersected at 2,644m TVD. The deepest aquifer expected at this location is the Top Springs Limestone (Gum Ridge Formation). The base of this unit was intersected at 202m TVD. Therefore a minimum offset of 2,442m is expected between the base of the deepest aquifer and the top of the uppermost target of the Velkerri formation (Figure 3-9). This significantly exceeds the minimum offset, of more than 600m, between top target zone and base aquifer as mandated by the Code of Practice. The Bukalara Sandstone, which is stratigraphically deeper than the Top Springs Limestone, is recognised as an aquifer on a regional basis. However, based available data acquired during drilling of offset wells (including water bores) the Bukalara Sandstone is not considered to be of sufficient quality (porosity and permeability) to constitute an aquifer at this location. The base of the Bukalara Sandstone is prognosed to be intersected 582m TVD. Thus even if the Bukalara Sandstone were regarded as an aquifer at this location, the offset to the top of the Velkerri (2,644m TVD) would still be 2,062m; which far exceeds the minimum offset required under the Code of 600m.	**3.3.3 Tanumbirini 1** The Tanumbirini 1 well was drilled to a total depth of 3946m (MD & TVD) and drilled through the Velkerri formation, which is the target for appraisal. The operator proposes to conduct a program of hydraulic fracture stimulations in various targets of the Velkerri formation, fracturing and testing the A, B, and C shales. The top of the Velkerri unit was intersected at 2,644m TVD. The deepest aquifer recognised at this location is the Gum Ridge Formation (Top Springs Limestone). The base of this unit was intersected at 202m TVD. Therefore a minimum offset of 2,442m is expected between the base of the deepest aquifer and the top of the uppermost target of the Velkerri formation (Figure 3-9). This significantly exceeds the minimum offset of more than 600m, between top target zone and base aquifer as mandated by the Code of Practice. The Inacumba unit, which is stratigraphically deeper than the Gum Ridge Formation, is recognised as hostring an aquifer on a local basis. However, based on available data acquired during drilling of offset wells (including water bores) the Inacumba unit is not considered to be of sufficient quality to support high-yielding water supply in the vicinity of Tanumbirini 1 (inferred moderate porosity from cuttings analysis) and may not constitute an aquifer at this location. Furthermore, the availability of reliable groundwater supply from the overlying Gum Ridge Formation and the depth of the Inacumba unit comprising the Inacumba aquifer reduces its potential value as a water supply aquifer. The base of the Inacumba unit is prognosed to be intersected 582m TVD. Thus even if the Inacumba aquifer were regarded as a viable aquifer at this location, the offset to the top of the Amungee Mbr C Shale (3,205m TVD) would still be 2,623m; which far exceeds the minimum offset required under the Code of 600m.

