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The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP)

Scoping study for material carbon abatement via carbon capture and storage

Supplementary Detailed Report

Notional pipeline route analysis

30 April 2019

Research Team

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Referenced throughout the UQ-SDAAP reports as **Wolhuter et al. 2019b.**

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1. Executive summary

With a view to investigating whether there were any immediate “show-stoppers” to pipeline routes to the high-graded, lowest risk sites, UQ-SDAAP produced an exploratory, notional pipeline routes. The exercise was a desk-top analysis only and it would be essential to ground truth the views and engage the local community well in advance of finalising any such routes.

The routes connected power stations to the sites using multiple-criteria decision-making tools, suitability analysis and least cost pathway analysis. Kogan Creek, Condamine, Darling Downs and Tarong North representing ~13 Mtpa were connected to the northernmost site and Millmerran (5.9 Mtpa) was connected to the two southern sites. We used up to 11 criteria that reflected technical, environmental and social constraints and costs of building a CO_2 pipeline. Four main route scenarios that may affect CO_2 pipeline construction costs were investigated including:

1. Base case – an attempt at a simple, relatively balanced approach
2. “Environmental” – environmental values (EV scenario) prioritised, mainly avoidance of key areas
3. “People-centred” – human/societal interests prioritised (PC scenario), mainly avoidance of buildings and communities
4. “Technical” – technical requirements prioritised

The intent was to undertake a desk-top, ‘exploratory’ study. The general approach to route analysis was to form thematic scenarios (1 to 4 above) and within each assign subjective “suitability” scores and more or less desirable “avoidance distances”, then let the algorithms find a (least cost) way through. Following this sensitivity to subjective ‘scores’ was analysed and ‘stress tested’ to see under what circumstances routes could not be found.

Generally speaking, even with uncertainty and variations in local value and with different approaches to route optimisation, there seem to be several routes which are able to connect sources to sinks. However, detailed pipeline engineering was beyond the scope of UQ-SDAAP, it would be recommended to undertake some feasibility engineering studies, especially on the Tarong North to Kogan Creek routes (where there are relatively large elevation changes). Furthermore, several GIS data sets used in this studies are dated, if the project progresses to the next phase significant effort may be required to update GIS database.

2. Introduction and purpose

Development of a large-scale carbon capture and storage (CCS) scheme in the Surat Basin is currently in the pre-appraisal, greenfield stage. More site-specific appraisal data are needed before confidence is established for whether there is a real, industrial scale CCS option (or not).

Based on historic data and analyses (Garnett et al. 2012; Hodgkinson and Grigorescu 2013), the key formation in the Surat Basin that fulfils the requirements for a potentially viable CCS project is the “Blocky Sandstone Reservoir” (Garnett et al. 2019d) of the Precipice Sandstone.

This report identifies notional CO_2 pipeline routes that might connect power stations to the notional injection sites identified in Wolhuter et al. 2019a.

A number of coal and gas fuelled power stations exist near the notional injection sites (Figure 1), with coal-fired power stations having higher emissions and emissions intensity and therefore providing a greater opportunity for CCS.

The three closest coal-fired power stations; Kogan Creek, Tarong North and Millmerran, and closed cycle gas power stations; Darling Downs and Condamine could supply CO_2 at the required quantities and rates for

CCS at the notional injection sites based on current knowledge of the Blocky Sandstone Reservoir properties (Rodger et al 2019d, Rodger et al 2019f).

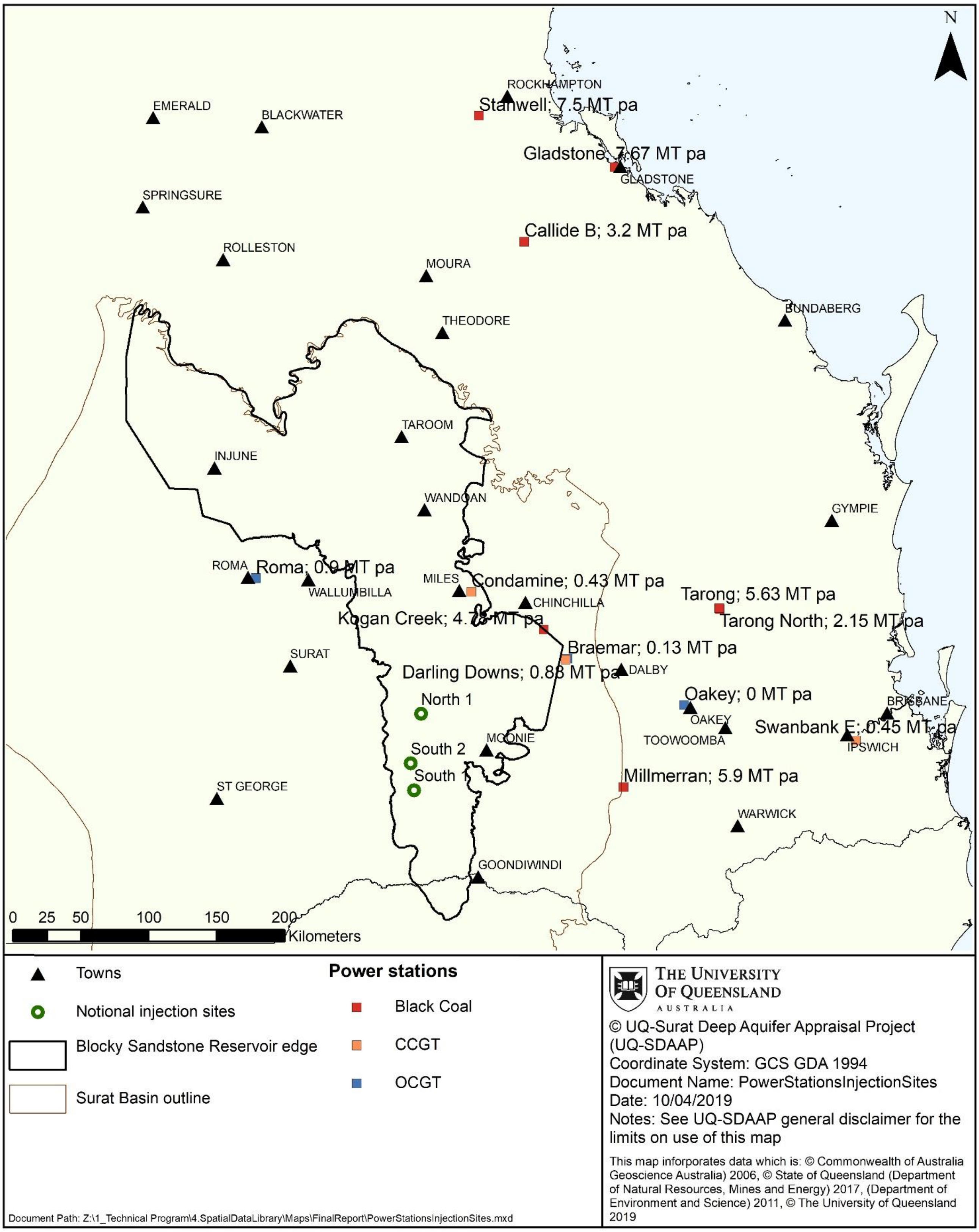
Detailed pipeline network design and planning was outside the scope of this project. However, the feasibility of material carbon abatement through CCS relies on the ability to find and licence suitable transport routes from sources to sinks. A scoping investigation to explore notional pipeline routes connecting the identified power stations to the notional injection sites was therefore conducted to discover whether there are any potential show-stoppers, or major cost-inducing route detours that may arise.

