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Memorandum

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Memo Subject	SGP Stage 1 CSG WMMP Monitoring network memorandum

1. Introduction

This memorandum has been developed to document the proposed monitoring network and monitoring program for the Surat Gas Project (SGP) Stage 1 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP). It addresses Approval Conditions 13e and 13f.

Condition 13(e): *Parameters and a sampling regime to establish baseline data for surface and groundwater resources that may be impacted by the action, including:*

- *Surface water quality and quantity in the project area, and upstream and downstream of potential impact areas*
- *Groundwater quality, levels and pressures for areas that may be impacted by the project; and*
- *For determining connectivity between surface water and groundwater that may be impacted by the project.*

Condition 13(f): *A best practice baseline monitoring network that will enable the identification of spatial and temporal changes to surface water and groundwater.*

This must include a proposal for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity (including potential groundwater dependence of Long Swamp and Lake Broadwater) and must also enable monitoring of all aquatic ecosystems that may be impacted by the action.

1.1. Approval conditions and related documents

In addition to the Environmental Impact Statement (EIS) and Supplementary Report to the EIS (SREIS), further supporting assessment for approval conditions is presented in separate memoranda, as summarised in Table 1.1. These documents provide the basis for the identification and assessment of potential impacts arising from the SGP and which may require ongoing monitoring to validate the predictions and allow for the early detection of and response to impacts that eventuate.

Table 1.1: Summary of Stage 1 CSG WMMP supporting assessments

Memoranda	Approval Conditions addressed	Document ID
Groundwater modelling technical memorandum (and referenced documents)	13a, 13b and 13d	ENAUABTF20484AA-M01
GDE and aquatic ecosystem impact assessment technical memorandum	13c and 13p	ENAUABTF20484AA-M03
Flood risk technical memorandum	13o	ENAUABTF20484AA-M02
Subsidence technical memorandum	13g	ENAUABTF20484AA-M05
Groundwater monitoring network and program technical memorandum (in progress)	13e, 13f	ENAUABTF20484AA-M07 (this document)
Early warning, limits and triggers memorandum	13j, 13k, 15	ENAUABTF20484AA-M08
Assessment of impacts and development of management measures memorandum	13j(iv)	ENAUABTF20484AA-M04
Surat Gas Project CSG Water Management Strategy	13l, 13m and 13n	ENAUABTF20484AA-WMS-R05

Future Stage 2 CSG WMMP development

Additional review, development and update of the Stage 1 CSG WMMP monitoring network will be undertaken as part of the development of the Stage 2 CSG WMMP in line with Approval Conditions 17(e) and 17(h).

For context, Approval Condition 17(h) states that the Stage 2 CSG WMMP must '*Review and update the monitoring network in Stage 1 WMMP to reflect changes in the understanding of impacts to water resources, including from baseline monitoring and relevant research*'.

Under Approval Condition 17(h), the Stage 2 CSG WMMP will provide details of an ongoing monitoring plan that:

i. *sets out the frequency of monitoring and rationale for the frequency*;

ii. *includes continued collection of baseline data for each monitoring site over the life of the project*;

iii. *outlines the approach to be taken to analyse the results including the methods to determine trends to indicate potential impacts; and*

iv. *builds upon the groundwater early warning system required at condition 13(j) and sets out early warning indicators and trigger thresholds and limits for groundwater and surface water*.

2. Groundwater monitoring

A fit for purpose groundwater monitoring network and sampling and analysis program is planned. This section outlines the requirements and rationale for monitoring, and presents the monitoring network locations and program.

2.1. Requirements

The groundwater monitoring network is required to comply with Approval Condition 13(f) and Arrow EIS/SREIS commitments. The network accounts for CSG related groundwater drawdown, which may lead to impacts, and takes into account the need to provide baseline data before development impacts occur, and to enable the identification of early warning conditions as monitoring data are acquired over time.

Table 2.1 details the overarching groundwater monitoring network requirements derived from Condition 13(f).

Table 2.1: Groundwater monitoring network requirements

Requirement	Approach
To establish baseline conditions, and to provide for early detection of impacts or incipient impacts to groundwater, in terms of fluctuating water pressure, level and quality	Establish a network of monitoring sites in specified aquifers to enable groundwater level monitoring. Sampling from the monitoring network for field-water quality and laboratory analysis.
To provide for the early detection of changes in connectivity with surface water	Groundwater-surface water interconnection can be assessed where necessary by monitoring groundwater levels in the vicinity of surface water bodies.
To monitor relevant formations to determine hydraulic connectivity	Monitoring wells will be used to establish hydraulic gradients across relevant formations, and in locations that take into account features that could enhance connectivity, such as faults.
To monitor potential impacts to GDEs including spring and non-spring based ecosystems, and provide for early detection of impact	Monitoring sites will be established at appropriate locations to enable monitoring of groundwater levels in relevant aquifers identified as associated with GDEs that may be affected by the Action.
To monitor the hydraulic connectivity of Long Swamp and Lake Broadwater	Monitoring sites will be established[1] in specified aquifers to enable groundwater levels and quality to be measured in the vicinity of these features.

1: Establishment of these monitoring sites dependent on obtaining relevant Queensland Government approvals.

2.2. UWIR monitoring

The Surat CMA UWIR sets out regional monitoring requirements for groundwater pressure and quality monitoring across the Surat CMA. Through this, a substantial network of groundwater monitoring locations has been established across the Surat CMA, as presented in Figure 2.1 (overview) and Figure 2.1A to I (by aquifer). The regional monitoring network specified in the 2016 UWIR comprises 675 groundwater pressure and/or quality monitoring points, of which 491 were established at the time of the release of the 2016 UWIR.

Arrow's UWIR monitoring locations, where in the vicinity of the SGP, are presented in Figure 2.1J superimposed on model predicted 1 m drawdown contours for key consolidated formation aquifers (cumulative case in year 2050).

The primary objectives of the UWIR monitoring network across the Surat CMA are to:

- Improve the understanding of system response within production areas.
- Identify pressure changes near specific areas of interest.

- Improve understanding of background trends in pressure.
- Provide sufficient data for model calibration.

Data collected from the greater UWIR monitoring network is considered to provide sufficient information to account for the heterogeneous nature of the system. The assigned UWIR monitoring locations are noted to provide spatial coverage across the key areas of predicted impact across the range of aquifer units. This includes the establishment of a number of nested (co-located) monitoring sites, which assist with the assessment of vertical change in groundwater pressure. The monitoring of these locations has resulted in the collection of a significant data set describing baseline groundwater pressure and quality, and provides OGIA with additional data for ongoing calibration and conceptualisation updates to its groundwater models.

In addition to the UWIR network, OGIA also receives data from tenure holders for other (non-UWIR) monitoring locations within the Surat CMA. In total, OGIA receive data from more than 1,000 monitoring points across the Surat CMA.

Under the Surat CMA UWIR, Arrow is assigned monitoring obligations. As set out in the Surat CMA UWIR, where a monitoring location is on a tenure holders land, the responsibility for monitoring will fall to that tenure holder. Monitoring obligations for locations that are not associated with a petroleum tenure holders land fall to the tenure holder closest to monitoring location.

Arrow's UWIR obligations for the establishment of a monitoring network partially fulfils the requirements of Conditions 13(e) and 13(f), and the network specified to meet these conditions therefore takes into account infrastructure already established (and proposed) under the UWIR requirements.

2.3. Baseline monitoring network

2.3.1. Design rationale

The baseline monitoring network design is underpinned by numerical groundwater modelling as set out in the Groundwater Modelling Technical Memorandum (Coffey document ENAUABTF20484AA-M01). In particular, for the establishment of baseline monitoring network locations, key modelling predictions that inform selection of locations are:

- Cumulative groundwater drawdown in consolidated aquifers.
- Cumulative groundwater drawdown in unconsolidated aquifers.
- Condamine Alluvium flux change due to Arrow water production.
- Condamine Alluvium drawdown timing due to Arrow water production.

The selection of baseline monitoring locations takes into account the predicted extent and timing of aquifer depressurisation due to the Action, as well as the need to acquire pre-development baseline data. In particular, the network design basis considers:

- Establishment of baseline data.
- The spatial extent and timing of aquifer depressurisation.
- Specific geological formations and environmental features that require monitoring.
- Groundwater pressure impacts that are anticipated to occur.
- Existing groundwater monitoring locations.
- Potential siting constraints for new locations (i.e. land access and/or government approvals).

Table 2.2 presents an overview of the analysis required and process for the establishment of monitoring infrastructure.

Table 2.2: Monitoring network – infrastructure establishment

Requirement	Monitoring infrastructure	Supporting comments
A best practice monitoring network to identify spatial and temporal changes to groundwater. To monitor groundwater level and pressure, including baseline, for areas that may be impacted by the project.	Install monitoring sites at strategic locations for groundwater level monitoring and water quality sampling.	Undertake spatial analysis against modelled drawdown to inform site locations. Monitoring locations selected to enable baseline, impact and early warning monitoring.
To determine connectivity between surface water and groundwater that may be impacted by the Action.	Install groundwater level monitoring sites near key surface water features that are predicted to be impacted by the Action.	Conceptualise where groundwater-surface water connectivity could occur, and select monitoring locations accordingly.
To monitor relevant aquifers to determine hydraulic connectivity.	Install nested monitoring sites for groundwater level monitoring in formations where impact could occur.	Review at risk formations in the vicinity of drawdown impacted areas. Establish suitable monitoring points using spatial assessment.
To monitor for potential GDE impacts.	Install monitoring sites for groundwater level monitoring in formations potentially supporting GDEs.	Monitoring to target aquifers predicted to be impacted by the Action and potentially supporting GDEs. Map identified GDEs against predicted drawdown to establish suitable monitoring locations.
To monitor for determining the hydraulic connectivity and groundwater dependence of Long Swamp and Lake Broadwater.	Install monitoring sites including nested sites for groundwater level monitoring and water quality sampling.	Monitor groundwater levels and investigate hydraulic relationship between aquifers and water bodies. Sample groundwater and surface water for chemical and isotopic analysis. Use Piper plots, Stiff diagrams and/or other methods to characterise water types.

2.3.2. Network locations

The Stage 1 CSG WMMP monitoring network comprises a total of 105 discrete monitoring intervals (including 57 WCM intervals) at 32 discrete monitoring locations, thereby comprising a comprehensive early warning monitoring network. As set out in Section 4.5 of the Groundwater Monitoring Network and Program technical memorandum, the Stage 1 CSG WMMP monitoring network includes 26 co-located (nested) sites, which assist with the assessment of vertical pressure gradients.

A summary of the total monitoring locations by formation is presented in Table 2.3, noting that at some monitoring locations, there are multiple monitoring intervals of the same formation (typically relating to different coal seams of the WCM).

Table 2.3: Stage 1 CSG WMMP formation monitoring

Formation	Number of monitoring locations and discrete monitoring intervals		
	Pressure only locations (intervals)	Pressure and water quality locations (intervals)	Total locations (intervals)
Condamine Alluvium	13 (13)	5 (5)	18 (18)
CA / WCM transition layer	7 (7)	0 (0)	7 (7)
Westbourne Formation	0 (0)	1 (1)	1 (1)
Springbok Sandstone	5 (5)	1 (1)	6 (6)
Walloon Coal Measures	30 (55)	2 (2)	32 (57)
Eurombah Formation	4 (4)	0 (0)	4 (4)
Hutton Sandstone	4 (4)	3 (3)	7 (7)
Evergreen Formation	2 (2)	0 (0)	2 (2)
Precipice Sandstone	0 (0)	3 (3)	3 (3)

Further detail on the monitoring network locations is provided in Table 2.4, including the primary purpose(s) of each monitoring location. Figures 2.2(a) to 2.2(e) present the groundwater monitoring network proposed for unconsolidated and consolidated aquifer formations, superimposed on predicted drawdown[1].

Figure 2.3 presents the proposed groundwater flux monitoring network for the Condamine Alluvium aquifer, superimposed upon model-predicted change in groundwater flux (cumulative impact case). This network utilises locations where there are existing co-located Condamine Alluvium and WCM monitoring wells to enable establishment of the differential pressure across the Walloon-Condamine interface. The flux monitoring network locations has taken into account:

- The timing of predicted drawdown.
- The extent of the Condamine Alluvium.
- The predicted maximum drawdown (i.e. consideration of areas of highest flux change, and areas of early flux change).
- Availability of suitable Arrow tenement locations (Arrow induced impacts will occur earlier within these tenements than outside).

The need for additional flux monitoring locations will be reviewed during the development of subsequent WMMPs. This allows for a more targeted approach to the installation of additional monitoring infrastructure (if required), taking in to account future modelling predictions (location, magnitude and timing of predicted impact) based on refined field development plans and data obtained from the defined Stage 1 monitoring network.

Monitoring requirements for GDEs are yet to be defined as they are dependent on the outcomes of further site investigations (refer Sections 2.3 and 2.4). These will be incorporated into the Stage 2 CSG WMMP where relevant.

[1] Cumulative drawdown under the median case for the Condamine Alluvium and the 1 m drawdown contour for the Springbok Sandstone, Walloon Coal Measures, Hutton Sandstone and Precipice Sandstone aquifers for the 2050 cumulative case.

Table 2.4: Stage 1 CSG WMMP monitoring locations

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Bora Creek-10	BC10_WCM	124	579	-27.9245	151.1249	WCM	Installed	✓			✓
Burunga Lane-174	BL174_EF	91	625	-26.2427	150.0502	Evergreen	Installed	✓			✓
Burunga Lane-174	BL174_PS	91	478, 479	-26.2427	150.0502	Precipice	Installed	✓	✓		✓
Burunga Lane-176	BL176_HS	91	476, 477	-26.2429	150.05	Hutton	Installed	✓	✓		✓
Burunga Lane-176	BL176_WCM	91	473, 474, 475	-26.2429	150.05	WCM	Installed	✓			✓
Carn Brea-17	CB17_CA	8	38, 39	-27.533	151.3664	Condamine Alluvium	Installed	✓	✓	✓	✓
Carn Brea-18	CB18_WCM	8	40, 41, 42, 43	-27.533	151.3663	WCM	Installed	✓	✓ (at 41 only)	✓	✓
Carn Brea-19	CB19_EF	8	46	-27.533	151.3662	Evergreen	Installed	✓			✓
Carn Brea-19	CB19_HS	8	44, 45	-27.533	151.3662	Hutton	Installed	✓	✓		✓
Carn Brea-20	CB20_PS	8	47, 48	-27.533	151.366	Precipice	Installed	✓	✓		✓
Carn Brea-21	CB21_WCM	19	94	-27.4376	151.3575	WCM	Installed	✓		✓	✓
Carn Brea-23	CB23_CA	19	92	-27.438	151.3576	Condamine Alluvium	Installed	✓		✓	✓
Carn Brea-24	CB24_CAWCM	19	93	-27.438	151.3574	CA / WCM transition layer	Installed	✓		✓	✓
Castledean-18	CA18_SS	73	375	-26.5529	150.222	Springbok	Installed	✓			✓
Castledean-18	CA18_WCM	73	376, 377, 378	-26.5529	150.222	WCM	Installed	✓			✓
Daandine-121	DA121_HS	37	182, 183	-27.1004	150.9557	Hutton	Installed	✓	✓		✓
Daandine-123	DA123_WCM	32	159	-27.1441	150.9481	WCM	Installed	✓			✓
Daandine-124	DA124_WF	32	157, 158	-27.1441	150.948	Westbourne	Installed	✓	✓		✓
Daandine-134	DA134_WCM	32	162, 163	-27.144	150.9486	WCM	Installed	✓			✓
Daandine-134	DA134_WCMe	32	164	-27.144	150.9486	Eurombah	Installed	✓			✓
Daandine-161	DA161_CA	34	166	-27.1185	151.0756	Condamine Alluvium	Installed	✓		✓	✓

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Daandine-163	DA163_CAWCM	34	167	-27.12	151.0759	CA / WCM transition layer	Installed	✓		✓	✓
Daandine-164	DA164_WCM	34	168	-27.12	151.076	WCM	Installed	✓		✓	✓
Daandine-254	DA254_WCM	32	160, 161	-27.1442	150.9483	WCM	Installed	✓			✓
Daandine-263	DA263_WCM	37	181	-27.1024	150.9613	WCM	Installed	✓			✓
Daandine-264	DA264_WCM	29	148	-27.1533	151.0445	WCM	Installed	✓			✓
Dundee-20	DD20_WCM	55	283, 284, 285	-26.7435	150.6784	WCM	Installed	✓		✓	✓
Glenburnie-19	GB19_WCM	4	23	-27.6392	151.1677	WCM	Installed	✓			✓
Hopeland-17	HL17_SS	142	615	-26.9732	150.6118	Springbok	Installed	✓			✓
Hopeland-17	HL17_WCM	142	616, 617, 618	-26.9732	150.6118	WCM	Installed	✓			✓
Kedron-570	KD570_WCM	143	628	-26.4134	150.1537	Eurombah	Installed	✓			✓
Kedron-570	KD570_HS	143	629	-26.4134	150.1537	Hutton	Installed	✓			✓
Kedron-570	KD570_SS	143	630	-26.4134	150.1537	Springbok	Installed	✓			✓
Kedron-570	KD570_WCM	143	626, 627	-26.4134	150.1537	WCM	Installed	✓			✓
Kogan North-56	KN56_WCM	42	209	-27.0093	150.9003	WCM	Installed	✓		✓	✓
Kogan North-79	KN79_CAWCM	42	208	-26.9989	150.9018	CA / WCM transition layer	Installed	✓		✓	✓
Kogan North-79	KN79_CA	42	207	-26.9989	150.9018	Condamine Alluvium	Installed	✓		✓	✓
Long Swamp-1	LS1_HS	17	620	-27.3586	151.1531	Hutton	Proposed (UWIR)	✓			✓
Long Swamp-1	LS1_WCM	17	83	-27.3431	151.1242	WCM	Installed	✓			✓
Longswamp-7	LS7_WCM	28	145, 146, 147	-27.1843	151.1274	WCM	Installed	✓			✓
Macalister-5	MA5_CA	47	245	-26.8951	150.9543	Condamine Alluvium	Installed	✓		✓	✓
Macalister-8	MA8_WCM	47	244	-26.8951	150.9544	WCM	Installed	✓		✓	✓
Meenawarra-21	MW21_SS	7	619	-27.5798	151.1335	Springbok	Installed	✓			✓
Meenawarra-21	MW21_WCM	7	34, 35, 36	-27.5798	151.1335	WCM	Installed	✓			✓
Meenawarra-5	MW5_WCM	7	33	-27.5779	151.1338	WCM	Installed	✓			✓