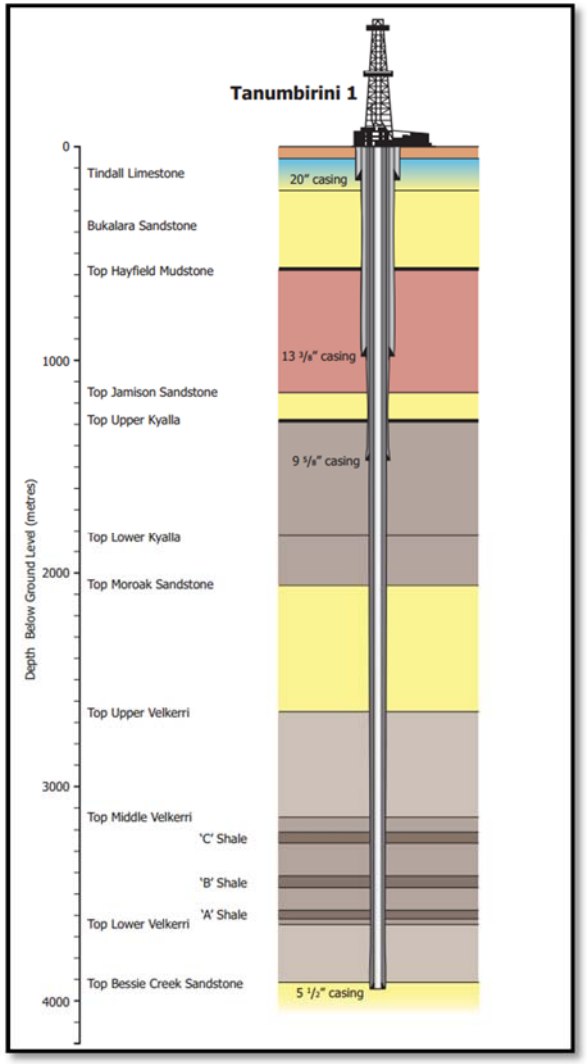


Figure 3-9

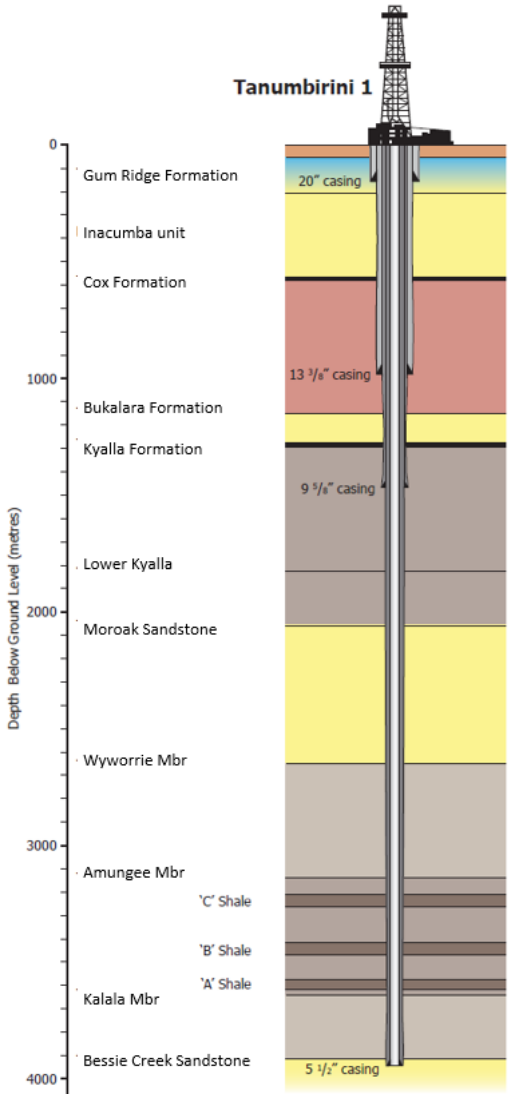


Figure 3-9

4.1.3 Geology The Velkerri Formation is overlain by other formations of the Roper Group (Maiwok Sub-group), including the Moroak Sandstone, Kyalla Formation, Bukalorkmi Sandstone and Chambers River Formation. These comprise a thick sequence of fine grained siltstones and mudstones interbedded with sandstones, which provide excellent isolation between the target zones in the underlying Velkerri Formation and the overlying aquifer (Top Springs Formation). The Roper Group sediments are unconformably overlain by Neoproterozoic sediments of the northern Georgina Basin, which constitute the Kiana Group Bukalara Sandstone at this location. On a regional basis the Bukalara Sandstone is recognised as an aquifer and has been used for agricultural purposes at Nutwood Downs and Hodgson River pastoral lease properties . Historically the Bukalara Sandstone has not been penetrated by (shallower) bores on Tanumbirini Station due to the presence of the overlying Cambrian Limestone Aquifer, and therefore was not recognised as a local aquifer. Bores RN040939 and RN041242 drilled in August and September 2019 respectively, penetrated the Bukalara Sandstone with observations of high variability in reservoir quality and possibly only a few thin intervals of higher permeability contributing to high water yield. The Bukalara Sandstone is unconformably overlain by the Cambrian age Top Springs Limestone (also known as the Gum Ridge Formation, and informally as the Cambrian Limestone Aquifer). This unit is recognised as a regional aquifer and is considered to be the deepest aquifer present at the proposed well locations. The Top Springs Limestone is unconformably overlain by undifferentiated Cretaceous to Quaternary sediments.	**4.1.3 Geology** The Velkerri Formation is overlain by other formations of the Roper Group (Maiwok Sub-group), including the Moroak Sandstone and Kyalla Formation. The Neoproterozoic Kiana Group including the Bukalara Sandstone and the Cox Formation rests unconformably above the Roper Group. These formations comprise of a thick sequence of fine grained siltstones and mudstones interbedded with sandstones, which provide excellent isolation between the target zones in the underlying Velkerri Formation and the overlying regional aquifer (Gum Ridge Formation) and a local aquifer (residing in the Inacumba unit). Historically the Inacumba unit has not been penetrated by (shallower) bores on Tanumbirini Station due to the presence of the overlying Cambrian Limestone Aquifer (Gum Ridge Formation), and therefore has not been previously recognised. Bores RN040939 and RN041242 drilled in August and September 2019 respectively, penetrated the Inacumba unit with observations of high variability in reservoir quality and possibly only a few thin intervals of higher permeability contributing to high water yield. Presently, there