Current methods to determine pipeline routes, or other linear infrastructure, generally begin with a desktop analysis of potential routes using multiple criteria decision analysis incorporated into a geographic information systems (GIS) framework (Seel et al. 2014). Spatial data relevant to the ease of building a pipeline/expenses that would be incurred in building a pipeline, such as slope and land use, are collated and used as criteria in a GIS analysis. The GIS analysis determines a least-cost path for the pipeline route based on an estimation of the relative influence that the spatial criteria have on the cost of pipeline construction. There is rarely sufficient information to directly link the spatial data with actual cost data, so estimations are usually based on expert estimation of the relative effect on cost (Beier et al. 2009). As an alternative to reducing costs, GIS analyses to determine a pipeline route may also focus on different aims, such as reducing the environmental or social impacts of pipeline placement. The pipeline routes produced in a desktop study are considered an exploratory analysis that may be used as a starting point to guide further investigation. Field investigations will also need to verify the data used and add any additional information that is relevant to the cost of building a pipeline.

For the purposes of UQ-SDAAP, the notional pipeline routes produced are the result of an initial desktop analysis using relevant publicly available spatial data. The notional pipeline routes connect Kogan Creek, Tarong North, Darling Downs and Condamine to the northern notional injection site, and Millmerran is connected to the two southern notional injection sites.

The analysis showed that several routes might be possible depending on local environmental values and other land use.

Figure 1 Power stations and notional injection locations.



3. Method

3.1 Analysis approach

We selected the notional pipeline routes using multiple criteria decision-making methods, geographic information systems (GIS) suitability analysis, and least cost pathway tools. We used a linear weighted combination method (Jiang & Eastman 2000) to combine the information about relevant surface features to determine whether an area was more or less suitable for hosting a CO_2 pipeline. We then used least-cost pathway tools to determine the pipeline route between a power station and the notional injection sites. We used a linear weighted combination for the suitability analysis. This was implemented in ArcMap and used for the analyses using several criteria, as well as criteria with many factors. In contrast, methods such as analytical hierarchy process (AHP) can be difficult to implement when attempting pairwise comparisons between many criteria, or factors within a criterion (Malczewski 2006). Fuzzy membership does not allow for criteria to be weighted according to their relative importance in determining suitability (Esri 2017), and so is not as effective at this exploratory study phase.

In linear weighted combination, any features relevant to determining suitability are represented by criteria (e.g. slope, land use) that vary spatially. The spatial variation for each criterion is represented by factors. Each factor within a criterion is given a score that represents that factor's suitability to host a CO_2 pipeline, or the relative "cost" of locating a pipeline over that area. For example, in land use we considered an area used for grazing native vegetation to be more suitable/less costly for laying a CO_2 pipeline than an area used for irrigated horticulture. We considered cost in a broad sense in this analysis, with cost referring to social and environmental matters, such as the potential impact on endangered species' habitat as well as a proxy for monetary costs. Each category is then weighted according to its relative contribution to the overall cost for constructing the pipeline. The score for each factor is multiplied by its criterion's weighting. Every area, represented by a pixel, is given an overall score, which is calculated by adding the weighted factor scores for all criteria in the area. A least cost path is then calculated using the cost distance (Esri 2018a) and cost path tools in ArcGIS (Esri 2018b). The suitability analysis method used to determine the notional pipeline routes was similar to the method used to determine the notional injection sites (Wolhuter et al. 2019a); however, in this analysis factors that are more suitable were given lower scores as they represent a lower cost. When aggregated to the accumulated cost surface, pixels with the highest suitability must have the lowest scores for the least cost path tool to work correctly (Esri 2018c).