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Pampas-18	PP18_CA	5	24	-27.6147	151.2267	Condamine Alluvium	Installed	✓		✓	✓
Pampas-5	PP5_WCM	5	25	-27.6146	151.2267	WCM	Installed	✓		✓	✓
Plainview-1	PV1_WCM	15	77	-27.3858	151.2165	WCM	Installed	✓			✓
Plainview-25	PV25_CAWCM	23	120	-27.2521	151.2922	CA / WCM transition layer	Installed	✓		✓	✓
Plainview-25	PV25_CA	23	119	-27.2521	151.2922	Condamine Alluvium	Installed	✓		✓	✓
Plainview-25	PV25_WCM	23	121	-27.2521	151.2922	WCM	Installed	✓		✓	✓
RN 41620043	41620043_SS	124	578	-27.9222	151.1214	Springbok	Installed	✓			✓
RN 42230088	42230088_CA	5	24	-27.5898	151.2341	Condamine Alluvium	Installed	✓		✓	✓
RN 42230209	42230209_CA	55	281, 282	-26.7422	150.6799	Condamine Alluvium	Installed	✓	✓	✓	✓
RN 42231294	42231294_CA	14	75	-27.3993	151.5484	Condamine Alluvium	Installed	✓		✓	✓
RN 42231295	42231295_WCM	14	76	-27.3975	151.5619	WCM	Installed	✓		✓	✓
RN 42231339	42231339_CA	9	49	-27.5306	151.5037	Condamine Alluvium	Installed	✓			✓
RN 42231370	42231370_CA	10	51, 52	-27.4915	151.3932	Condamine Alluvium	Installed	✓	✓		✓
RN 42231463	42231463_CA	8	37	-27.5488	151.313	Condamine Alluvium	Installed	✓		✓	✓
Stratheden-63	SE63_SS	29	622, 623	-27.1989	151.0268	Springbok	Installed	✓	✓		✓
Tipton-157	TP157_WCM	13	72, 73, 74	-27.3981	151.0889	WCM	Installed	✓			✓
Tipton-195	TP195_CA	18	84, 85	-27.3205	151.2054	Condamine Alluvium	Installed	✓	✓	✓	✓
Tipton-196A	TP196_CAWCM	18	86	-27.3202	151.205	CA / WCM transition layer	Installed	✓		✓	✓
Tipton-197	TP197_WCM	18	88, 89, 90, 91	-27.3202	151.2053	WCM	Installed	✓	✓ (at 89 only)	✓	✓
Tipton-204	TP204_CAWCM	50	150	-27.1496	151.2094	CA / WCM transition layer	Installed	✓		✓	✓
Tipton-204	TP204_CA	30	149	-27.1496	151.2094	Condamine Alluvium	Installed	✓		✓	✓
Tipton-204	TP204_WCM	50	151	-27.1496	151.2094	WCM	Installed	✓		✓	✓

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Tipton-206	TP206_WCMe	27	141	-27.2157	151.3489	Eurombah	Installed	✓			✓
Tipton-206	TP206_WCMc	27	142	-27.2157	151.3489	WCM	Installed	✓		✓	✓
Tipton-221	TP221_CA	27	138	-27.2156	151.3489	Condamine Alluvium	Installed	✓		✓	✓
Tipton-222	TP222_CAWCM	27	139	-27.2156	151.3488	CA / WCM transition layer	Installed	✓		✓	✓
UWIR Site 41	UWIR41_CA (Macalister 7)	41	203	-27.01	151.114	Condamine Alluvium	Installed	✓		✓	✓
UWIR Site 41	UWIR41_WCM (Macalister 6)	41	204	-27.01	151.114	WCM	Installed	✓		✓	✓
UWIR Site 41	UWIR41_WCM (Macalister 6)	41	205	-27.01	151.114	Eurombah	Installed	✓			✓
UWIR Site 48 (Wyalla 16, 17, 18)	UWIR Site 48_HS	48	624	26.84	150.7866	Hutton	Proposed (UWIR)	✓			✓
UWIR Site 94	UWIR Site 94_HS	94	497	-26.2301	149.9534	Hutton	Proposed (UWIR)	✓			✓
UWIR Site 94	UWIR Site 94_WCM	94	494, 495, 496	-26.2301	149.9534	WCM	Proposed (UWIR)	✓			✓
Wyalla-16	WY16_CA	48	246, 248	-26.8662	150.755	Condamine Alluvium	Installed	✓	✓	✓	✓
Wyalla-17	WY17_PS	48	252, 253	-26.8663	150.755	Precipice	Installed	✓	✓		✓
Wyalla-18	WY18_WCM	48	249, 250, 251	-26.8661	150.7551	WCM	Installed	✓		✓	✓

Proposed (UWIR): borehole proposed for installation under the Surat CMA UWIR

2.4. GDE monitoring

GDE connectivity investigations are being undertaken by Arrow Energy (refer Section 4.4) to investigate and analyse field and laboratory data to establish, using multiple lines of evidence, the degree of connectivity between formations overlying the WCM within each of four selected study sites including Lake Broadwater and Long Swamp.

The outcomes of the study are intended to be considered in conjunction with the results of site specific GDE assessments conducted by 3D Environmental and Earth Search (refer Section 4.3). In combination, these studies seek to address the Stage 1 Approval Condition 13(f), and will be presented in detail in the Stage 2 CSG WMMP in accordance with Approval Condition 17(g).

2.5. Groundwater monitoring program and schedules

The groundwater monitoring program is based upon collection of groundwater pressure and quality data to establish baseline conditions for the groundwater resources, and also to:

- Enable the identification of spatial and temporal changes to surface water.
- Provide for the early detection and ongoing monitoring of impacts.
- Initiate responses where early warning conditions, trigger thresholds or limits are exceeded.
- Avoid the exceedance of groundwater limits.
- Provide data for decision making and groundwater modelling.

2.5.1. Pressure/level monitoring schedule

Groundwater pressure will be monitored at all active monitoring network locations. The following monitoring frequencies will be adopted for the Stage 1 CSG WMMP and are consistent with the Surat CMA UWIR monitoring requirements:

- Hourly frequency of data collection where a data logger[2] is installed. Where this occurs, 6-monthly basis (bi-annual) manual readings will also be collected in wells with open standpipes. This data will be used in conjunction with logger download data.
- Fortnightly data collection where a data logger is not installed.

Monitoring data collected will be reviewed on a 6-monthly basis to characterise groundwater pressure and trends, and reported on an annual basis. Where there is confidence that the baseline trends are established, the monitoring frequency may be reduced.

Within 30 days of the end of each 6-monthly period, data validation and a comparison of data against the EWMS early warning indicators, trigger thresholds and limits of the data collected will be completed. Collection of additional field data (if required) will be completed as soon as practicable but not within the aforementioned 30 day period.

2.5.2. Quality monitoring – schedule and parameters

Fifteen groundwater monitoring wells, at nine discrete monitoring locations have been specified for groundwater quality sampling (refer Table 2.5). These will provide baseline groundwater quality data as well as ongoing monitoring data.

Groundwater quality sampling frequency is scheduled in Table 2.6. Physical parameters and analytical suites for laboratory analysis are presented in Table 2.7.

Bi-annual sample scheduling for the ongoing sampling is adopted because:

- The frequency is consistent with the UWIR sampling schedule.
- Bi-annual sampling reduces the effect of seasonality, due to generally consistent sampling periods from year to year.

[2] Pressure transducer or vibrating wire piezometer (VWP) with data logging capabilities

Table 2.6: Sampling schedule

	Laboratory sampling suite		
	Full suite	Standard suite	Supplementary suite
Frequency	Bi-annually (for first year)	Bi-annually (for following years)	Discretionary based on full / standard suite analytical results

Table 2.7: Sample parameters and analysis

Suite	Parameters	Explanation
Physical parameters	▪ Electrical conductivity (µS/cm @ 25°C) ▪ pH ▪ Redox potential (Eh) ▪ Dissolved oxygen (DO) ▪ Temperature ▪ Free gas at wellhead (CH_4)	Field analysis only – undertake at each sampling event
Full laboratory analytical suite	▪ Total dissolved solids (TDS) ▪ Major ions (calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate, carbonate), total alkalinity ▪ Fluoride ▪ Dissolved metals (arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, zinc) ▪ Dissolved methane	Full suite to be analysed during first year. Subsequent to this, the parameter suite may be amended or reduced, depending on the results of the initial analysis (to be assessed on a well-by-well basis).
Supplementary (discretionary)	▪ Stable isotopes ▪ Silica ▪ Bromine ▪ Lithium ▪ Speciated nitrogen (nitrate, nitrite, ammonia) ▪ Total nitrogen, TKN ▪ Total phosphorus	Targeted laboratory analysis where field observations or circumstances indicate need.

Monitoring for hydrocarbon analytes (TPH, BTEX, etc) as an indicator of connectivity with coal-bearing formations is not planned, because of the significant potential for false positives due to spurious causes, and in particular due to sources associated with the drilling and well construction process. In addition, modelling predictions demonstrate that pressure gradients due to CSG extraction result in hydraulic gradients towards the Walloon Coal Measures (and not the reverse). Monitoring for hydraulic connectivity will primarily be based on pressure response monitoring.

2.6. Existing baseline data

Comprehensive water monitoring data have already been collected for the SGP, providing a baseline against which impacts can be assessed and trends established. Groundwater level baseline monitoring is being undertaken in all active wells (77 in total) forming the Stage 1 CSG monitoring network (Section 2.3.2), according to the program described in Section 2.5.1. Groundwater level baseline monitoring for the Stage 1 CSG WMMP well network commenced in 2008 and as monitoring wells have been installed the baseline monitoring program has expanded.

Table 2.8 lists the year baseline groundwater level monitoring commenced for monitoring wells in each formation of the Stage 1 CSG WMMP monitoring network. The majority of the baseline groundwater level monitoring commenced in 2013 and 2014, providing 4 to 5 years of historic groundwater level data to date.

Table 2.8: Stage 1 CSG WMMP monitoring network – history of groundwater level baseline activities

Formation	Year of commencement of baseline groundwater level monitoring and number of monitoring well locations						
	2008	**2013**	**2014**	**2015**	**2016**	**2017**	**Total monitoring well locations**
Condamine Alluvium		9	3	1	3	2	18
CA / WCM transition layer		1	3	1		2	7
Westbourne Formation		1					1
Springbok Sandstone		4	1	1			6
Walloon Coal Measures	4	5	11	7	3	1	31
Eurombah Formation		1	1	1		1	4
Hutton Sandstone		1	3				4
Precipice Sandstone		1	2				3
Evergreen Formation		1	1				2
Total monitoring well locations	**5**	**24**	**25**	**11**	**6**	**6**	**77**

As described in Section 2.3.2, fifteen groundwater monitoring wells, at nine discrete monitoring locations, have been specified for groundwater quality sampling to provide baseline groundwater quality data as well as ongoing monitoring data. Formations targeted for baseline groundwater quality monitoring include the Condamine Alluvium, Westbourne Formation, Springbok Sandstone, Walloon Coal Measures, Hutton Sandstone and Precipice Sandstone.

Groundwater sampling of these locations for baselining purposes commenced in 2013 and 2014 and at bi-annual frequencies in accordance with the program specified in Section 2.5.2, providing 4 to 5 years of historic groundwater baseline quality data to date.

In addition to the baseline data that has already been collected across the Stage 1 CSG WMMP network, a substantial volume of data is baseline data is available across the broader Surat CMA UWIR network (refer Section 2.2) as well as monitoring wells registered in the DNRM database.

2.7. Monitoring network review and update

Over time, changes are likely to be made to the Field Development Program (FDP) for rollout and production under the SGP. Necessarily, such changes may result in the requirement for the groundwater monitoring network to adapt to revised predictions of groundwater drawdown and potential impact. In addition, ongoing development and recalibration of numerical groundwater models may also lead to revised predictions.

As a result, additional monitoring locations may be required to ensure monitoring program relevance. These additional locations will be monitored in accordance with the sampling schedule and parameters provided in Section 2.5. Similarly, existing monitoring locations may become redundant, or of limited use. Such wells will be designated as inactive, and cease to be monitored. Where this is proposed, it will be documented in ongoing revisions of the CSG WMMP, including the Stage 2 CSG WMMP and required annual reports. Cessation of monitoring locations will only be adopted following review and endorsement in accordance with approvals processes set out in the Approval Conditions.

3. Surface water and aquatic ecology monitoring

A surface water and aquatic ecology monitoring network is required in the case that surface water resources or aquatic ecosystems may be impacted by the Action.

As presented in the 'GDE and Aquatic Ecosystem Impact Assessment Technical Memorandum', surface water features and aquatic ecosystems are not predicted to be impacted by depressurisation of the WCM whereby adverse effects to ecosystems would arise. Further, under the SGP, discharge of produced water to surface water systems is not proposed. Therefore, impacts to surface water resources or aquatic ecosystems are not expected and subsequently a monitoring network to address these components of conditions 13(e) and 13(f) is not currently proposed.

However, should a future revision of the FDP result in the potential for surface water or aquatic ecology impacts due to groundwater depressurisation and/or should discharge form a future project requirement then a monitoring network will be required. This section outlines the requirements and rationale for surface water and aquatic ecosystem monitoring.

3.1. Requirements

Conditions 13(e) and 13(f) require establishment of a best practice monitoring network. As presented in the 'GDE and Aquatic Ecosystem Impact Assessment Technical Memorandum', surface water features and aquatic ecosystems are not predicted to be impacted by depressurisation of the WCM whereby adverse effects to ecosystems would arise. In addition, as set out above, discharge of produced water to surface water systems is not proposed, therefore limiting monitoring requirements. Nomination of actual monitoring locations will occur should future project requirements (and a revised CSG WMMP submitted for approval by the Minister) include the need for discharge and/or future revision of the FDP result in the potential for impact to surface water systems and aquatic ecology due to groundwater depressurisation. This will allow for a site-specific approach for establishment of baseline conditions, and where required, impact monitoring.

Conditions 13(e) and 13(f) require a monitoring network to enable identification of spatial and temporal changes to surface water quality and quantity, including for determining connectivity between surface water and groundwater, and monitoring of aquatic ecosystems that may be impacted by SGP development. Should a network be required, it will allow for a site-specific approach for establishment of baseline data before impacts occur, and to enable the identification of early warning conditions as monitoring data are acquired over time.

The existing environment associated with surface water and aquatic ecology for the project area is described in the SGP EIS/SREIS. This data will be consolidated with the results of any ongoing monitoring to provide a robust dataset against which potential impacts may be assessed.

Table 3.1 details the overarching surface water monitoring network requirements derived from the Approval Conditions.

Table 3.1: Surface water monitoring network requirements

Requirement	Approach
To establish baseline conditions for surface water resources (quality and quantity) that may be impacted by the Action	Establish a network of monitoring sites within potentially impacted surface water systems to enable flow and quality monitoring, prior to any impact from the Action. Sampling from the monitoring network locations for field-water quality and laboratory analysis. Survey and sampling from the monitoring network for ecological analysis.
To establish a monitoring network that enables the identification of spatial and temporal changes to surface water resources and aquatic ecosystems that may be impacted by the Action	The monitoring network will include locations both upstream and downstream of areas potentially impacted by the Action to enable the identification of spatial and temporal changes. The established baseline conditions will be used as the basis for comparison.

3.2. Baseline monitoring network

A network of surface water and aquatic ecology monitoring locations was established as part of the SGP EIS/SREIS process, as summarised in Table 3.2. These included surface water quality, flow and aquatic ecology monitoring locations. Locations were selected to provide baseline data across representative conditions for the different surface water systems and land uses within the SGP area, at the time of the EIS/SREIS. The location of these sites is presented in Figures 3.1a, b and c. Further to this, baseline data is available via the Queensland DNRME state monitoring network, with 17 currently open surface water gauging stations situated in or in close proximity to Arrow's tenure, 15 of which monitor water quality (sites 422361A and 422343A do not have water quality baseline data).

These figures show that a network of baseline monitoring locations are established in the vicinity of connected reaches of the Condamine River south of Chinchilla (monitoring site 69 and 422308C), several sites immediately south of Cecil Plains (e.g. monitoring sites 7, 422316A, and DA9-2), monitoring site 422355A south-east of Millmerran and monitoring site 10 at Lake Broadwater. Note: as shown in Figure 3.1a, 3.1b and 3.1c, additional monitoring of surface water has also been undertaken in reaches of the Condamine River and tributaries not connected to groundwater.