is limited information available regarding the extent of the Inacumba unit. It is only known from the few bores around the Inacumba 1 well lease. The north-eastern and south-eastern extent can be reasonably defined from the Santos drilling and surface geology. The north-western extent is limited by its absence in Burdo 1. The main unknown is the western and south-western extent. Based on this knowledge 1,500 km^2 is a reasonable estimate of the unit's extent. Its total thickness is 390 m in Tanumbirini 1 The Inacumba unit is unconformably overlain by the Cambrian aged Gum Ridge Formation (also known as the Top Springs Limestone, and informally as one interval of the Cambrian Limestone Aquifer).
4.1.6 Groundwater Table 4-3 summarises the regional hydrostratigraphy of the Beetaloo Basin. Table 4-3 Regional hydrostratigraphy of the Beetaloo Basin (taken from Fuller and Knapton, 2015)	**4.1.6 Groundwater** Table 4-3 summarises the regional hydrostratigraphy of the Beetaloo Basin. Table 4-3 Regional Hydrostratigraphy of the Beetaloo Basin (modified from Fulton and Knapton, 2015)

PROVINCE	PERIOD / AGE	FORMATION		AQUIFER STATUS	THICKNESS (m)	YIELD (l/s)	AVE. EC (µs/cm)
CARPENTARIA BASIN	CRETACEOUS 145 – 66 Ma	Undifferentiated		*Local Aquifer*	0 - 130	0.3 - 4	1800
GEORGINA BASIN	CAMBRIAN 497-630 Ma	Cambrian Limestone Aquifer (CLA)	Anthony Lagoon Beds	REGIONAL AQUIFER	0 – 200	1 - 10	1600
			Gum Ridge Formation	REGIONAL AQUIFER	0 – 300	0.3 - >20	1400
		Antrim Plateau Volcanics		REGIONAL AQUITARD *Local Aquifer*	0 – 440	0.3 - 5	900
		Bukalara Sandstone		*Local Aquifer*	0 – 75	0.3 - 5	1000
BEETALOO BASIN (ROPER GROUP)	NOT KNOWN	Hayfield Mudstone		REGIONAL AQUITARD *Local Aquifer*	0 – 450	-	32000
		Jamison Sandstone		*Local Aquifer*	0 – 150	-	138000
	MESO-PROTEROZOIC 1430-1500 Ma	Kyalla Formation		REGIONAL AQUITARD	0 – 800	-	-
		Moroak Sandstone		*Local Aquifer*	0 – 500	0.5 - 5	131000
		Velkerri Formation		REGIONAL AQUITARD	700 – 900	-	-
		Bessie Ck Sandstone		*Local Aquifer*	450	0.5 - 5	-

The major hydrogeological units of the Roper River catchment are the Cambrian limestones of the Daly, Wiso and Georgina Basins. These major groundwater systems provide dry season inputs to the Roper River (Knapton, 2009).The Cambrian Limestone Aquifer (CLA) forms the major water resource in the region and where it is absent, local scale, Proterozoic fractured rock aquifers are utilised with varied success. The Bukalara Sandstone is also considered to be a local aquifer in the Project Area, with the nearest recognised water bores into the Bukalara Sandstone located north of Nutwood Downs Station, approximately 100 km from the Project Area. .

The CLA is a regional scale aquifer that provides groundwater resources for pastoral enterprises, domestic bores at homesteads and town water supplies at a number of small communities across the region. The CLA is subdivided into the Anthony Lagoon Beds (ALB) and the Gum Ridge Formation (GRF).