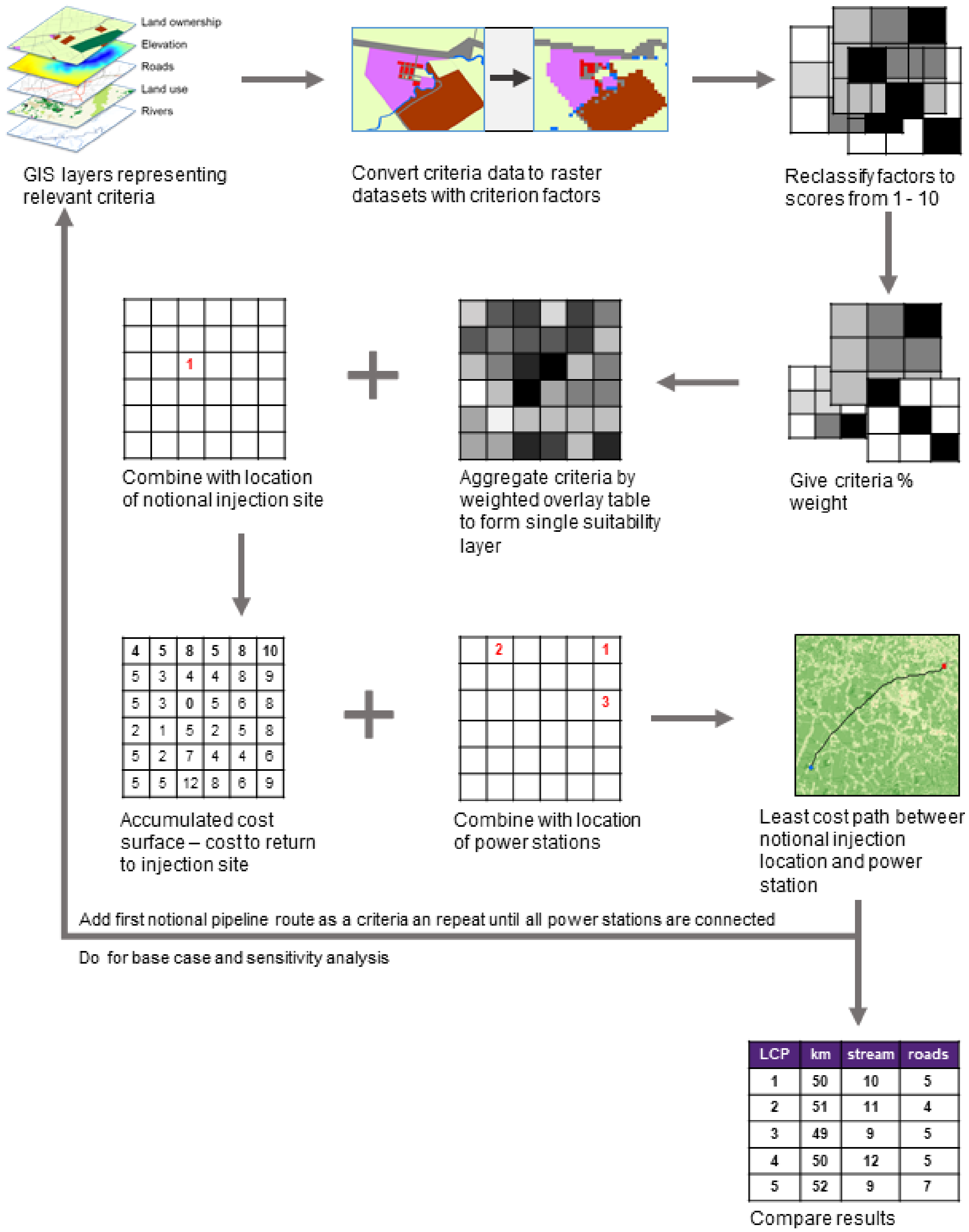
The base case analysis involved assigning criteria weights and factor scores that reflected the relative effect of different factors and criteria on the cost of constructing a CO_2 pipeline and also represented a balance of different considerations as determined by the UQ-SDAAP team. Factors within each criterion were given a score of one to ten, with a lower score indicating a lower cost/better suitability for CO_2 pipeline construction. We then assigned criteria weighting, with the sum of the weights adding to 100 to fulfil the requirements of the weighted overlay tool. The criterion weights used were an attempt to balance technical, environmental and social considerations along with relevant regulatory requirements. This analysis formed our base case pipeline route.

We then conducted a sensitivity analysis where factor scores and criteria weighting were assigned values that prioritised "environmental", "human concerns" (people centred) or "technical constraints".

When considering "human concerns", we included only factors that reflect an impact on human activities, such as infrastructure or agriculture. While many people would be concerned about environmental factors, these were not included in the human concerns criteria as they are better captured in the environmental constraint's analysis. We therefore refer to this analysis as one where human concerns are prioritised as "people-centred".

We then compared our base case pipeline route with the routes created in the sensitivity analysis. The pipeline routes were compared using the metrics of pipeline length, number of roads, railway lines, pipelines and powerlines crossed and the elevation profile of the pipeline. Figure 2 shows the process we used for the analysis.

Figure 2 Flow chart showing analysis methods.



3.2 Analysis area and criteria

Our analysis involved connecting five power stations, Kogan Creek, Tarong North, Condamine, Darling Downs and Millmerran to three notional injection locations. Kogan Creek, Tarong North, Condamine, and the Darling Downs power stations would be connected to the northern notional injection location, while Millmerran would be connected to the middle and southern notional injection locations (Figure 1).

We used a stage-gated approach to connect the power stations to the northern notional injection site as the CO_2 injection from the power stations and building of the CO_2 pipelines would be phased, i.e. the network would grow as each of the power stations was ready to provide CO_2 for CCS. The Kogan Creek power station was connected first as it has high CO_2 emissions and is the closest to the notional injection location. The CO_2 pipeline connecting Kogan Creek to the notional injection location then became the connection location for the next least cost path analysis to connect Tarong North, Condamine and Darling Downs.

The criteria used in the notional pipeline route identification (described further in section 3.3) was chosen as they represent the technical, social and environmental risks associated with the location and construction of a CO_2 pipeline and were available in good quality spatial datasets. When deciding which datasets to include, we attempted to ensure relevant technical, social and environmental considerations were represented in a dataset without having the same consideration covered by several datasets. The datasets also represented criteria that varied at the appropriate scale for analysis, or had relevant data mapped that could therefore have some effect on the pipeline route. We didn't include datasets that did not or barley varied across the extent of the analysis. For example, the Australian Geological Survey Organisation 2000 earthquake risk dataset shows the range of earthquake risk is the same across the analysis area, so while earthquake risk is usually a relevant consideration, it was not included in this analysis. We also did not include information on soil. Soil data for the area exists as land system and land resource maps (see for example Environment and Science, Queensland Government, Murilla, Tara and Chinchilla Shires Land Management Manual, Southern Queensland MWD v1.0). However, the spatial data available electronically only provides descriptions of agricultural land classes, such as "Brigalow plains" rather than information about soils that would be usable for determining the difficulty of digging trenches for the pipeline in a GIS framework.