It is also noted that the OGIA set out the requirements for responsible tenure holders for monitoring of potentially affected watercourse springs. Arrow are not the responsible tenure holder for any identified watercourse springs, and no monitoring sites nominated by the OGIA are located within relevant areas for the SGP.

Table 3.2: Summary of EIS/SREIS surface water and aquatic ecology monitoring

	Project phase	No. sites monitored	Monitoring events
Surface water quality	EIS	35	October 2009 November 2009 March 2010
	SREIS	14	February 2013
	DNRME[1] active network	10[2]	1993 - present (continuous EC and temperature monitoring)
		15[2]	1962 - present (Periodic monitoring of a broad water quality suite)
Aquatic ecology	EIS	11	November 2009 May 2010
	SREIS	22	February / March / May 2013

Where required, a surface water monitoring network will monitor surface water flow, quality and aquatic ecology at specific locations to confirm baseline conditions should future assessment indicate the potential for groundwater drawdown related impact. Monitoring activities will commence in advance of the potential for impact to occur, to enable the establishment of baseline conditions and development of Water Quality Objectives (WQOs) where required.

The following will be taken into consideration when selecting surface water and aquatic ecology monitoring sites:

- Establishment of reference sites where required.
- Permanent, semi-permanent, lotic or lentic nature of water bodies.
- Ephemeral or perennial nature of streams.

3.3. Surface water and aquatic ecosystem monitoring program and schedules

3.3.1. Design rationale

Surface water flow, quality and aquatic ecology monitoring will be carried out at specific locations to establish baseline conditions if future assessment indicates the potential for groundwater drawdown related impact. Monitoring activities will commence in advance of the potential for impact to occur, to enable the establishment of baseline conditions and development of WQOs where required.

Minimum requirements for monitoring data collection are defined (DEHP, 2009) for the establishment of baseline conditions, in particular for the establishment of reference[3] sites.

DEHP (2009) generally require reference sites to be relatively unaffected by surrounding land use, and not significantly affected by surface water abstraction or regulation. Data collected from reference sites are used to establish water quality guidelines, and ultimately WQOs based on calculated percentiles.

For slightly disturbed to moderately disturbed[4] water bodies, the 20th and 80th percentiles of reference site values should be used based on:

- Eight data points (minimum) collected over at least 12 months from one or two reference sites; or
- Twelve data points (minimum) collected over at least 12 months from three or more reference sites; or
- Eight data points collected over 12 months for interim data sets (subject to validation and update based on further data collection); and
- For ephemeral sites, a minimum of two reference sites are used to derived WQOs.

3.3.2. Monitoring schedule

Should future assessment indicate the potential for groundwater drawdown related impact, the monitoring frequency for establishment of baseline conditions and ongoing monitoring detailed in Table 3.3 will be adopted, noting that the proposed monitoring frequencies will be reviewed against the EIS/SREIS baseline monitoring sites and if necessary, revised and locations specified.

Given the variable flow conditions and site setting of each monitoring location the specific monitoring requirements at each location should be tailored to suit the specific data quality objectives for that site, and also take into account the robustness of the available dataset. The identification of impacts may also trigger additional monitoring requirements.

Table 3.3: Monitoring frequencies for baseline condition and impact monitoring

Monitoring domain	Monitoring type	Frequency	Monitoring suite (refer Table 3.4)
Ephemeral streams	Water quality and flow	Continuous (logged)	EC, temperature and water level. Flow derived from level.
	Water quality	Bi-annual (when flowing)	Physical parameters Full surface water baseline
	Aquatic ecology	Annually	Aquatic ecology
Perennial streams	Water quality and flow	Continuous (logged)	EC, temperature and water level. Flow derived from level.

[3] Sites considered to be suitable baseline or benchmark for the assessment and management of sites in similar water bodies
[4] Watercourses within the SGP development area are reported to range from slightly to highly disturbed

Monitoring domain	Monitoring type	Frequency	Monitoring suite (refer Table 3.4)
	Water quality Aquatic ecology	Bi-annual (nominally pre- and post-wet season)	Physical parameters Full surface water baseline Aquatic ecology
	Aquatic ecology	Bi-annual	Aquatic ecology

3.3.3. Monitoring parameters

The suite of parameters (refer Table 3.4) is consistent with water quality assessments carried out for the EIS/SREIS. The suite would be reviewed and amended as required for site-specific conditions based on available data and the nature of potential impacts predicted.

Table 3.4: Surface water and aquatic ecology monitoring parameters

Suite	Parameters	Explanation
Physical parameters	▪ Electrical conductivity ▪ pH ▪ Dissolved oxygen (DO) ▪ Temperature ▪ Turbidity ▪ Redox potential (Eh)	In-situ analysis only.
Full surface water (laboratory)	▪ Total dissolved solids (TDS) and total suspended solids (TSS) ▪ Major cations and anions (calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate alkalinity, carbonate alkalinity) ▪ Total alkalinity ▪ Speciated nitrogen (nitrate, nitrite, ammonia) ▪ Total nitrogen, total oxidised nitrogen, TKN ▪ Reactive phosphorus, total phosphorus ▪ Fluoride ▪ Sodium adsorption ratio ▪ Total and dissolved metals (arsenic, boron, cadmium, cobalt, copper, lead, mercury, nickel, selenium, vanadium, zinc) ▪ Phenol ▪ Triethylene glycol (TEG)	Full suite to be analysed during first year. Subsequent to this the suite may be reduced, depending on the results of the initial analysis and ongoing assessment requirements.
Aquatic ecology	▪ Physical parameters (as above) ▪ AusRivAS assessment ▪ Fish and habitat assessment	

3.4. Monitoring network review and update

Future changes to the monitoring network and program in relation to aquatic ecology and ecosystems will be captured in annual review reports, future iterations of the WMMP and other ongoing revisions required by the Approval Conditions.

4. Aquifer connectivity studies

Arrow has commissioned and contributed to a number of studies aimed at advancing the understanding of connectivity between the WCM, aquifers potentially affected by depressurisation of the WCM, and surface water features.

This section provides a summary of relevant completed, in progress and proposed studies that demonstrate compliance with the requirements for determining connectivity between surface water and groundwater that may be impacted by the project (Approval Condition 13e) and for aquifer connectivity studies (Approval Condition 13f).

4.1. Condamine Interconnectivity Research Project

The Condamine Interconnectivity Research Project (CIRP) (OGIA, 2016) is an OGIA-directed project aimed to further quantify connectivity between the Condamine Alluvium and the WCM. The CIRP is now complete and represents a significant package of work in advancing understanding around hydraulic connectivity between these formations. The CIRP included:

- Interpretation and modelling of geology to map the transition zone (interface) between the Condamine Alluvium and the WCM.
- Surveying and mapping of Condamine Alluvium and WCM groundwater levels to establish differences in groundwater pressure between the formations.
- Hydrochemical assessment to test hypotheses about groundwater mixing between the Condamine Alluvium and WCM.
- Aquifer pumping tests and associated drilling at selected sites to establish physical and hydraulic characteristics of the transition zone, and to establish high-value long-term monitoring sites.

Arrow contributed significantly to the project including establishing monitoring points and completion of hydraulic testing. Outcomes of the CIRP resulted in the following conclusions:

- Geologic data shows that a clay-rich or mudstone horizon at the base of the Condamine Alluvium and the top of the WCM acts as a physical barrier that impedes flow between the formations.
- Persistent differences in groundwater pressure between the formations, and flow patterns within the formations, demonstrate that impediments to flow exist between the formations.
- Hydrochemical data suggests there has been little past movement of water between the formations, even in areas where significant groundwater pressure differences have existed for a prolonged period.
- Detailed aquifer pumping tests at two sites found no significant flow between the formations in response to pumping tests near those sites. The tests show that vertical hydraulic conductivity for the material between the formations is consistent with that of a highly effective aquitard.
- The hydraulic connectivity between the Condamine Alluvium and the WCM is low.

No further specific studies into the connectivity of the WCM and Condamine Alluvium are currently proposed.

4.2. Integrated surface water-groundwater modelling

To meet Condition 13(b), Arrow commissioned CDM Smith (2016) to establish an integrated groundwater-surface water model, referred to as the CDM Smith Condamine Alluvium Model, a numerical model based on the Central Condamine Alluvium Model (CCAM), originally developed by KCB (2016).

The CDM Smith Condamine Alluvium Model has been used to predict drawdown in the Condamine Alluvium due to CSG production, and quantify the impact that flux changes to the Condamine

Alluvium may have on surface water flow in the Condamine River. The model provides for a more detailed understanding of gaining or losing reaches of the Condamine River than previously available.

The model predicted impacts were also used as inputs to the Condamine River Integrated Quantity and Quality Model (IQQM)[5]. This enabled evaluation of impacts on river flows and users that may result from CSG induced drawdown.

Revised integrated surface water-groundwater modelling will be presented with the Stage 2 CSG WMMP, in accordance with Approval Condition 17(b).

4.3. GDE field studies

Arrow engaged consultants to carry out a staged desktop assessment and subsequent field surveys, as presented in 3D Environmental (2017; 2018). The studies have advanced knowledge around the presence and distribution of GDEs in areas at risk of groundwater drawdown due to SGP depressurisation. Included in this was area-specific hydrogeological conceptualisation to provide a basis for the assessment of connectivity between aquifers affected by depressurisation and GDEs.

4.3.1. Objectives

The objectives of the GDE assessment and monitoring program are to:

- Identify if vegetation accesses groundwater (permanently or intermittently) to verify assumptions used in previous desktop GDE assessments.
- Identify the degree of connection between aquifer units (including coal formations) to verify if propagation of drawdown in deeper coal measures will impact shallow formations.
- Identify stratigraphy to confirm geological mapping at monitoring sites.

The scope of work includes field ecological and hydrogeological characterisation of potential GDE sites, and installation of monitoring infrastructure.

Two sites have been chosen for investigations based on the assessed risk to potential GDE landscapes, as set out in the GDE and Aquatic Ecosystem technical memorandum, as well Long Swamp and Lake Broadwater. Specifically, the site are:

- The southern part of designated Risk Area 3b, referred to as Glenburnie (south west of Cecil Plains).
- The northern part of designated Risk Area 4, referred to as Burunga Lane (near Wandoan).
- Long Swamp GDE investigation site.
- Lake Broadwater GDE investigation site.

The initial two sites were chosen to satisfy Approval Condition 13(c) whilst monitoring of Lake Broadwater and Long Swamp areas is a requirement of Approval Condition 13(f).

4.3.2. Approach

The proposed approach is that of carry out field studies to provide multiple lines of evidence for the assessment of GDE status, taking into account ecological and hydrogeological information, including:

- Assessment of tree rooting depth.
- Groundwater monitoring bore installation and sampling.

[5] IQQM is a hydrological modelling tool used for planning and evaluating water resources, developed by the NSW Department of Primary Industries.

- Soil moisture potential measurement.
- Leaf water potential measurement.
- Stable isotope analysis.
- Baseline ecological and hydrogeological characterisation.

These studies are ongoing and the results will be presented in detail in the Stage 2 CSG WMMP in accordance with Approval Condition 17(g).

4.4. Long Swamp and Lake Broadwater – groundwater connectivity studies

Specific assessment of the hydraulic connectivity of Long Swamp and Lake Broadwater to underlying aquifers that may be affected by depressurisation of the WCM is in progress. Arrow has nominated specific monitoring targets and field program planning is underway, as set out in Section 4.3.

Groundwater monitoring locations will be established at both Long Swamp and Lake Broadwater. Field studies will be carried out to assess the connectivity of these features to local and regional flow systems, as well as the potential for groundwater-surface water interaction and the presence of terrestrial GDEs. The proposed scope of work for each monitoring location is:

- Installation of monitoring bores.
- Aquifer parameter testing if required.
- Downhole geophysical logging, where relevant.
- Shallow coring adjacent to a mature tree identified as being potentially groundwater dependent to verify tree root depths through direct observation and, where relevant, laboratory analysis of tree root matter in drill core.
- Installation of data loggers in specified bores to record and compile groundwater level and temperature data.
- Groundwater and surface water quality sampling and analysis.

These studies seek to address the Stage 1 Approval Condition 13(f), and will be presented in detail in the Stage 2 CSG WMMP in accordance with Approval Condition 17(g) when finalised.

4.5. Co-located groundwater monitoring sites

Arrow's proposed Stage 1 CSG WMMP monitoring network includes a number of monitoring points at the same location that will facilitate improved understanding of vertical connectivity between monitored aquifers. These monitoring locations are shown in Figure 4.1 and summarised in Table 4.1.

Table 4.1: Summary of Stage 1 CSG WMMP co-located monitoring points

Site	Location IDs	Number of formations monitored	Monitored formations
1	Burunga Lane-174 and 176	4	WCM, Evergreen, Hutton, Precipice
2	Kedron-570	4	Springbok, WCM, Eurombah, Hutton
3	Castledean-18	2	Springbok, WCM
4	RN 42230209, Dundee-20	2	Condamine Alluvium, WCM
5	Wyalla-16, 17 and 18	3	Condamine Alluvium, WCM, Precipice
6	Hopeland-17	2	Springbok, WCM
7	Kogan North-79	2	Condamine Alluvium, CA-WCM transition layer, WCM
8	Daandine-121 and 263	2	Hutton, WCM
9	Daandine-161, 163 and 164	2	Condamine Alluvium, CA-WCM transition layer, WCM
10	Daandine-123, 124, 134 and 254	2	Westbourne, WCM
11	Tipton-204	3	Condamine Alluvium, CA-WCM transition layer, WCM
12	Longswamp-7	1	WCM
13	Tipton-206, 221 and 222	2	Condamine Alluvium, CA-WCM transition layer, WCM
14	Plainview-25	2	Condamine Alluvium, CA-WCM transition layer, WCM
15	Tipton-195, 196A and 197	2	Condamine Alluvium, CA-WCM transition layer, WCM
16	Tipton-157	1	WCM
17	Carn Brea-21, 23 and 24	2	Condamine Alluvium, CA-WCM transition layer, WCM
18	Carn Brea-17, 19 and 20	5	Condamine Alluvium, WCM, Evergreen, Hutton, Precipice
19	Meenawarra-5 and 21	2	Springbok, WCM
20	Pampas-5 and 18	2	Condamine Alluvium, WCM
21	RN 41620043, Bora Creek-10	2	Springbok, WCM
22	Long Swamp-1	2	WCM, Hutton
23	UWIR Site 94 (Proposed)	2	WCM, Hutton
24	RN42231294, RN42231295	2	Condamine Alluvium, WCM
25	Macalister 5 and 8	2	Condamine Alluvium, WCM
26	UWIR Site 41 (Macalister 6 & 7)	2	Condamine Alluvium, WCM

Note: Some formations may have multiple screen intervals

5. Data management and analysis

Implementation of the CSG WMMP will generate significant volumes of data including field records and observations, electronically logged water pressure and laboratory water quality data. All data generated will be collated and stored in digital form.

At a minimum, this will comprise a database containing details of:

- WMMP well locations, construction details and monitored aquifer.
- Well drilling records, geophysical logs and interpreted stratigraphy.
- Any permanent well infrastructure or instrumentation.
- Groundwater pressure and quality records.
- Surface water quality and flow records.
- Aquatic ecosystem monitoring records.

Data will be subject to a review program or system to identify data or transcription errors, and to ensure quality control. For each monitoring location, at the end of the first year of monitoring data will be reviewed in detail to determine whether it is appropriate to reduce the monitoring frequency, as described in Section 2.

The Arrow monitoring obligations tabulated in Appendix 1 reflect the status of the network at the time the UWIR was released in March 2016.

6. References

3D Environmental and Earth Search, 2017. *Identification and Assessment of Groundwater Dependent Ecosystems*. Arrow Surat Gas Project.

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Department of Environment and Heritage Protection (DEPH) (2009). Queensland Water Quality Guidelines, Version 3 July 2013.