Figure 4-5 shows the elevation of the base of the GRF relative to the proposed well locations. This shows that the GRF is expected to be present at the proposed well locations.

The Anthony Lagoon Beds also overly the GRF across parts of the basin. Figure 4-6 shows the elevation of the top of the Gum Ridge Formation, and the lateral extent of the

PROVINCE	PERIOD / AGE	FORMATION		AQUIFER STATUS	THICKNESS (m)	YIELD (l/s)	AVE. EC (µs/cm)
CARPENTARIA BASIN	CRETACEOUS 145 – 66 Ma	Undifferentiated		*Local Aquifer*	0 - 130	0.3 - 4	1800
GEORGINA BASIN	CAMBRIAN 497-541 Ma	Cambrian Limestone Aquifer (CLA)	Anthony Lagoon Beds	REGIONAL AQUIFER	0 – 200	1 - 10	1600
			Gum Ridge Formation	REGIONAL AQUIFER	0 – 300	0.3 - >20	1400
		Antrim Plateau Volcanics		REGIONAL AQUITARD *Local Aquifer*	0 – 440	0.3 - 5	900
		Inacumba unit		*Local Aquifer*	0 – 75	0.3 - 5	1000
BEETALOO BASIN (ROPER GROUP)	NEO-PROTEROZOIC 541-1000 Ma	Cox Formation		REGIONAL AQUITARD *Local Aquifer*	0 – 450	-	32000
		Bukalara Sandstone		*Local Aquifer*	0 – 150	-	138000
	MESO-PROTEROZOIC 1430-1500 Ma	Kyalla Formation		REGIONAL AQUITARD	0 – 800	-	-
		Moroak Sandstone		*Local Aquifer*	0 – 500	0.5 - 5	131000
		Velkerri Formation		REGIONAL AQUITARD	700 – 900	-	-
		Bessie Ck Sandstone		*Local Aquifer*	450	0.5 - 5	-

The major hydrogeological units of the Roper River catchment are the Cambrian limestones of the Daly, Wiso and Georgina Basins. These major groundwater systems provide dry season inputs to the Roper River (Knapton, 2009).The Cambrian Limestone Aquifer (CLA) forms the major water resource in the region and where it is absent, local scale, Proterozoic fractured rock aquifers are utilised with varied success. The Inacumba unit is considered to be a local aquifer in the Project Area, but of variable reservoir quality.

The CLA is a regional scale aquifer that provides groundwater resources for pastoral enterprises, domestic bores at homesteads and town water supplies at a number of small communities across the region. The CLA is subdivided into the Anthony Lagoon Beds (ALB) and the Gum Ridge Formation (GRF).

Figure 4-5 shows the elevation of the base of the GRF relative to the proposed well locations. This shows that the GRF is expected to be present at the proposed well locations.

The Anthony Lagoon Beds also overly the GRF across parts of the basin. Figure 4-6 shows the elevation of the top of the Gum Ridge Formation, and the lateral extent of the ALB. This map shows that the ALB are not expected to be present at the location of the proposed well sites.

ALB. This map shows that the ALB are not expected to be present at the location of the proposed well sites.

Where fractured and cavernous the GRF can support bore yields of up to 100 L/s although yields from pastoral bores are typically less than 5 L/s but often reflect the stock water demand rather than the potential aquifer yield (Fulton 2018). Bore RN040939 penetrated the Bukalara Sandstone with a maximum yield of 23 L/s reported.

Depth to groundwater in the CLA ranges from 32 to 123 mBGS (metres below ground surface) with groundwater levels generally deeper further away from the basin margin in the south-west of EP 161 (Fulton 2018).

The regional groundwater flow direction in the GRF is north-west toward Mataranka, where the aquifer discharges into the Roper River approximately 100 km north-west of the Beetaloo Sub-basin where it supports significant groundwater dependent ecosystems (Fulton 2018).

The groundwater flow direction in the GRF broadly follows the north-west regional flow pattern however, gradients are very flat (0.0001) with little change in groundwater elevations observed over large distances. This is shown in Figure 4-8. Large decadal changes in discharge rates to the Roper River suggest that most recharge of the Roper River occurs close to the discharge zone, i.e. beyond the Beetaloo Sub-basin region (Fulton 2018).