All spatial datasets used were freely available through government data portals and had associated metadata and contact details ensuring that there was some reliability in the source of the data.

The criteria we used in the analysis include:

- Slope
- Distance from watercourses
- Distance from buildings
- Distance from roads, pipelines and railways
- Distance from powerlines
- Land ownership (cadastral data)
- Land use
- Native Title
- Easements
- Vegetation regulated under the *Vegetation Management Act (1999)*
- Areas to avoid (e.g. military bases, mine sites, areas requiring extra surveys)

Table 1 sets out the weighting for each of the criteria that we used as the base case and sensitivity analyses with environmental, social or technical concerns prioritised. For the sensitivity analysis, where factors were not entirely relevant to the concerns being prioritised (not the top priority), we put them in the same relative position or order as the base case. The total weightings for all criteria had to add up to 100. The weightings used for the base case are an attempt to balance the interests of people living near the injection site. This included indigenous interests, perceived environmental values and practical considerations related to the construction of a CO_2 pipeline. Further details of the data used for each of these criteria, any changes that we made to the data, the factors within each criterion and the factor scores that we applied for the base case and sensitivity analysis can be found in section 4. Uncertainties associated with the data sets are also presented.

Table 1 Weighing for each criteria in the base case and sensitivity analysis for the pipeline route selection.

Layer	% influence base case	% influence environment	% influence social	% influence technical
Slope	14	6	5	14
Easements	13	8	11	13
Distance from buildings	12	4	14	9
Distance from watercourses	11	12	8	12
Distance from powerlines	10	5	4	11
Distance from roads, pipelines & railway	9	8	6	10
Land ownership	8	10	13	8
Land Use	8	14	10	8
Native Title	6	9	12	5
Regulated vegetation (VMA)	5	13	9	6
Areas to avoid	4	11	8	4

3.3 Software and GIS model specifications

We used ArcMap 10.6 to run the suitability analysis. The model boundary for the suitability analysis was as shapefile that defined an area around the notional injection locations and power stations used in the analysis. We used GDA94 MGA Zone 55 (EPSG 28355) as the coordinate system and the digital elevation model to align raster cell extents in the analysis.

4. Data description and key variables

The surface criteria represent a set of sometimes competing factors that can be traded against each other to show whether a location is more or less suitable for hosting a CO_2 pipeline in comparison to another location. In this section we describe the data we used to represent the criteria in the analysis, including the source of the dataset and a description of possible sources of error or uncertainty in the data. We also describe how we assigned factor scores to each of the criteria in our base case analysis.

An 'exploratory' study. The general approach to route analysis has been to provide subjective "suitability" scores and more or less desirable "avoidance distances", then let the algorithms find a (least cost) way through. Following this sensitivity to subjective 'scores' was analysed an 'stress tested' to see under what circumstances routes could not be found.

4.1 Location of powerplants and notional injection sites

We used the notional injection site locations, and the locations of the power stations for the distance and least cost pathway steps in the analysis. Report Wolhuter et al. 2019a details the method we used for determining the notional injection sites. We used Geoscience Australia's 2014 National Major Power Stations Database for the location of the power stations used in the analysis.