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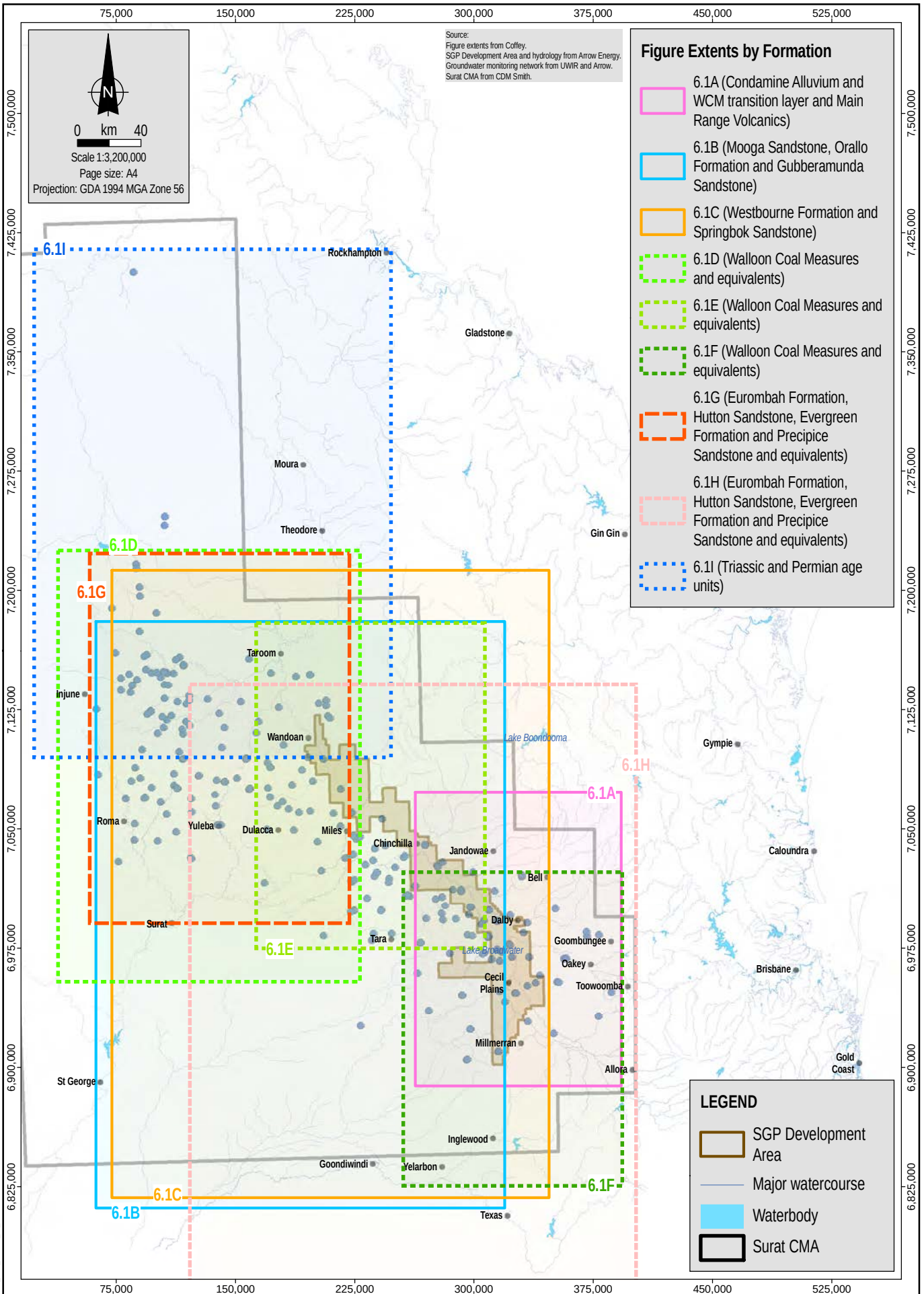
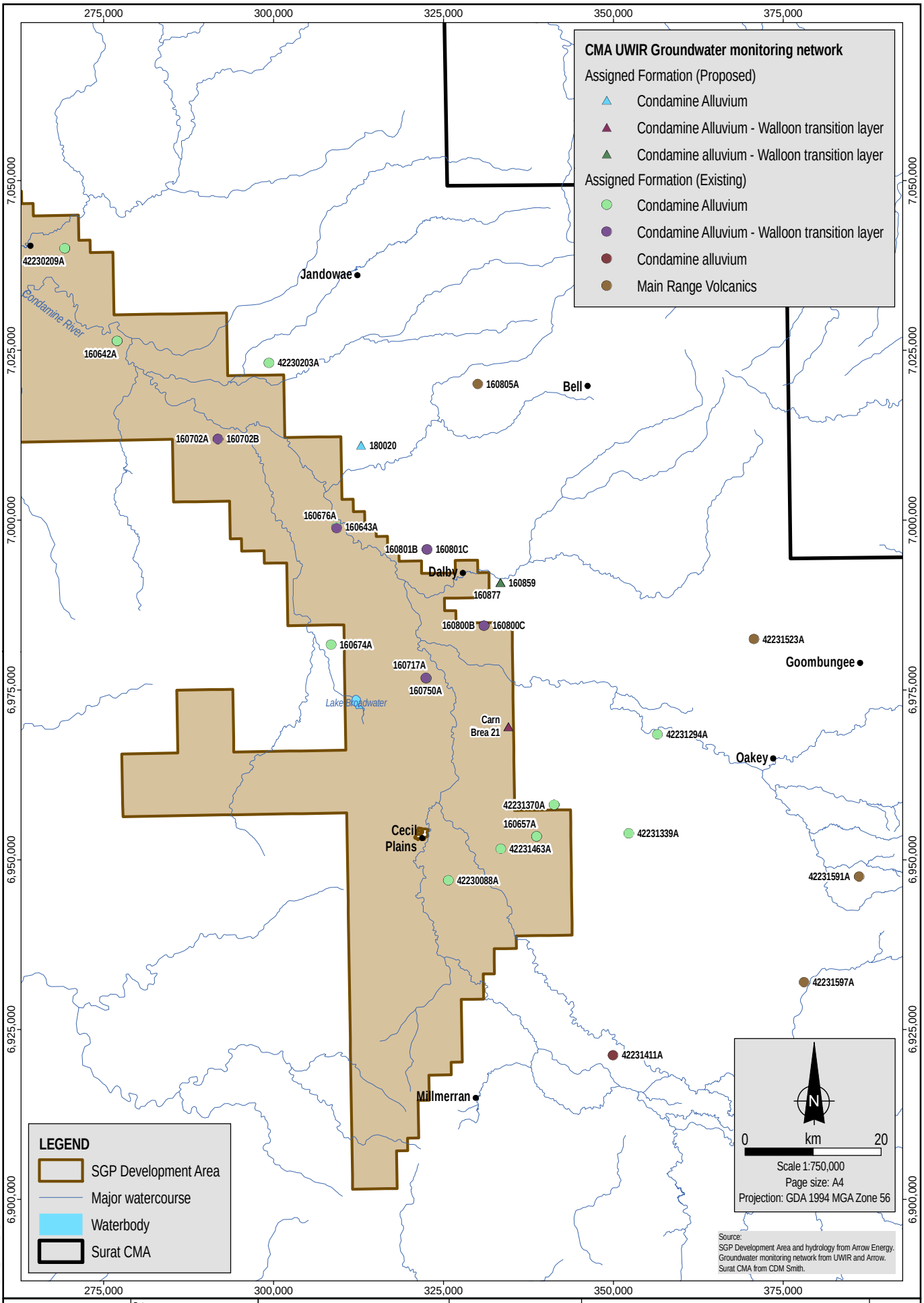
Office of Groundwater Impact Assessment (OGIA) (2016a). Underground Water Impact Report for the Surat Cumulative Management Area.

Figures



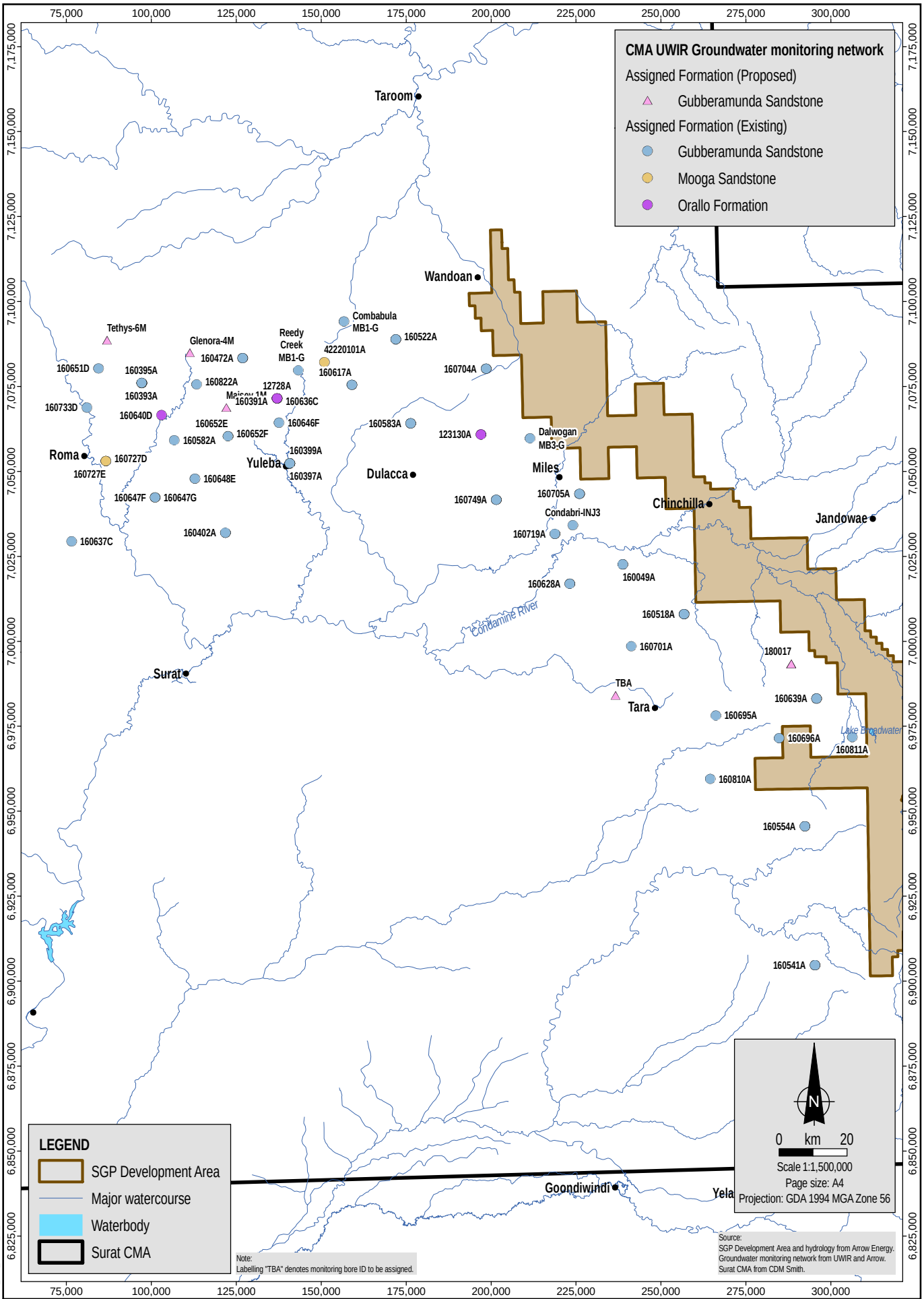
MXD Reference: 20484AB_M03_GIS038_v0_1

coffey A TETRA TECH COMPANY	Date: 25.09.2018 Project: ENAUABTF20484AA File Name: 20484AB_M03_F02.1A_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Surat CMA UWIR groundwater monitoring network overview	Figure No: 2.1



coffey A TETRA TECH COMPANY	Date: 25.09.2018 Project: ENAUABTF20484AA File Name: 20484AB_M03_F02.1B_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Surat CMA UWIR groundwater monitoring network - Condamine Alluvium and WCM transition layer and Main Range Volcanics	Figure No: 2.1A

MXD Reference: 20484AB_M03_GIS029_v0_2



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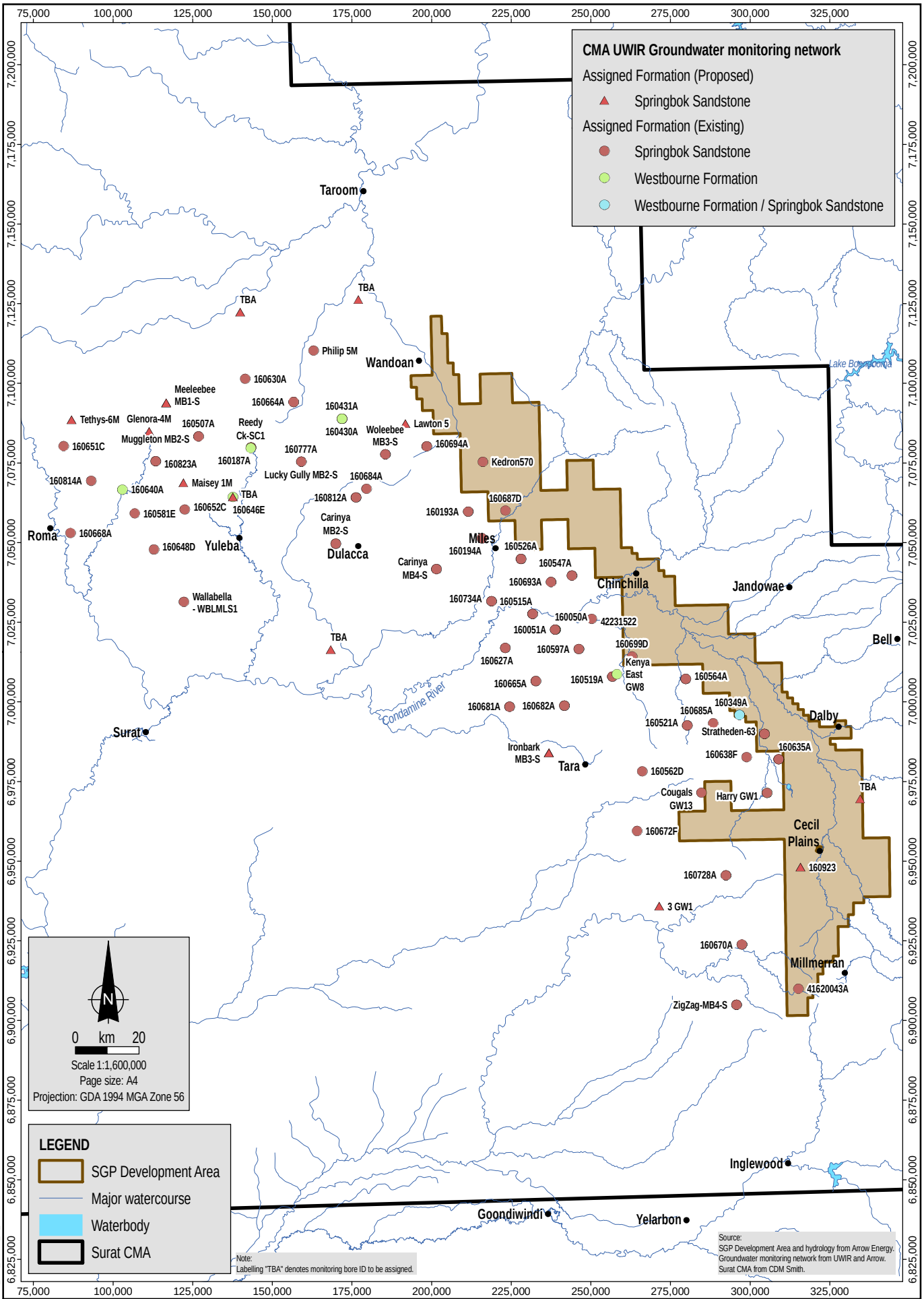

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coffey
A TETRA TECH COMPANY

Date: 25.09.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F02.1D_GIS

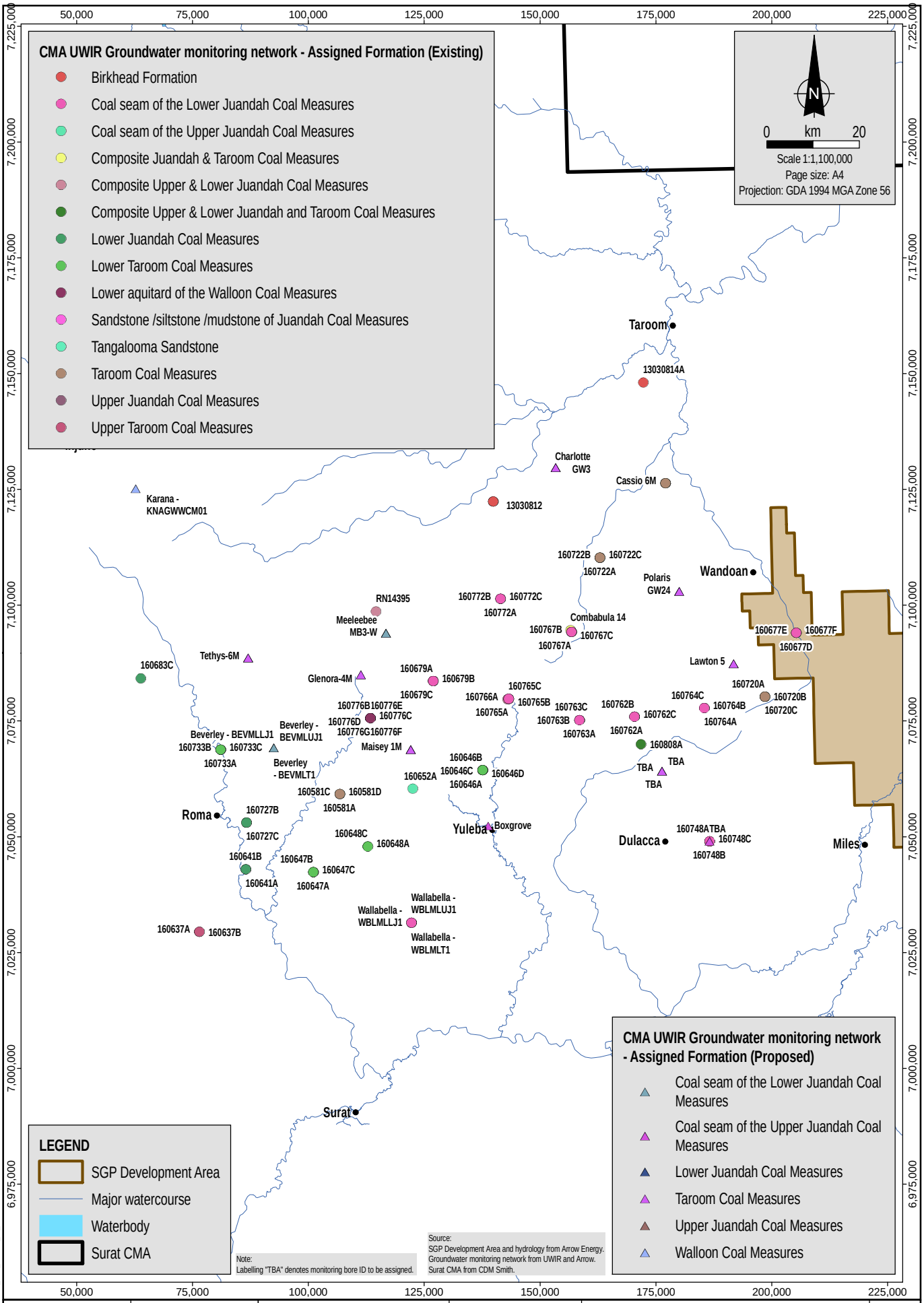
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Surat CMA UWIR groundwater monitoring network - Westbourne Formation and Springbok Sandstone