Groundwater recharge mechanisms to the CLA are poorly characterised but are likely to be dominated by infiltration through sinkholes and soil cavities. Recharge is likely to be lower in areas where the overlying Cretaceous deposits, which contain clay and mudstone sequences, are thick and continuous (Fulton 2018). The Project Area straddles the north-east margin of the Georgina Basin. The Top Springs Limestone (main constituent of the CLA in the area) is present across the centre and south-west of the Project Area but pinches out in the north-east where Roper Group formations outcrop (Fulton 2018).

Drilling and geophysical logs confirm a local stratigraphy as per Table 4-4. This was confirmed by geophysical logging of the Tanumbirini 1 exploration well at the location of the proposed well sites.

Table 4-4 Stratigraphy logged at the location of Tanumbirini 1

Formation	Depth to formation top (m)	Thickness (m)
Undifferentiated Cretaceous	Surface	43.9
Gum Ridge Formation	52	150
Bukalara Sandstone	202	380
Chambers River Formation	582	570
Bukalorkmi Sandstone	1152	145
Kyalla Sandstone	1297	772
Moroak Sandstone	2069	368
Velkerri Formation	2437	1482.5

Where fractured and cavernous the GRF can support bore yields of up to 100 L/s although yields from pastoral bores are typically less than 5 L/s but often reflect the stock water demand rather than the potential aquifer yield (Fulton 2018). Bore RN040939 penetrated the Inacumba unit with a maximum yield of 23 L/s reported.

Depth to groundwater in the CLA ranges from 32 to 123 mBGS (metres below ground surface) with groundwater levels generally deeper further away from the basin margin in the south-west of EP 161 (Fulton 2018).

The regional groundwater flow direction in the GRF is north-west toward Mataranka, where the aquifer discharges into the Roper River approximately 100 km north-west of the Beetaloo Sub-basin where it supports significant groundwater dependent ecosystems (Fulton 2018).

The groundwater flow direction in the GRF broadly follows the north-west regional flow pattern however, gradients are very flat (0.0001) with little change in groundwater elevations observed over large distances. This is shown in Figure 4-8. Large decadal changes in discharge rates to the Roper River suggest that most recharge of the Roper River occurs close to the discharge zone, i.e. beyond the Beetaloo Sub-basin region (Fulton 2018).

Groundwater recharge mechanisms to the CLA are poorly characterised but are likely to be dominated by infiltration through sinkholes and soil cavities. Recharge is likely to be lower in areas where the overlying Cretaceous deposits, which contain clay and mudstone sequences, are thick and continuous (Fulton 2018). The Project Area straddles the north-east margin of the Georgina Basin. The Gum Ridge Formation (main constituent of the CLA in the area) is present across the centre and south-west of the Project Area but pinches out in the north-east where Roper Group formations outcrop (Fulton 2018).

Drilling and geophysical logs confirm a local stratigraphy as per Table 4-4. This was confirmed by electric wireline logging of the Tanumbirini 1 exploration well at the location of the proposed well sites.

Table 4-4 Stratigraphy logged at the location of Tanumbirini 1

Formation	Depth to formation top (m)	Thickness (m)
Undifferentiated Cretaceous	Surface	43.9
Gum Ridge Formation	52	150
Inacumba unit	202	380
Cox Formation	582	570
Bukalara Sandstone	1152	145
Kyalla Formation	1297	772
Moroak Sandstone	2069	368
Velkerri Formation	2437	1482.5
Bessie Ck Sandstone	3920	>30.5

Bessie Ck Sandstone	3920	>30.5

A baseline survey of water bores in the vicinity of the proposed well sites was undertaken in 2018. The bore locations are shown in Figure 4-9. This shows that the Gum Ridge Formation is expected to be absent (north and east of the proposed well locations) there are more bores completed in undifferentiated Proterozoic fractured rock aquifers are targeted by water bores. These fractured rock aquifers are not present at the location of the proposed well sites.