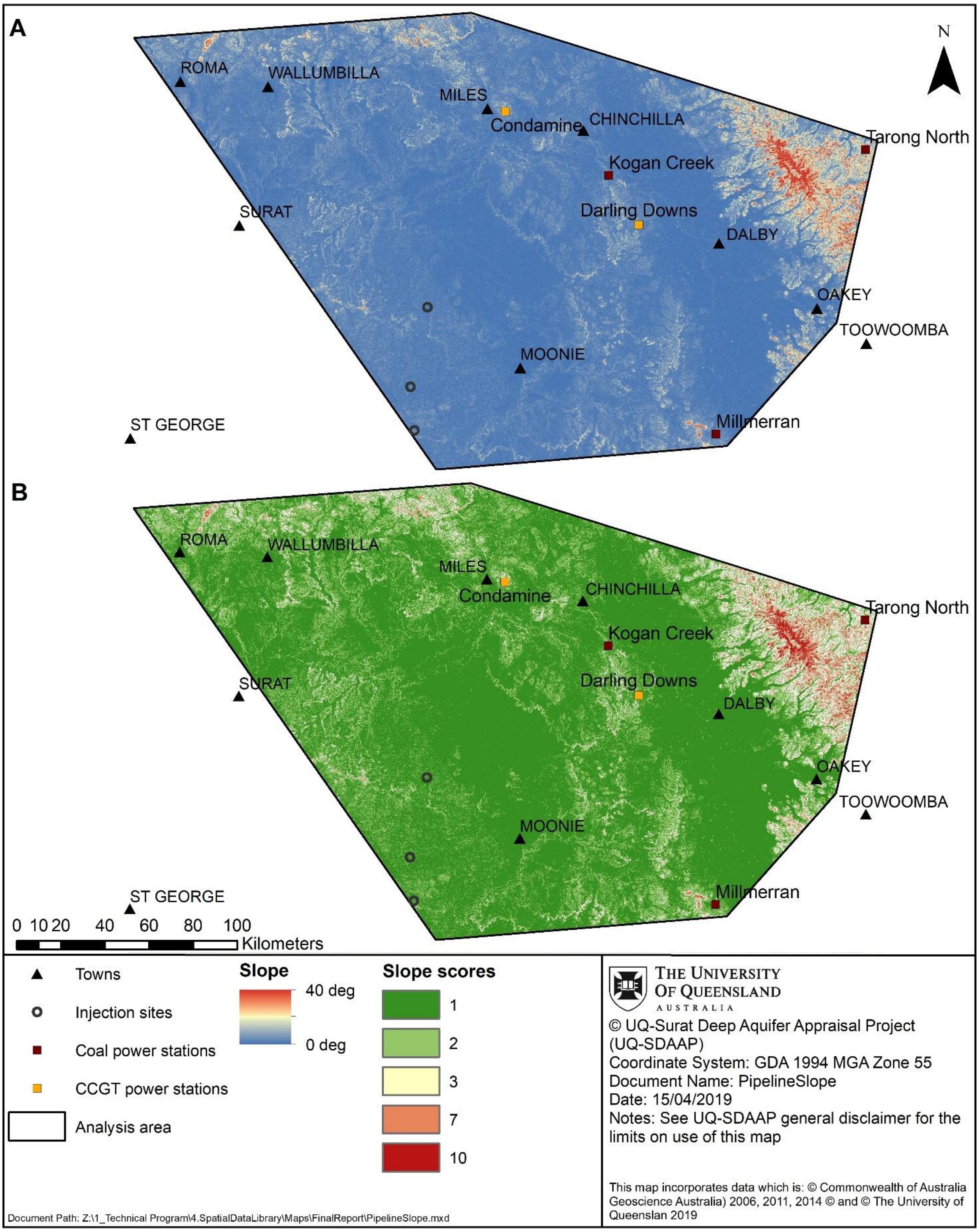
4.2 Rate of change of elevation

To reduce pressure issues and costs, pipeline routes generally seek to minimise elvation changes in general and rapid elevation changes in particular. We used Geoscience Australia's three second SRTM smoothed digital elevation model (DEM) (Geoscience Australia 2011) to set the size and location of the raster grids for processing in the suitability analysis and used the slope function in ArcMap to create the slope criterion. We used GIS software to classify the slope range into five categories (Table 2, Figure 3). We did not vary slope categories or values for the sensitivity analysis, as slope is a technical criterion and even if non-technical criteria are prioritised, it still makes sense to preferentially build a pipeline on flatter ground. Three arc seconds represent approximately 90m. The 3 second DEM was created by resampling a one arc second gridded Shuttle Radar Topographic Mission (STRM) DEM. Any inaccuracies in the data are therefore likely to be derived from processing and resampling the STRM data.

Table 2 Rate of change of elevation (slope) cateogy values

Slope (degrees)	score
0 – 1.1	1
1.1 – 2.8	2
2.8 – 5.7	4
5.7 – 11.4	7
>11.4	10
No Data	No Data

Figure 3 Distribution of ground slope. (A) Data. (B) Slope scores used in analysis.



4.3 Distance from watercourses

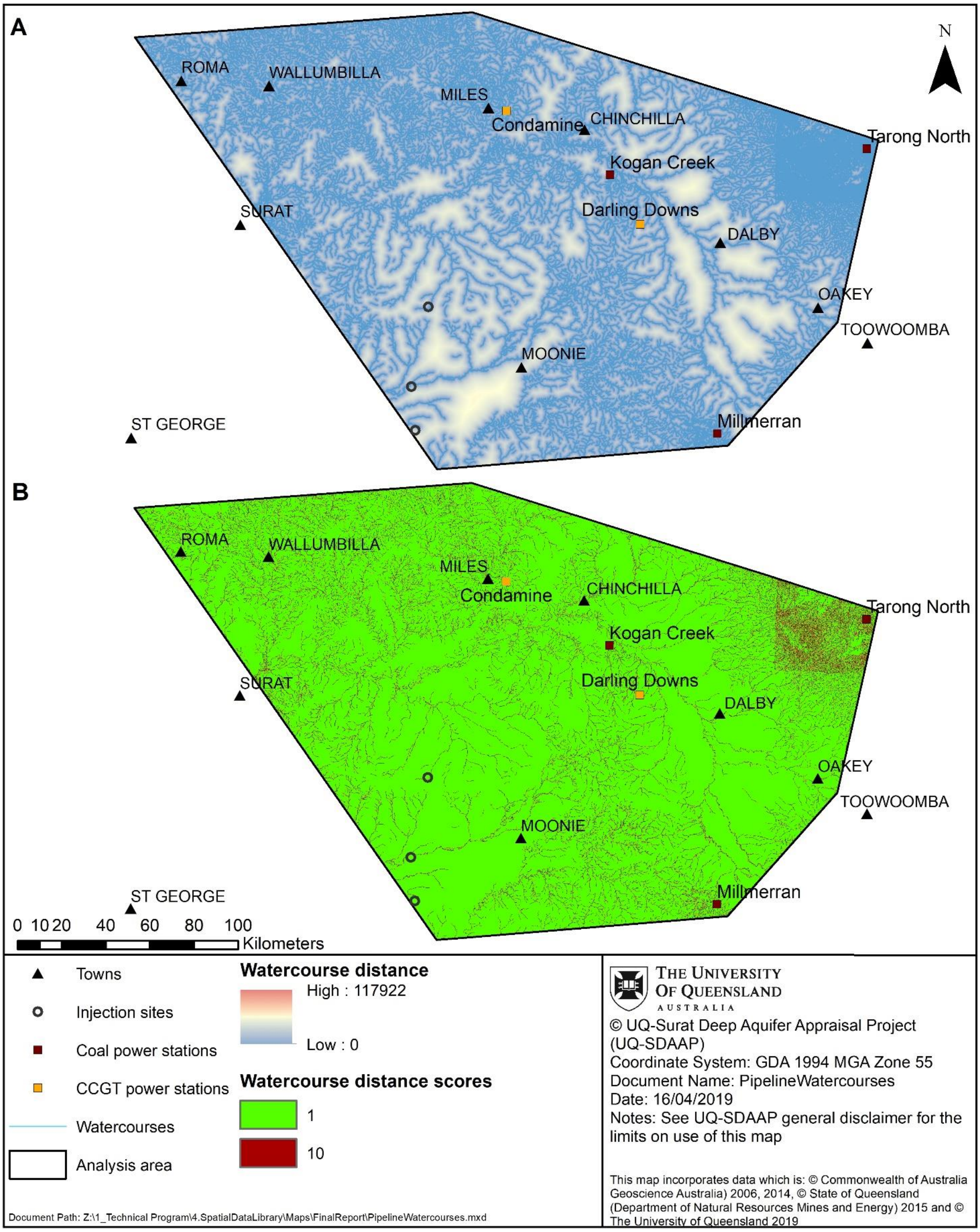
To reduce the potential for environmental damage caused by interference with watercourses and the vegetation buffers around watercourses, we included the distance from a watercourse as a criterion in the analysis. We used the Vegetation management watercourse and drainage feature map (1:100000 and 1:250000) – version 2.0 dataset from the Department of Natural Resources, Mines and Energy 2018 (originally from Geoscience Australia) to represent watercourses. Avoiding the features is also in line with elevation or gradient criteria (above). We used the Euclidean distance function in ArcMap to calculate the distance from watercourses. The score categories in the distance from watercourses criterion were chosen to reflect watercourse buffer distances (watercourse and area of vegetation around it) used in planning in the analysis area. Initial watercourse separation scores are shown in Table 3 and Figure 4) for the base case and all categories in the sensitivity analysis. Avoiding watercourses is preferable whether environmental, social or technical concerns are being prioritised.