Figure No:
2.1C



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A TETRA TECH COMPANY

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Project: ENAUABTF20484AA
File Name: 20484AB_M03_F02.1E_GIS

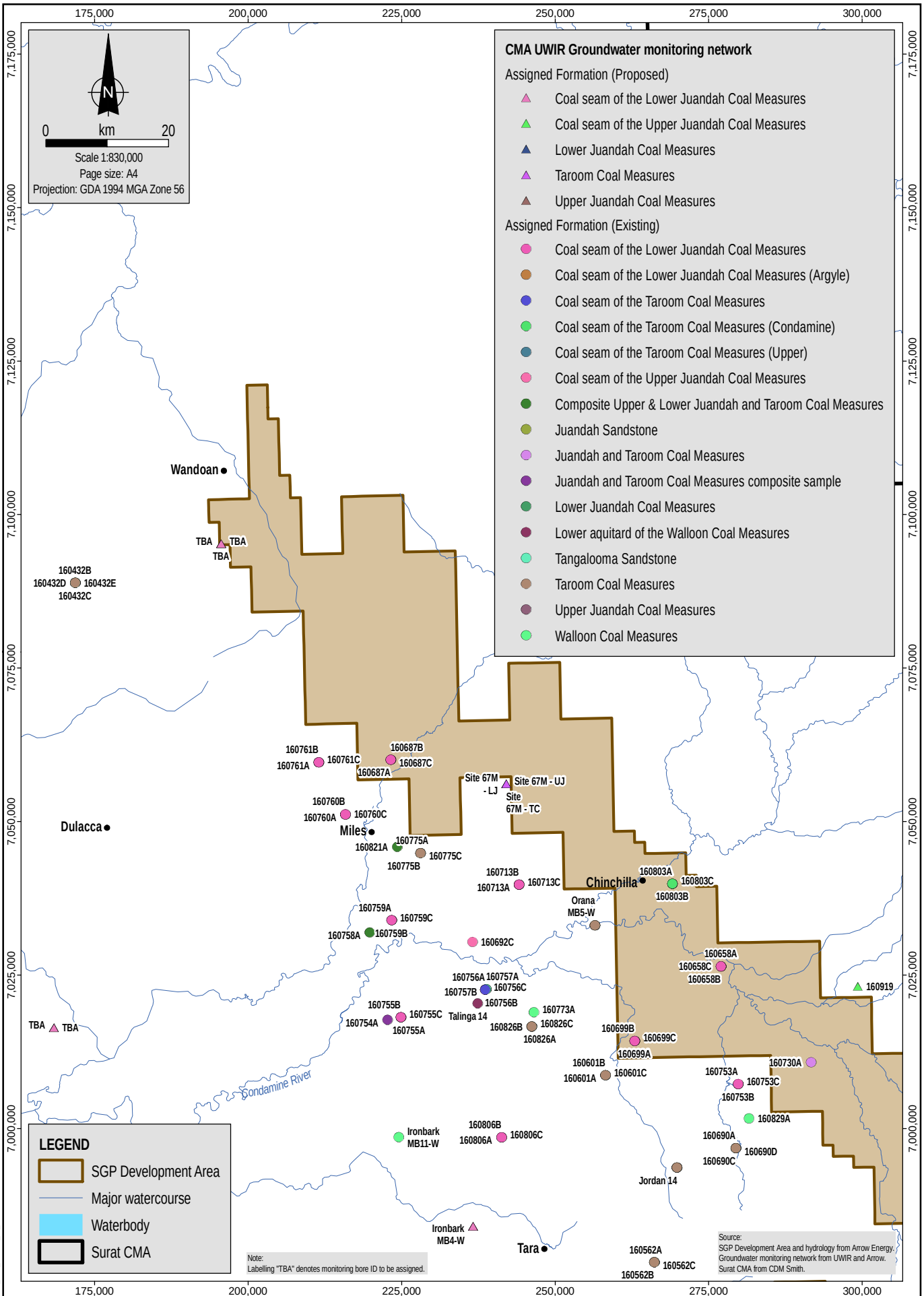
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Surat CMA UWIR groundwater monitoring network - Walloon Coal Measures and equivalents - Northern extent

Figure No:
2.1D



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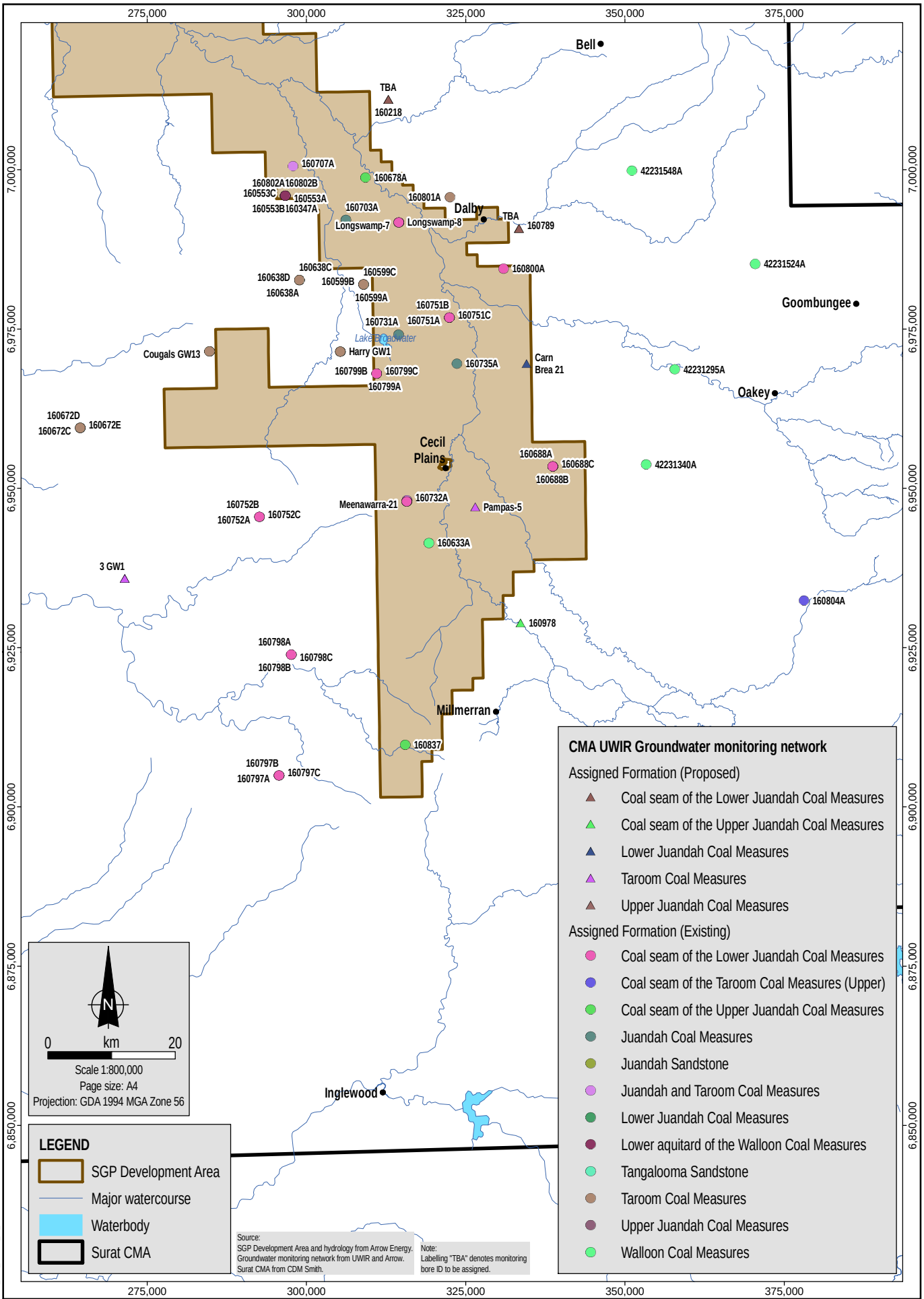
coffey A TETRA TECH COMPANY	Date: 25.09.2018 Project: ENAUABTF20484AA File Name: 20484AB_M03_F02.1F_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Surat CMA UWIR groundwater monitoring network - Walloon Coal Measures and equivalents - Central extent	Figure No: 2.1E



MXD Reference: 20484AB_M03_GIS034_v0_2

coffey
A TETRA TECH COMPANY

Date: 25.09.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F02.1G_GIS

Arrow Energy

Surat Gas Project WMMP

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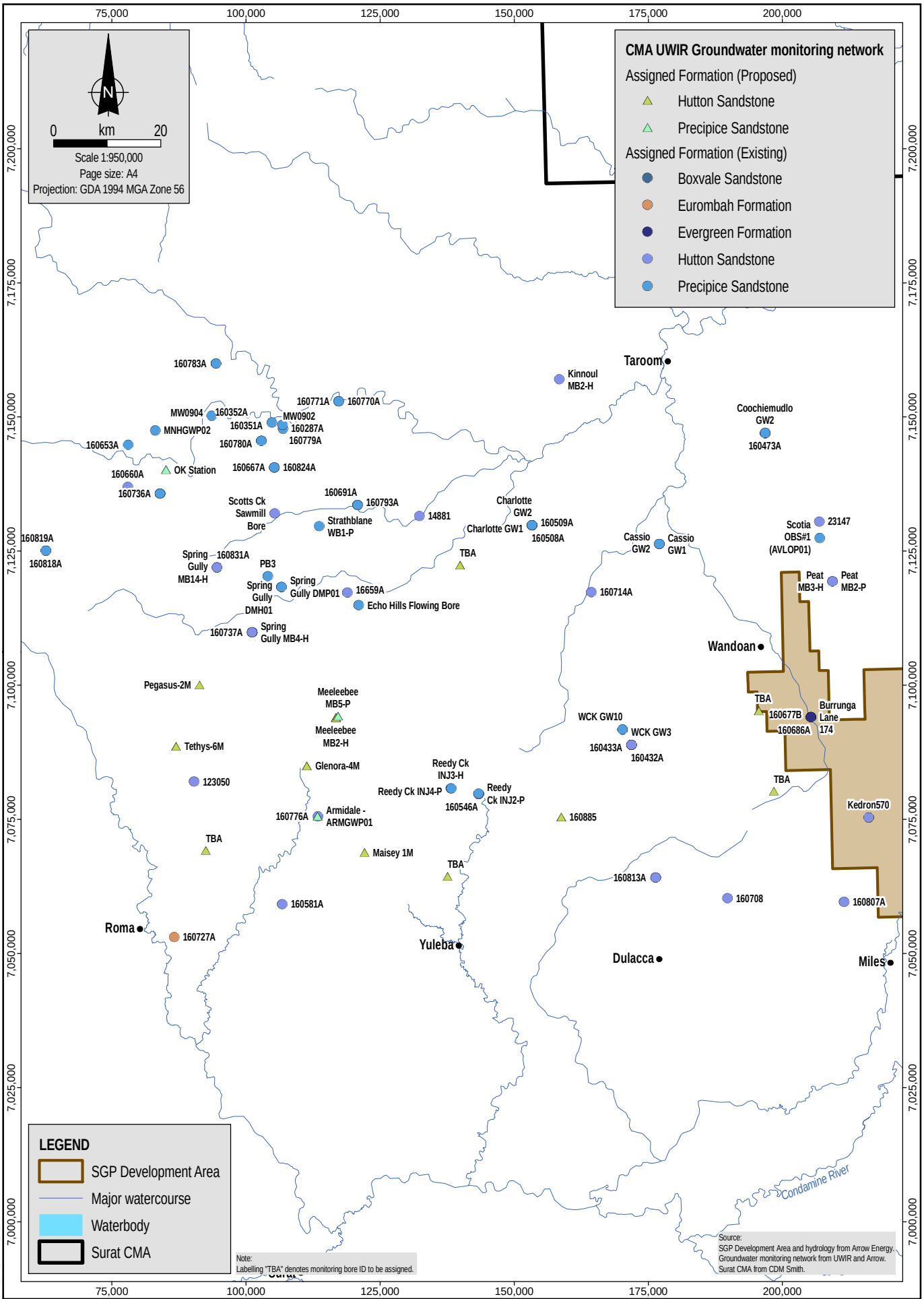
go further

Surat CMA UWIR groundwater monitoring network - Walloon Coal Measures and equivalents - Southern extent

Figure No: 2.1F



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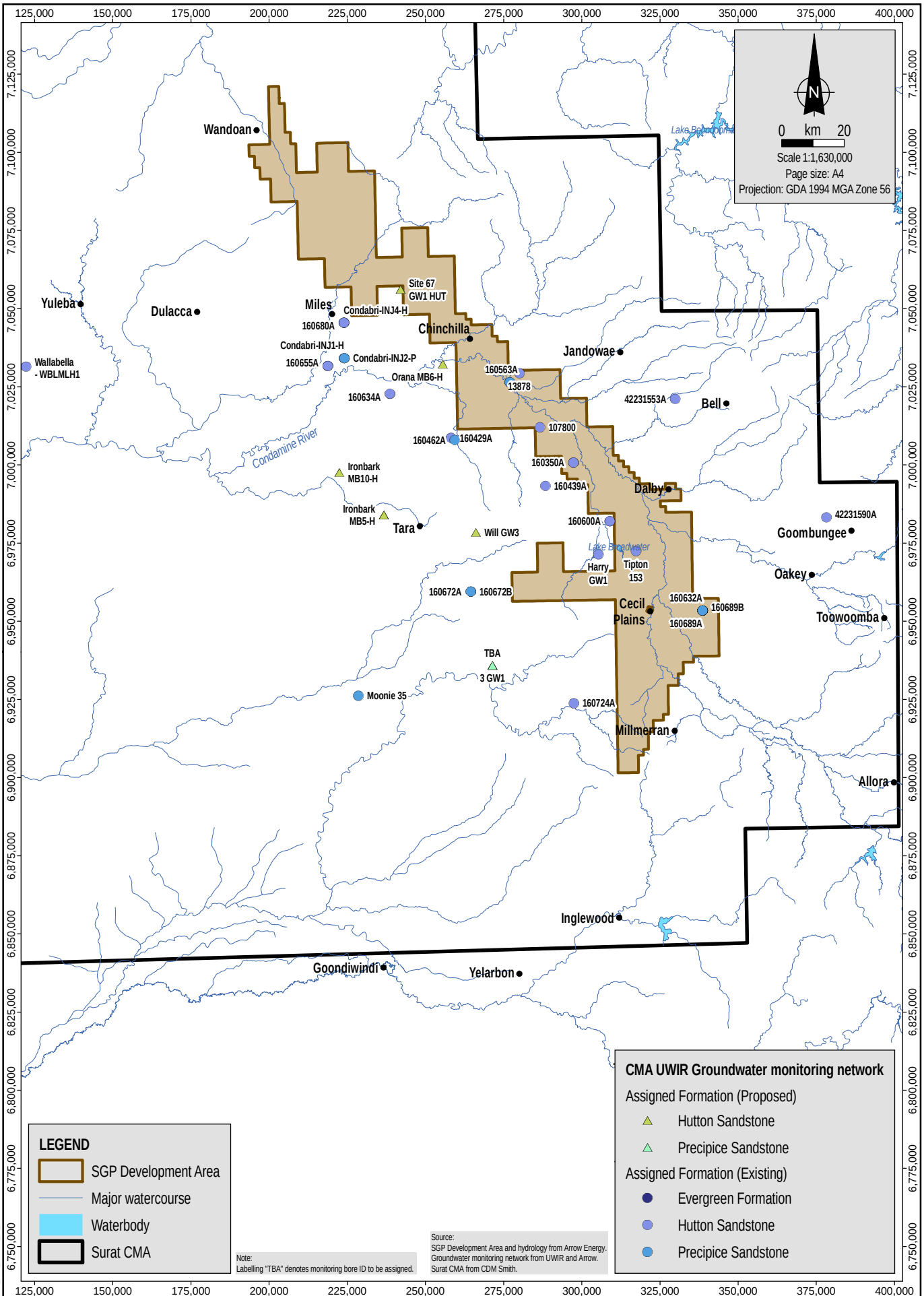
coffey A TETRA TECH COMPANY	Date: 25.09.2018 Project: ENAUABTF20484AA File Name: 20484AB_M03_F02.1H_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Surat CMA UWIR groundwater monitoring network - Eurombah Formation, Hutton Sandstone, Evergreen Formation and Precipice Sandstone and equivalents - Western extent	Figure No: 2.1G



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coffey
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Date: 25.09.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F02.1I_GIS