Groundwater Electrical Conductivity (EC) in the CLA ranges from 1170 - 2260 µS/cm (average of 1580 µS/cm) and the pH is typically neutral (6.3 - 7.3) (Fulton 2018). Figure 4-7 maps the distribution of total dissolved solids (mg/L) detected in all groundwater relative to the proposed well sites. Santos has established groundwater monitoring bores at the Tanumbirini 1/2H location and Inacumba 1/1H location. The groundwater from these bores is fresh, ranging between 800-1000 mg/L TDS. Table 4-5 provides a more detailed breakdown of the groundwater chemistry in the Gum Ridge Formation (compliant with the sampling and testing requirements outlined in the Preliminary Guideline: Groundwater Monitoring Bores for Exploration Wells in the Beetaloo Sub-basin (DENR, 2018)).

Table 4-10 Environmental Values and/or Sensitivities that may be affected by the project

Environmental Factors	Environmental Values and Sensitivities	Summary
Inland water environmental quality	Groundwater	The Cambrian Limestone Aquifer is a regional scale aquifer that provides groundwater resources for pastoral enterprises, domestic bores at homesteads and town water supplies at a number of small communities across the region. The groundwater resource in this area is understood to connect to the Roper River where groundwater discharge supports aquatic, riparian and floodplain ecosystem function.

A baseline survey of water bores in the vicinity of the proposed well sites was undertaken in 2018. The bore locations are shown in Figure 4-9. This shows that the Gum Ridge Formation is expected to be absent (east of the proposed well locations) where there are more bores completed in undifferentiated Proterozoic fractured rock aquifers. These fractured rock aquifers are not present at the location of the proposed well sites.

Groundwater Electrical Conductivity (EC) in the CLA ranges from 1170 - 2260 µS/cm (average of 1580 µS/cm) and the pH is typically neutral (6.3 - 7.3) (Fulton 2018). Figure 4-7 maps the distribution of total dissolved solids (mg/L) detected in all groundwater relative to the proposed well sites. Santos has established groundwater monitoring bores at the Tanumbirini 1/2H location and Inacumba 1/1H location. The groundwater from these bores is fresh, ranging between 800-1000 mg/L TDS. Table 4-5 provides a more detailed breakdown of the groundwater chemistry in the Gum Ridge Formation (compliant with the sampling and testing requirements outlined in the Preliminary Guideline: Groundwater Monitoring Bores for Exploration Wells in the Beetaloo Sub-basin (DENR, 2018)).

Table 4-10 Environmental Values and/or Sensitivities that may be affected by the project

Environmental Factors	Environmental Values and Sensitivities	Summary
Inland water environmental quality	Groundwater	The Cambrian Limestone Aquifer is a regional scale aquifer that provides groundwater resources for pastoral enterprises, domestic bores at homesteads and town water supplies at a number of small communities across the region. In addition, the Water Resources Division Technical Report 20/2020 confirms the presence of a newly discovered aquifer, referred to as the Inacumba aquifer. Presently, there is limited information available regarding the extent of the Inacumba aquifer. It is only known from a few bores within the vicinity of the Inacumba 1 well lease. The use of this aquifer as a groundwater resource is unlikely and not currently observed.

Table 6.1 Risk Assessment

Potential Impact	Risk source	EMP Commitment
Reduction in groundwater and surface water quality	Cross-flow during hydraulic fracture stimulation, Faults or major structures enables cross-flow.	Distance of target shale formation (Velkerri formation) from nearest high quality aquifer (Cambrian Limestone aquifer) is over 2000 m.
Impacts to groundwater dependant ecosystems	Cross-flow during hydraulic fracture stimulation, Faults or major structures enables cross-flow.	Distance of target shale formation (Velkerri formation) from nearest high quality aquifer (Cambrian Limestone aquifer) is over 2000 m.

7.4.1 Aquifers to be monitored

The Guideline states that groundwater monitoring at well sites in the Beetaloo Sub-Basin is required for aquifers in the Antony Lagoon and Gum Ridge Formations (or equivalents) where they are present below the water table. Neither formation is considered an aquifer where it lies above the water table.