As the dataset was derived from 1:100 000 and 1:250 000 watercourse network maps from Geoscience Australia (DNRME 2018), the main source of uncertainty comes from positional accuracy, and variations in positional accuracy depending on the accuracy of the original data. The analysis also did not take account of watercourse size or stream order. Many watercourses in the analysis area are ephemeral but were treated the same as permanently flowing watercourses. However, this is consistent with legislative requirements under the *Vegetation Management Act 1999* as well as technical requirements, as the ephemeral watercourses may have high water flow rates that might be disturbed by the pipeline..

Table 3 Factor values for distance from watercourses.

Distance from watercourses (m)	score
0 – 100	10
>100	1
No Data	No data

Figure 4 Distribution of watercourses. (A) Data. (B) Distance from watercourse scores used in analysis.



4.4 Distance from (presumed) dwellings

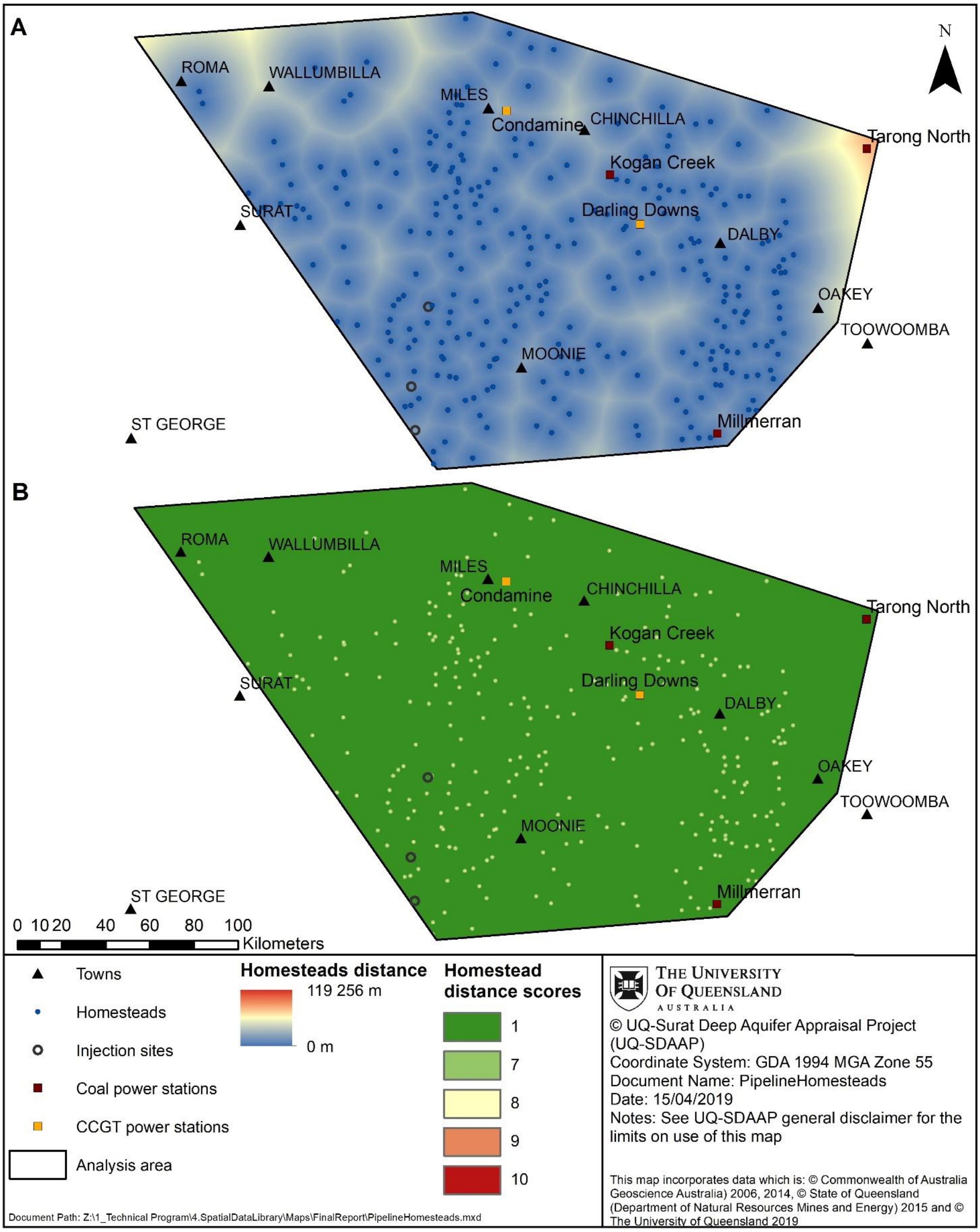
It would be undesirable to construct pipelines near dwellings because of the noise of construction and risks posed by a potential pipeline leak. We therefore included information on the location of presumed dwellings that would not be captured under the residential land use category such as farmhouses. We used Geoscience Australia's TOPO 250K Series 3 National Topographic Data – Habitation, "presumed dwellings" 2006 dataset to represent these dwellings. We used the Euclidean distance function in ArcMap to calculate the distance from presumed dwellings. Initial scores are shown in Table 4 and Figure 5.