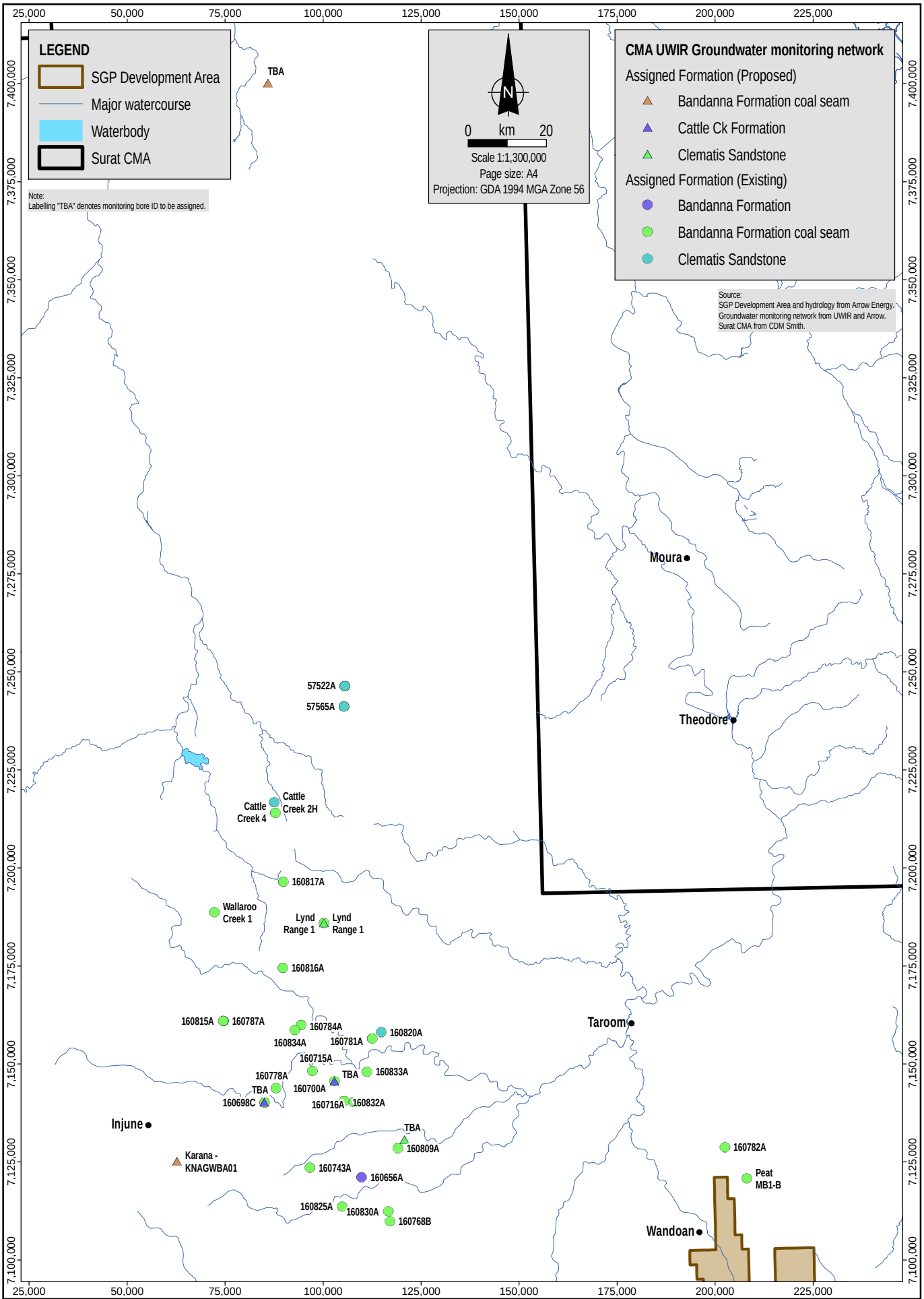
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

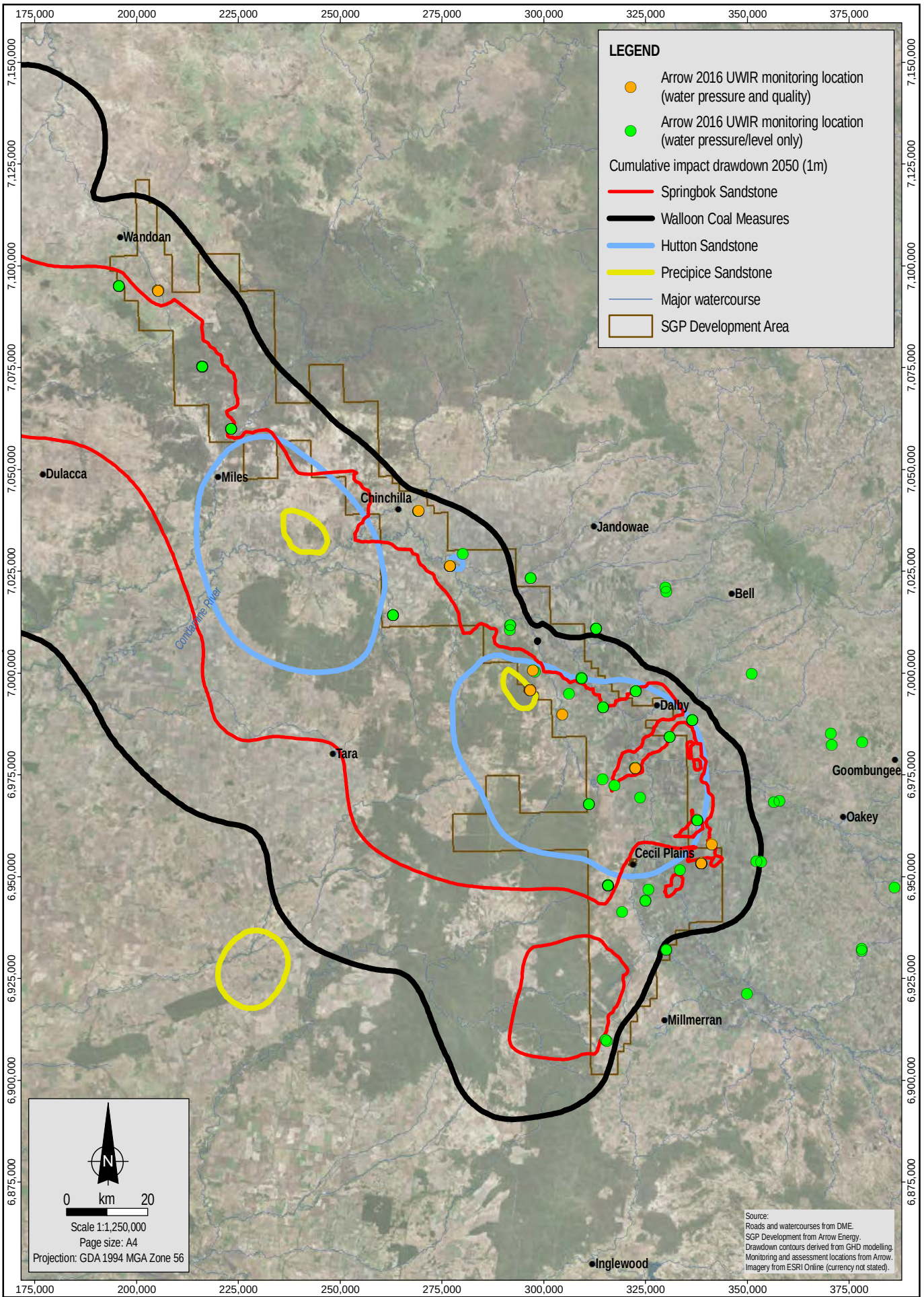
Surat CMA UWIR groundwater monitoring network - Eurombah Formation, Hutton Sandstone, Evergreen Formation and Precipice Sandstone and equivalents - Eastern extent

Figure No:
2.1H



coffey A TETRA TECH COMPANY	Date: 25.09.2018 Project: ENAUABTF20484AA File Name: 20484AB_M03_F02.1J_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Surat CMA UWIR groundwater monitoring network - Triassic and Permian age units	Figure No: 2.1J

MXD Reference: 20484AB_M03_GIS037_v0_2



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coffey
A TETRA TECH COMPANY

Date: 19.10.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F02.1_GIS

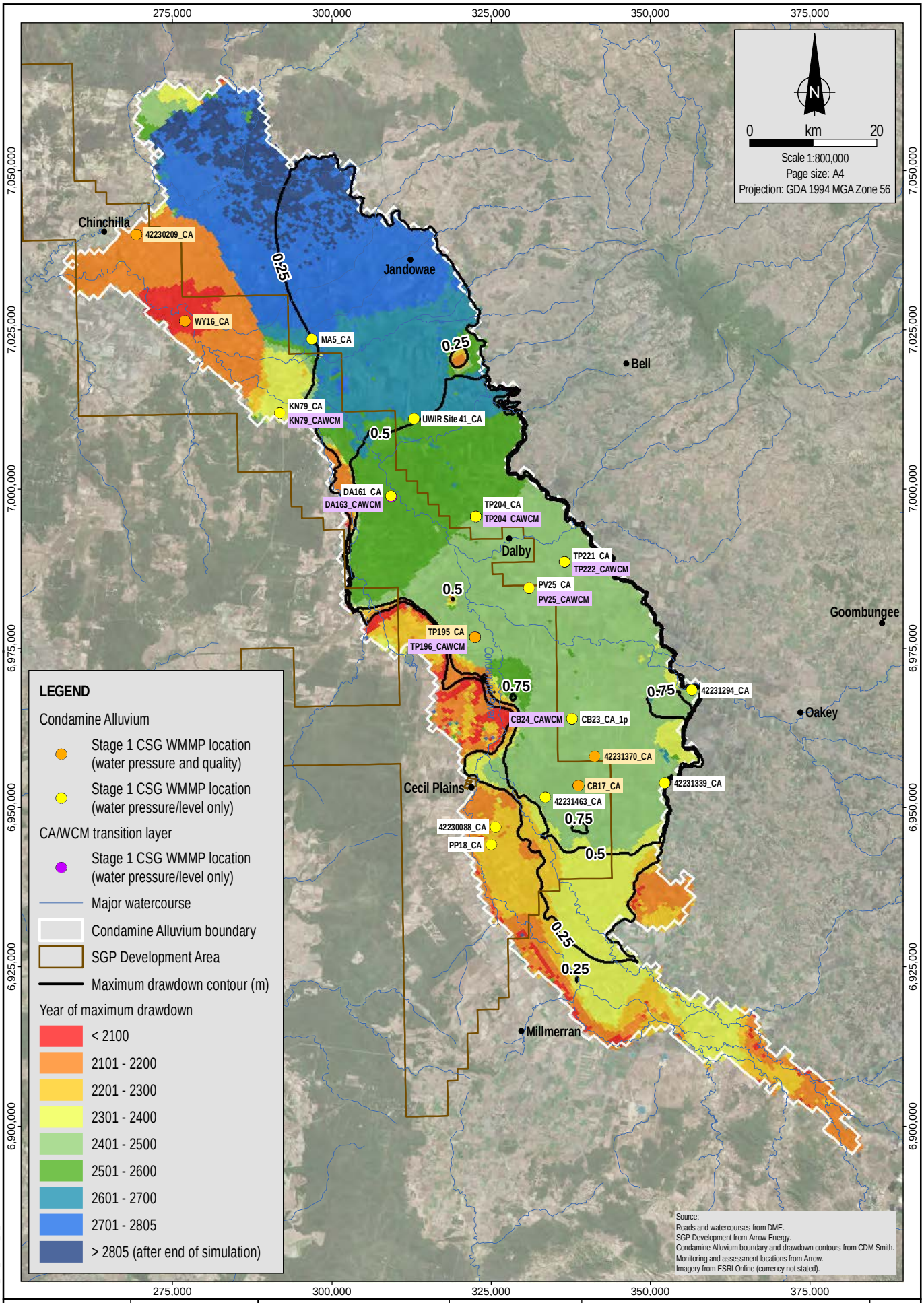
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Arrow 2016 UWIR monitoring locations

Figure No:
2.1J



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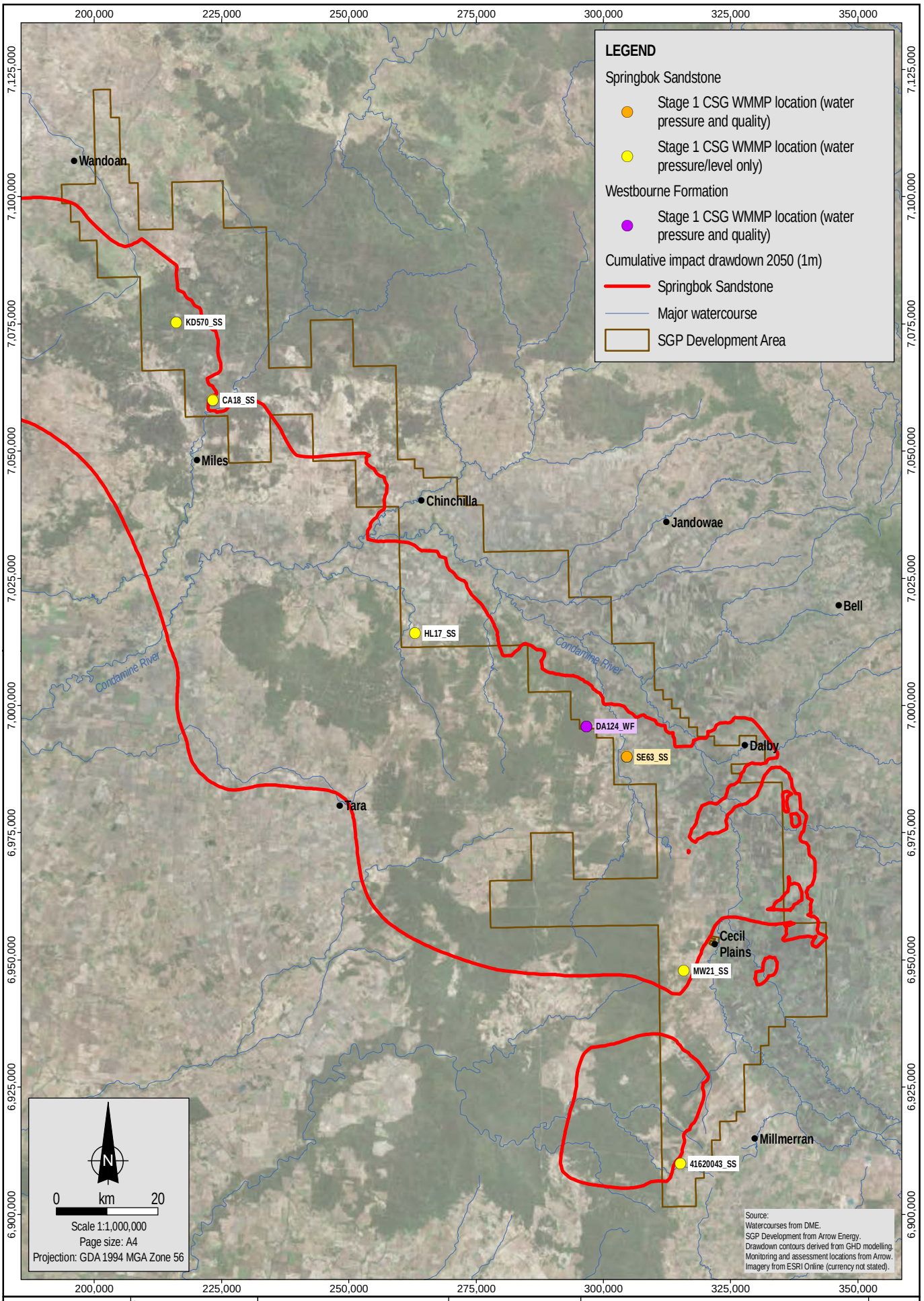
coffey A TETRA TECH COMPANY	Date: 25.09.2018 Project: ENAUABTF20484AA File Name: 20484AA_M07_F002.2a_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Stage 1 CSG WMMP monitoring points (Condamine Alluvium aquifer and CA/WCM transition layer)	Figure No: 2.2a



MXD Reference: 20484AA_M07_GIS013_v0_1

coffey
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Date: 27.06.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F002.2b_GIS