The interpreted hydro-stratigraphy at the location of each the proposed well sites is summarised in Table 7-2. Down-hole gamma logs were provided to DENR Water Assessment Branch as they became available post-drilling but prior to the completion of the holes as monitoring bores. The interpretation of these logs confirmed that the Anthony Lagoon Formation was not encountered or was not an aquifer at the monitoring well locations. Therefore monitoring of the Gum Ridge Formation of the Cambrian Limestone aquifer is required in accordance with the Guideline.

Table 7-2 Stratigraphy encountered at the proposed well sites.

Well / Multi-well pad	Tanumbirini 1/2H	Inacumba 1/1H
Observed water table	59.6 mbgl	73.43 mbgl
Top Anthony Lagoon Formation	45.0 mbgl	Not present

		The groundwater resource in this area is understood to connect to the Roper River, where groundwater discharge supports aquatic, riparian and floodplain ecosystem function.

Table 6.1 Risk Assessment

Potential Impact	Risk source	EMP Commitment
Reduction in groundwater and surface water quality	Cross-flow during hydraulic fracture stimulation, Faults or major structures enables cross-flow.	Distance of target shale formation from nearest aquifer of use is over 2000 m vertically.
Impacts to groundwater dependant ecosystems	Cross-flow during hydraulic fracture stimulation, Faults or major structures enables cross-flow.	Distance of target shale formation from nearest aquifer of use is over 2000 m vertically.

7.4.1 Aquifers to be monitored

The Guideline states that groundwater monitoring at well sites in the Beetaloo Sub-Basin is required for aquifers in the Antony Lagoon and Gum Ridge Formations (or equivalents) where they are present below the water table. Neither formation is considered an aquifer where it lies above the water table.

The interpreted hydro-stratigraphy at the location of each the proposed well sites is summarised in Table 7-2. Down-hole gamma logs were provided to DENR Water Assessment Branch as they became available post-drilling but prior to the completion of the holes as monitoring bores. The interpretation of these logs confirmed that the Anthony Lagoon Formation was not encountered or was not an aquifer at the monitoring well locations. Therefore monitoring of the Gum Ridge Formation of the Cambrian Limestone aquifer is required in accordance with the Guideline.

Gamma log correlations clearly showed that the Gum Ridge Formation thins to the east. At the Inacumba 1 location the Gum Ridge Formation of the Cambrian Limestone aquifer is present, although not producing water volumes required for use.

The Water Resources Division Technical Report 20/2020 confirms the presence of a newly discovered aquifer, referred to as the Inacumba aquifer. Presently, there is limited

Top Gum Ridge Formation	57.0 mbgl	56.0 mbgl
Top Bukalara Sandstone	188.0 mbgl	102.5 mbgl

information available regarding the extent of the Inacumba aquifer. It is only known from a few bores within the vicinity of the Inacumba 1 well lease. Where this aquifer is being used as a water resource and an appropriate water licence for this resource is in place (i.e. Inacumba 1) monitoring of Inacumba aquifer is required in accordance with the Guideline.

Table 7-2 Stratigraphy encountered at the proposed well sites.

Well / Multi-well pad	Tanumbirini 1/2H	Inacumba 1/1H
Observed water table	60 mTVD	73mTVD
Top Anthony Lagoon Formation	45 mTVD	Not present
Top Gum Ridge Formation	57 mTVD	56 mTVD
Top Inacumba Unit	202 mTVD	130 mTVD

Environmental Factors	Environmental Values and Sensitivities	Uncertainty Ranking
Groundwater extraction	Reduction in groundwater quantity	Type A Risk – Risks are well-understood. The regional understanding of the CLA is sufficient to understand the risks. Groundwater Monitoring has been undertaken and will continue.
Groundwater extraction	Reduction in groundwater available for other users	Type A Risk – Risks are well-understood. The regional understanding of the CLA is sufficient to understand the risks. Groundwater Monitoring has been undertaken and will continue.

Environmental Factors	Environmental Values and Sensitivities	Uncertainty Ranking
Groundwater extraction	Reduction in groundwater quantity	Type A Risk – Risks are well-understood. The regional understanding of the groundwater is sufficient to understand the risks. Groundwater Monitoring has been undertaken and will continue.
Groundwater extraction	Reduction in groundwater available for other users	Type A Risk – Risks are well-understood. The regional understanding of the groundwater is sufficient to understand the risks. Groundwater Monitoring has been undertaken and will continue.