The GEODATA TOPO 250K Series 3 contains information from a range of sources including satellite imagery, GEODATA TOPO 250K Series 2 and other 1:250 000 scale maps. Any inaccuracies from the source datasets may have been incorporated into the GEODATA TOPO 250K Series 3 dataset. An additional uncertainty arises from the currency of the data. The data in GEODATA TOPO 250K Series 3 was current in 2006 and is updated infrequently; it is possible that some new presumed dwellings may have been built within the analysis area and some presumed dwellings may no longer be occupied.

Table 4 Factor values for distance from presumed dwellings.

Distance from building values (m)	score
0 – 100	10
100 – 200	9
200 – 500	8
5000 – 1000	7
>1000	1
No Data	No Data

Figure 5 *Distribution of presumed dwellings (A) Data. (B) Distance from homestead scores used in analysis.*



4.5 Distance from roads, railway lines, pipelines representing possible easements.

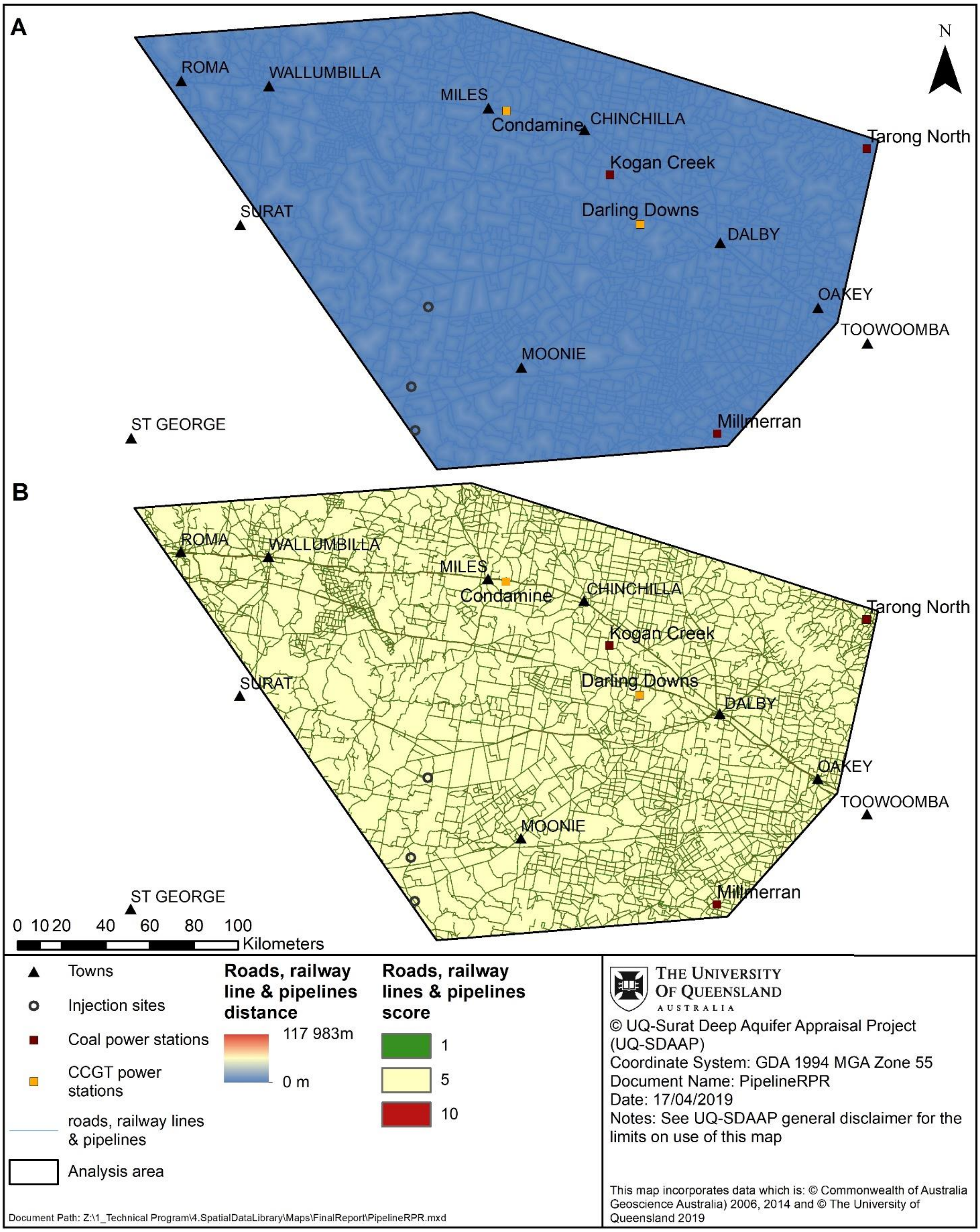
We combined the Geoscience Australia's TOPO 250K Series 3 National Topographic Data – Utility "pipelines" and Transport "roads" and "railways" 2006 datasets to represent a potential corridor that could be used for the pipeline route. We merged the pipeline, road and railways shapefiles and used the Euclidean distance function in ArcMap to calculate the distance from the combined layer. We gave areas within 80 m of a road, railway or pipeline a value of 10, as there would be additional construction costs locating the pipeline too close to existing infrastructure. A smaller value representing existing offsets between infrastructure would have been used, however the raster grid size of ~90m would not allow anything smaller. Using 80 m meant that we would get the smallest possible buffer on either side of the road, railway or pipeline. We gave areas within 80 m and 200 m of a road, railway line or pipeline, a score of one, representing an area close to, but not on top of the linear infrastructure as the most suitable place to lay a CO_2 pipeline. Areas further than 200 m from a road railway line or pipeline were given an intermediate value of five (Table 5).

The GEODATA TOPO 250K Series 3 contains information from a range of sources including satellite imagery, GEODATA TOPO 250K Series 2 and other 1:250 000 scale maps. Any inaccuracies from the source datasets may have been incorporated into the GEODATA TOPO 250K Series 3 dataset. An additional uncertainty arises from the currency of the data. The data in GEODATA TOPO 250K Series 3 was current in 2006 and is updated infrequently. It is possible that some roads and railway lines may have subsequently been built within the analysis area.