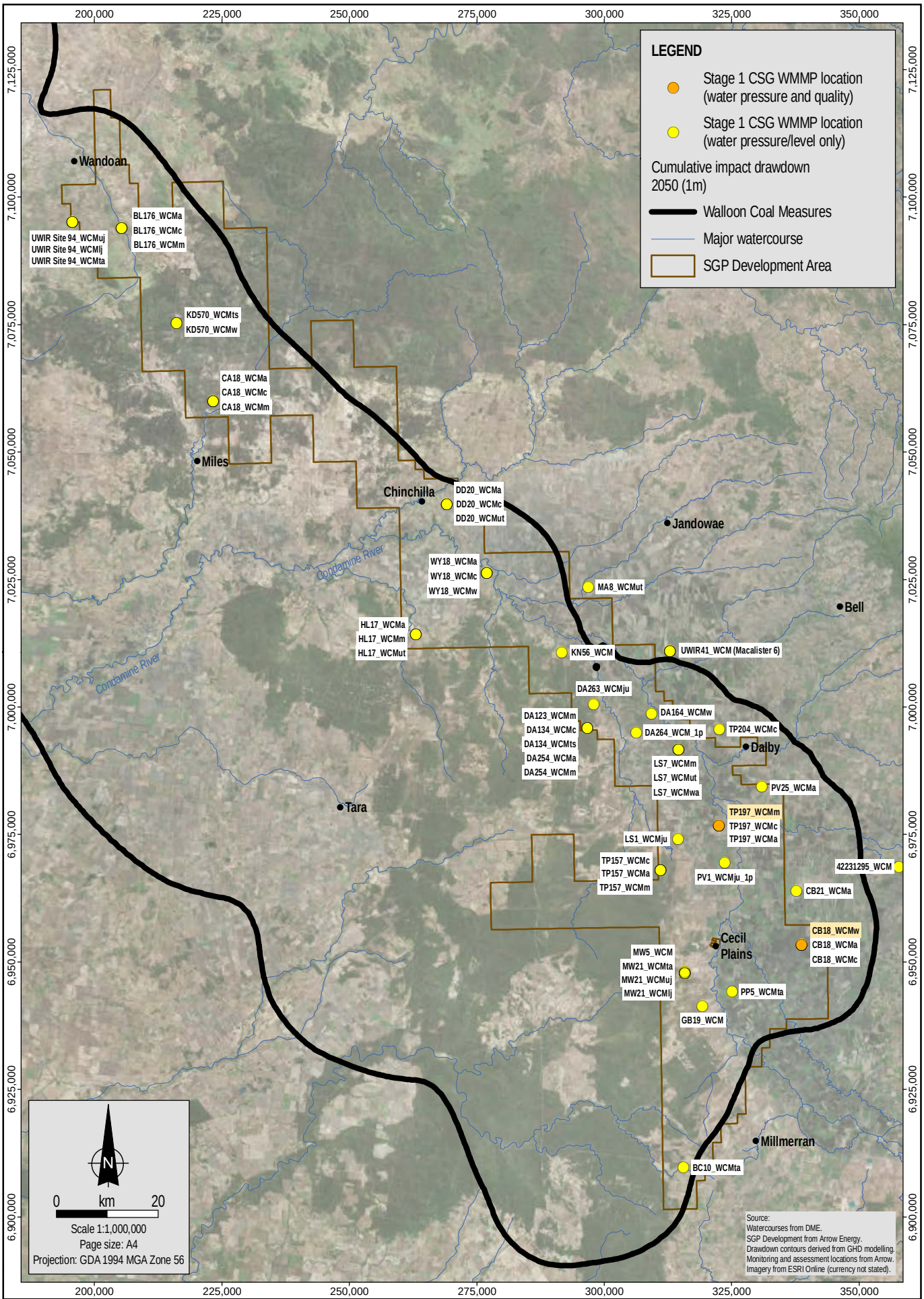
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Stage 1 CSG WMMP monitoring points (Springbok Sandstone aquifer and Westbourne Formation)

Figure No:
2.2b



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Date: 19.10.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F002.2c_GIS

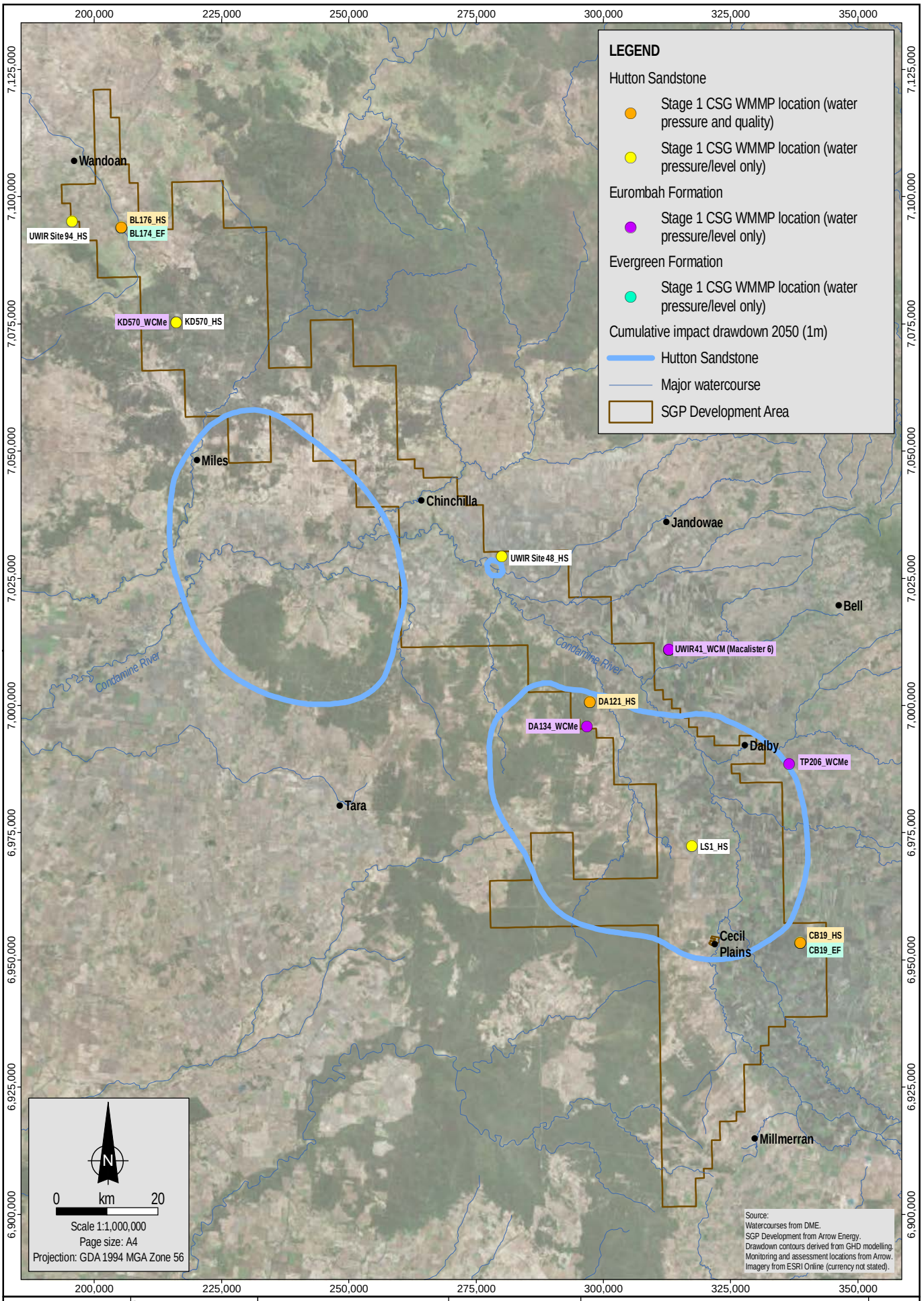
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Stage 1 CSG WMMP monitoring points (Walloon Coal Measures aquifer)

Figure No:
2.2c



MXD Reference: 20484AA_M07_GIS016_v0_2

coffey
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Date: 19.10.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F002.2d_GIS

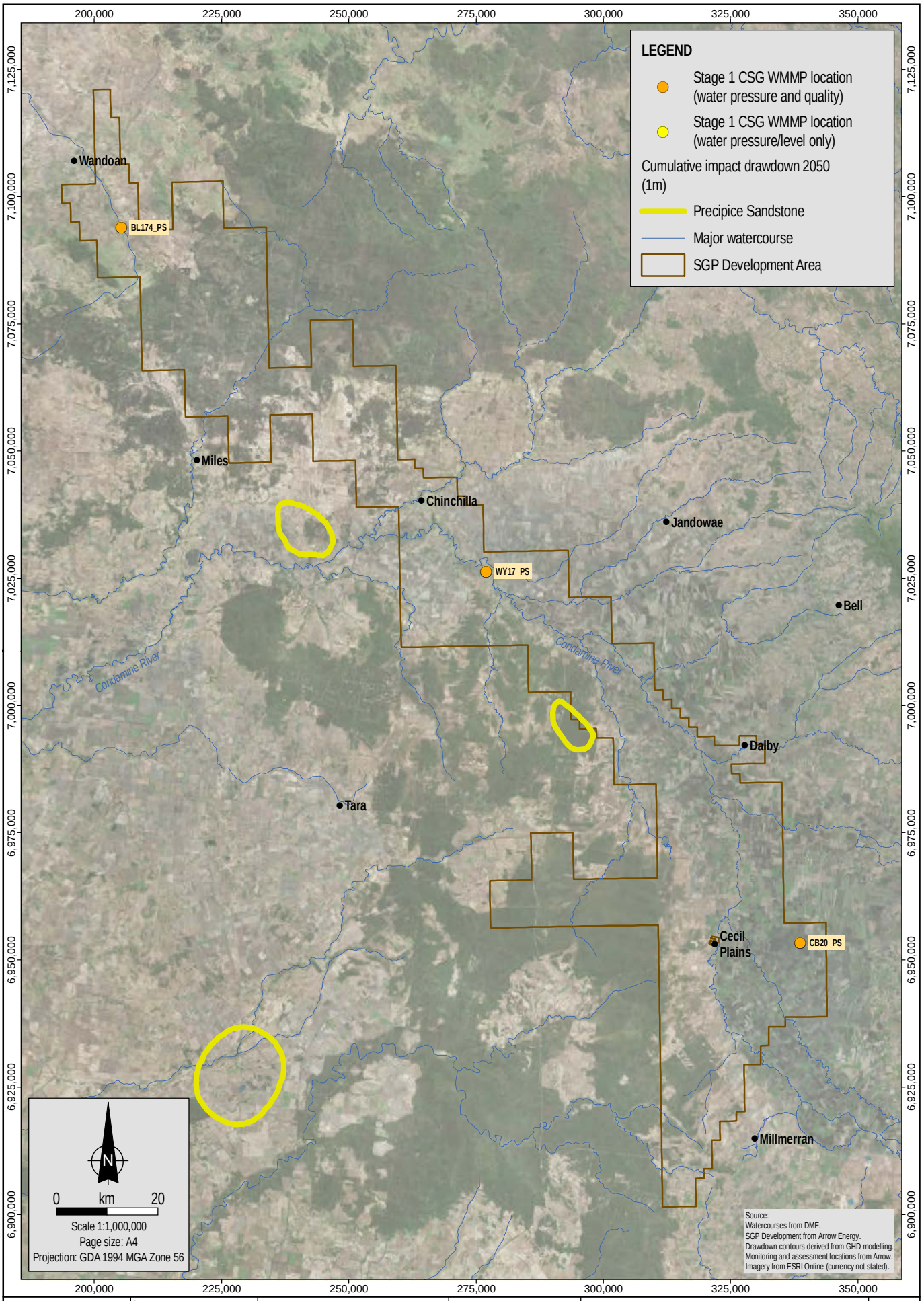
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Stage 1 CSG WMMP monitoring points (Hutton Sandstone aquifer, Eurombah Formation and Evergreen Formation)

Figure No:
2.2d



MXD Reference: 20484AA_M07_GIS017_v0_1

coffey
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Date: 19.10.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F002.2e_GIS

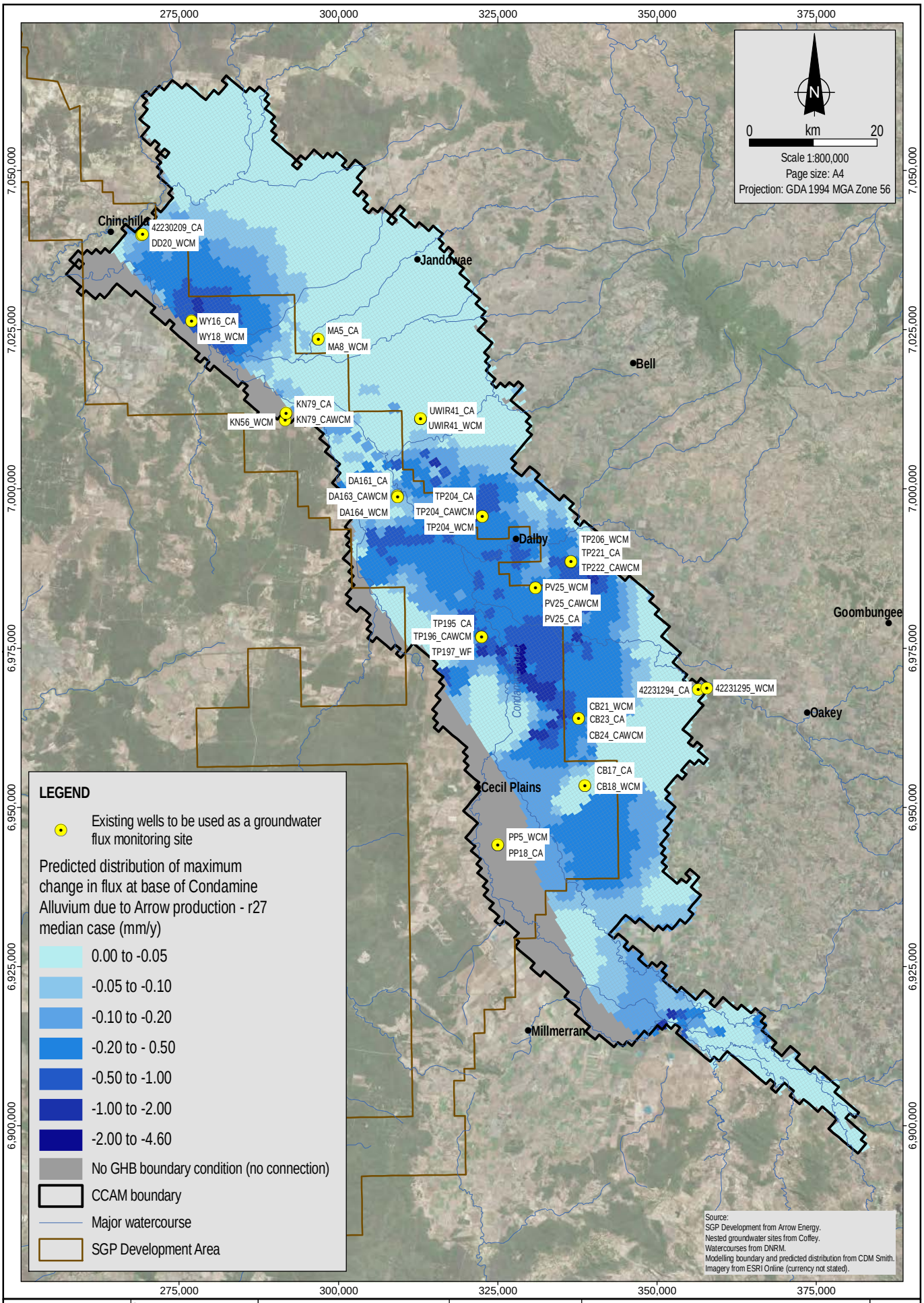
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Stage 1 CSG WMMP monitoring points (Precipice Sandstone aquifer)

Figure No:
2.2e



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coffey
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Date: 19.10.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F002.3_GIS

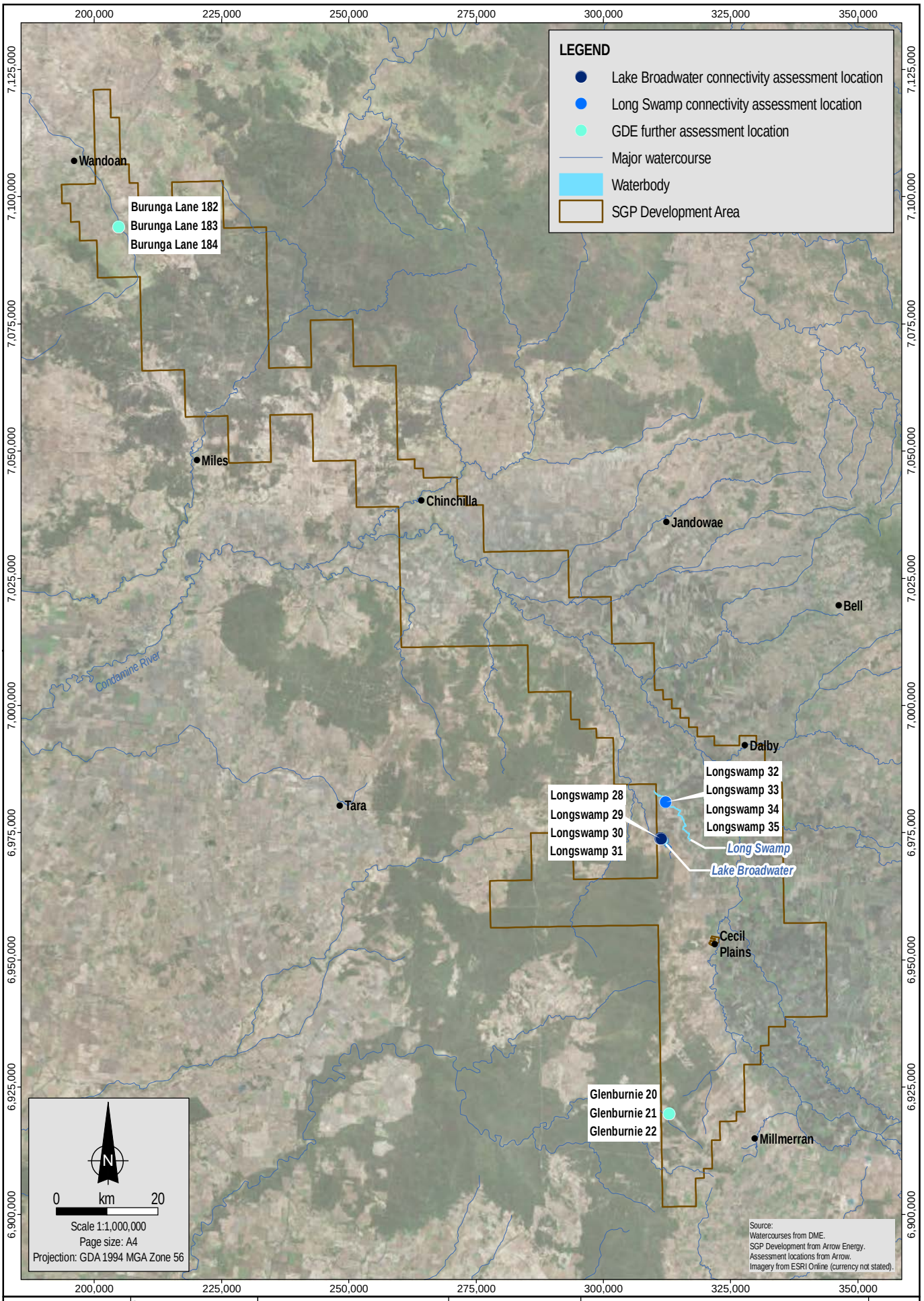
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Condamine Alluvium flux monitoring sites

Figure No: 2.3



MXD Reference: 20484AA_M07_GIS019_v0_1

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Date: 27.06.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F02.4_GIS

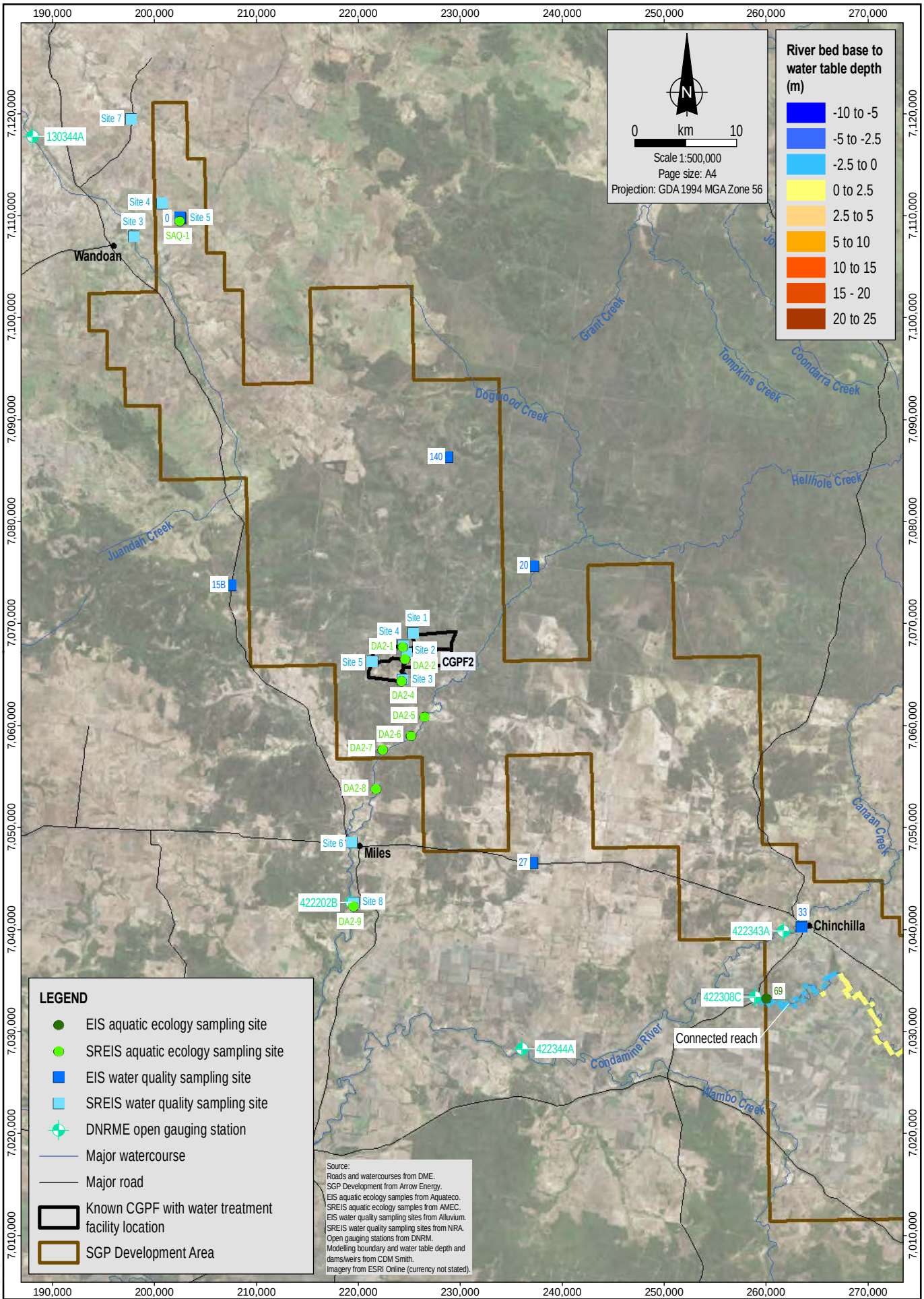
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Proposed GDE monitoring locations

Figure No:
2.4



MXD Reference: 20484AB_M03_GIS039_v0_4

coffey
A TETRA TECH COMPANY

Date: 25.09.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F03.1a_GIS

Arrow Energy

Surat Gas Project WMMP

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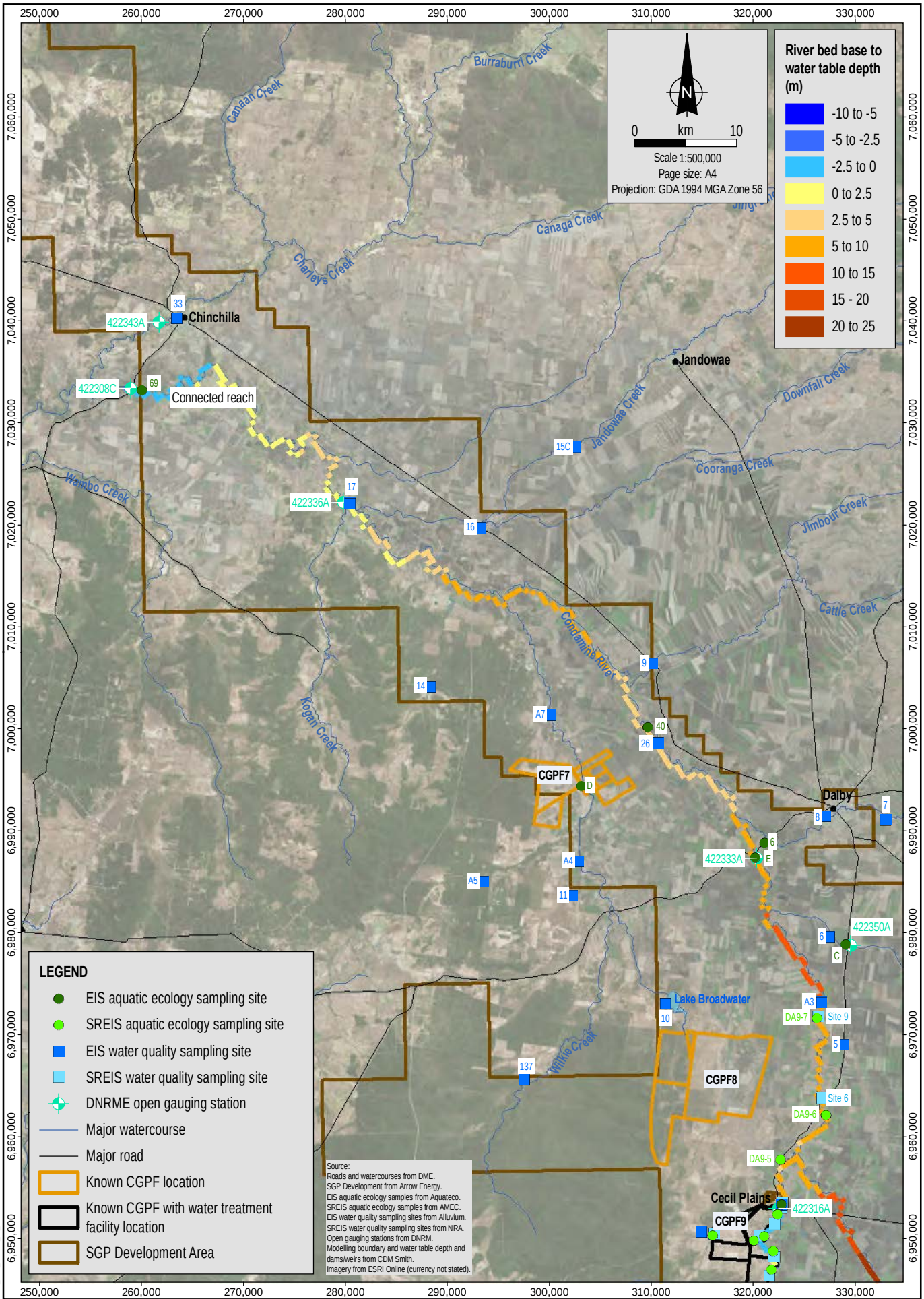
Surface water and aquatic ecology monitoring locations and modelled groundwater – Condamine River connectivity
Page 1 of 3

Figure No:
3.1a



coffey
A TETRA TECH COMPANY

Date: 25.09.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F03.1b_GIS

Arrow Energy

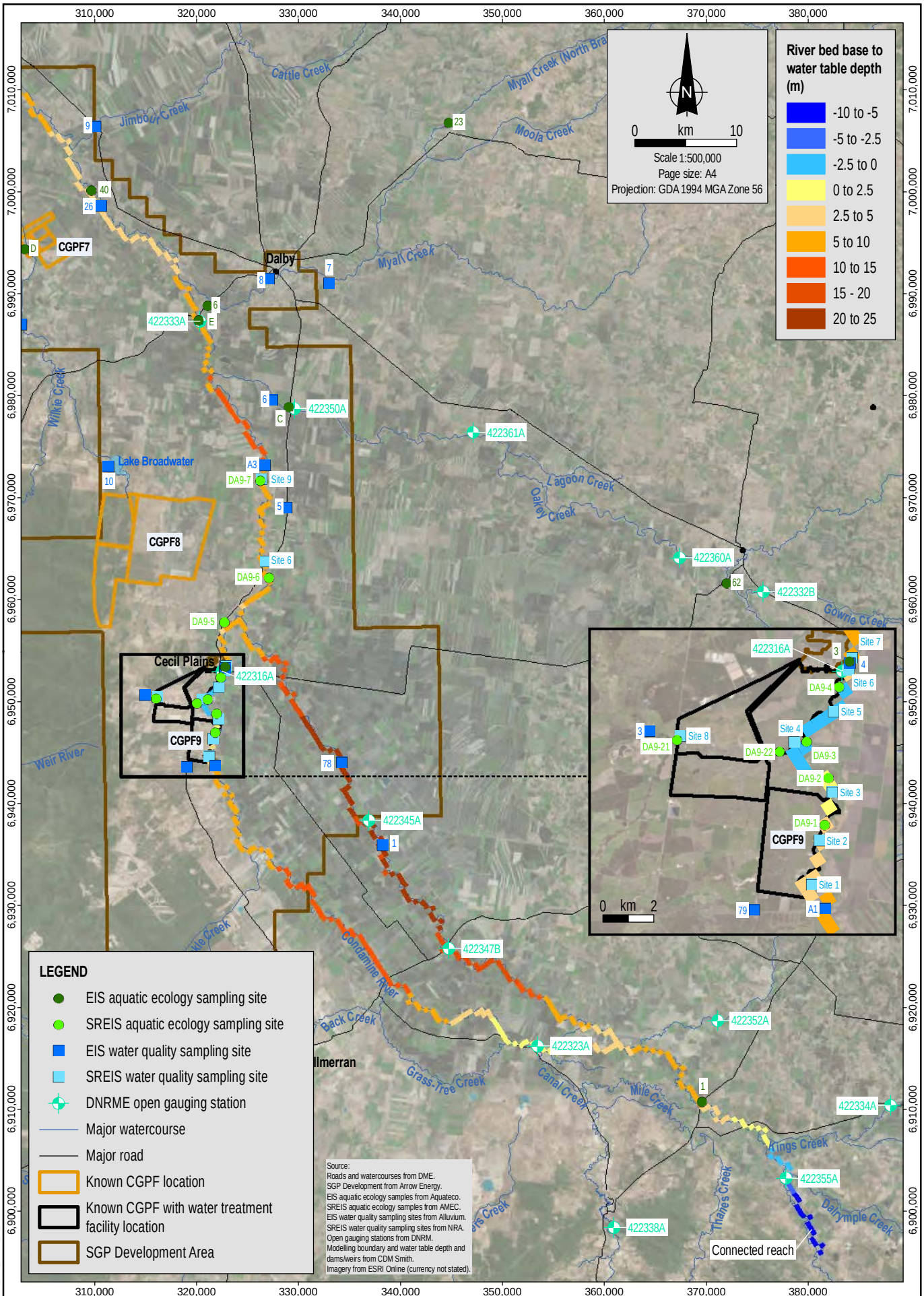
Surat Gas Project WMMP

arrow energy go further

Surface water and aquatic ecology monitoring locations and modelled groundwater – Condamine River connectivity
Page 2 of 3

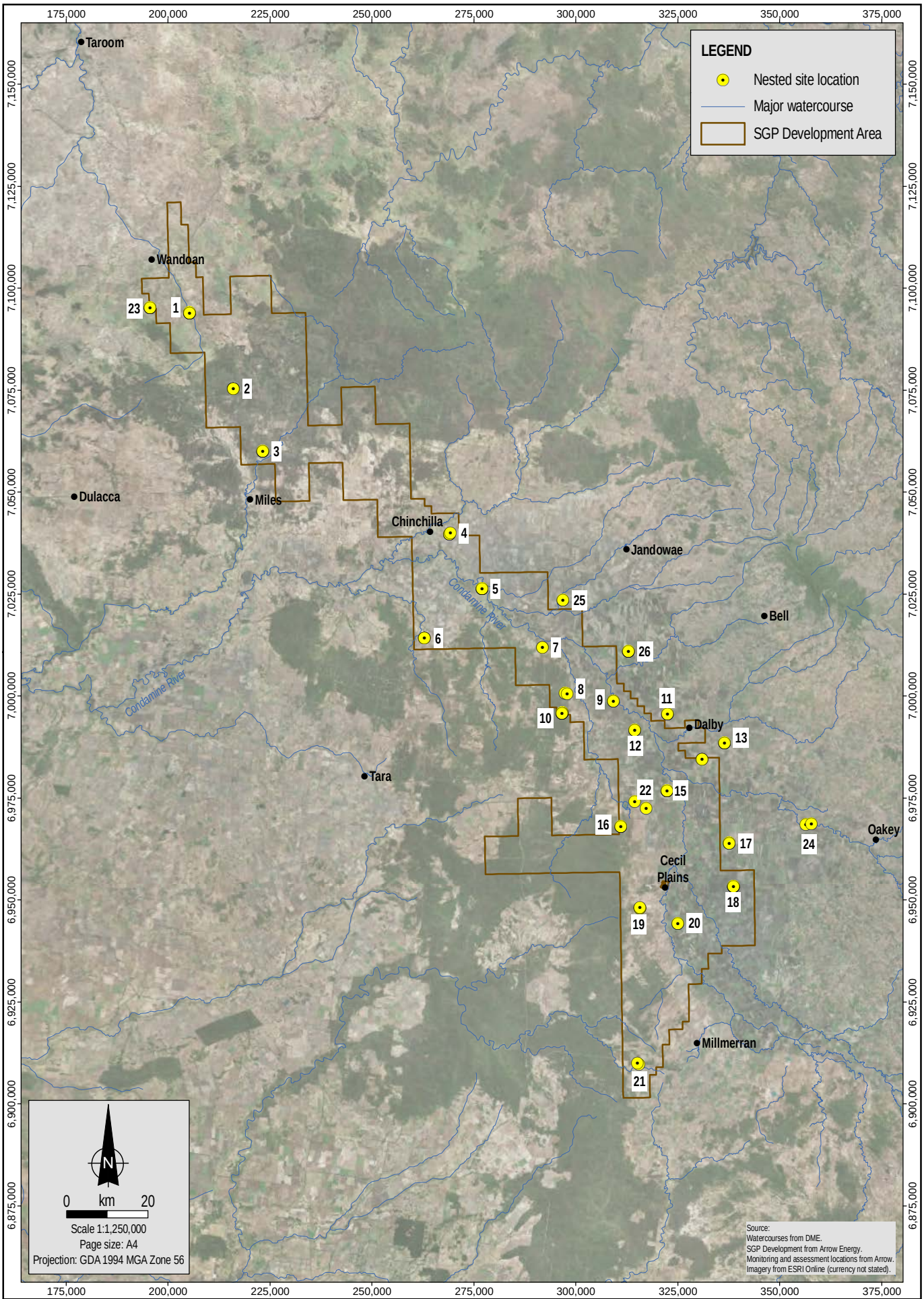
Figure No: 3.1b

MXD Reference: 20484AB_M03_GIS039_v0_4



coffey A TETRA TECH COMPANY	Date: 25.09.2018 Project: ENAUABTF20484AA File Name: 20484AB_M03_F03.1c_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Surface water and aquatic ecology monitoring locations and modelled groundwater – Condamine River connectivity Page 3 of 3	Figure No: 3.1c

MXD Reference: 20484AB_M03_GIS039_v0_4



MXD Reference: 20484AA_M07_GIS018_v0_4

coffey
A TETRA TECH COMPANY

Date: 09.10.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M07_F04.1_GIS

Arrow Energy

Surat Gas Project WMMP

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go further

Nested monitoring site locations

Figure No:
4.1