Table 5 Factor values for distance from roads, railway lines and pipelines

Distance values (m)	Weighting
0 – 80	10
80 – 200	1
>200	5
No Data	No Data

Figure 6 *Distribution of roads, railway lines and pipelines. (A) Data. (B) Distance from roads, railway lines and pipeline scores used in analysis.*



4.6 Distance from powerlines

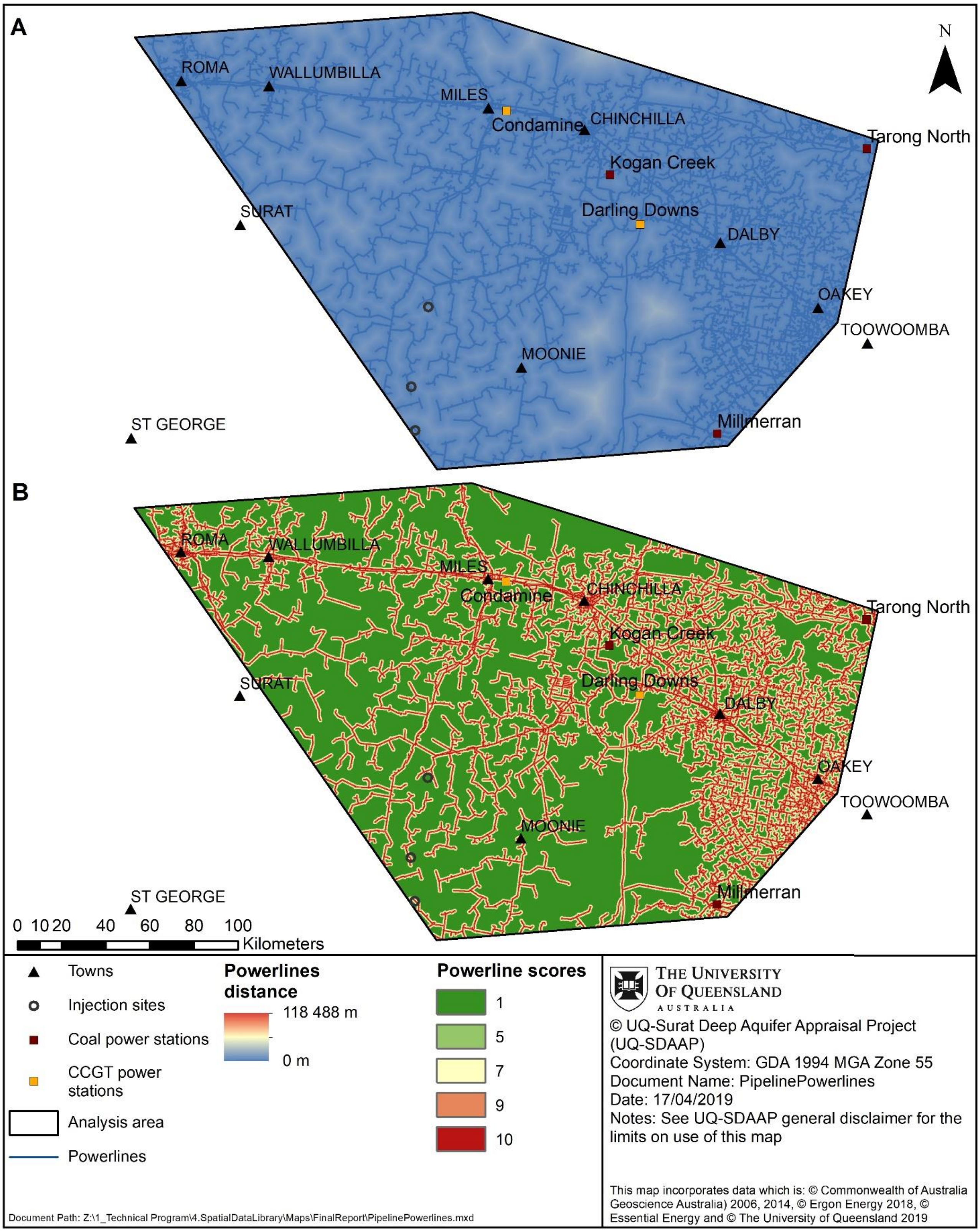
Proximity between pipelines and powerlines can cause a current to be induced in the pipeline (Al-Badi et al. 2007). To avoid the risk of a current being induced and the cost of additional pipeline installation works to reduce the risk we included distance from powerlines as a criterion in the analysis. We combined Geoscience Australia's TOPO 250K Series 3 National Topographic Data – Utility "powerlines" 2006, the Electrical distribution network – overhead and underground from Ergon Energy 2018 and Essential Energy's Goondiwindi Depot overhead electricity network map to represent powerlines. Initial scores are shown in Table 6, Figure 7. We did not vary powerline distance categories or values for the sensitivity analysis, as distance from powerlines is a technical criterion and even if non-technical criteria are prioritised, it is still preferable to avoid the risk of current induction and the cost of additional instillation works.

The GEODATA TOPO 250K Series 3 contains information from a range of sources including satellite imagery, GEODATA TOPO 250K Series 2 and other 1:250 000 scale maps. Any inaccuracies from the source datasets may have been incorporated into the GEODATA TOPO 250K Series 3 dataset. An additional uncertainty arises from the currency of the data. The data in GEODATA TOPO 250K Series 3 was current in 2006 and is updated infrequently It is possible that more powelines may have been built since the creation of the dataset. The electrical distribution network dataset provides an indication of the location of sub-transmission, high voltage and low voltage lines and as it is regularly updated and refined, it may not be complete (Ergon Energy 2018). No information regarding the accuracy of Essential Energy's overhead electricity network maps is available, however the maps are generally made available on request for safety purposes in aviation and agricultural activities.

Table 6 Factor values for distance from powerlines

Distance from powerlines (m)	score
0 – 200m	10
200 – 500	9
500 – 800	7
800 – 1000	5
>1000	1
No data	No data

Figure 7 Distribution of powerlines. (A) Data. (B) Distance from powerline classes used in analysis.



4.7 Land ownership (cadastral database)

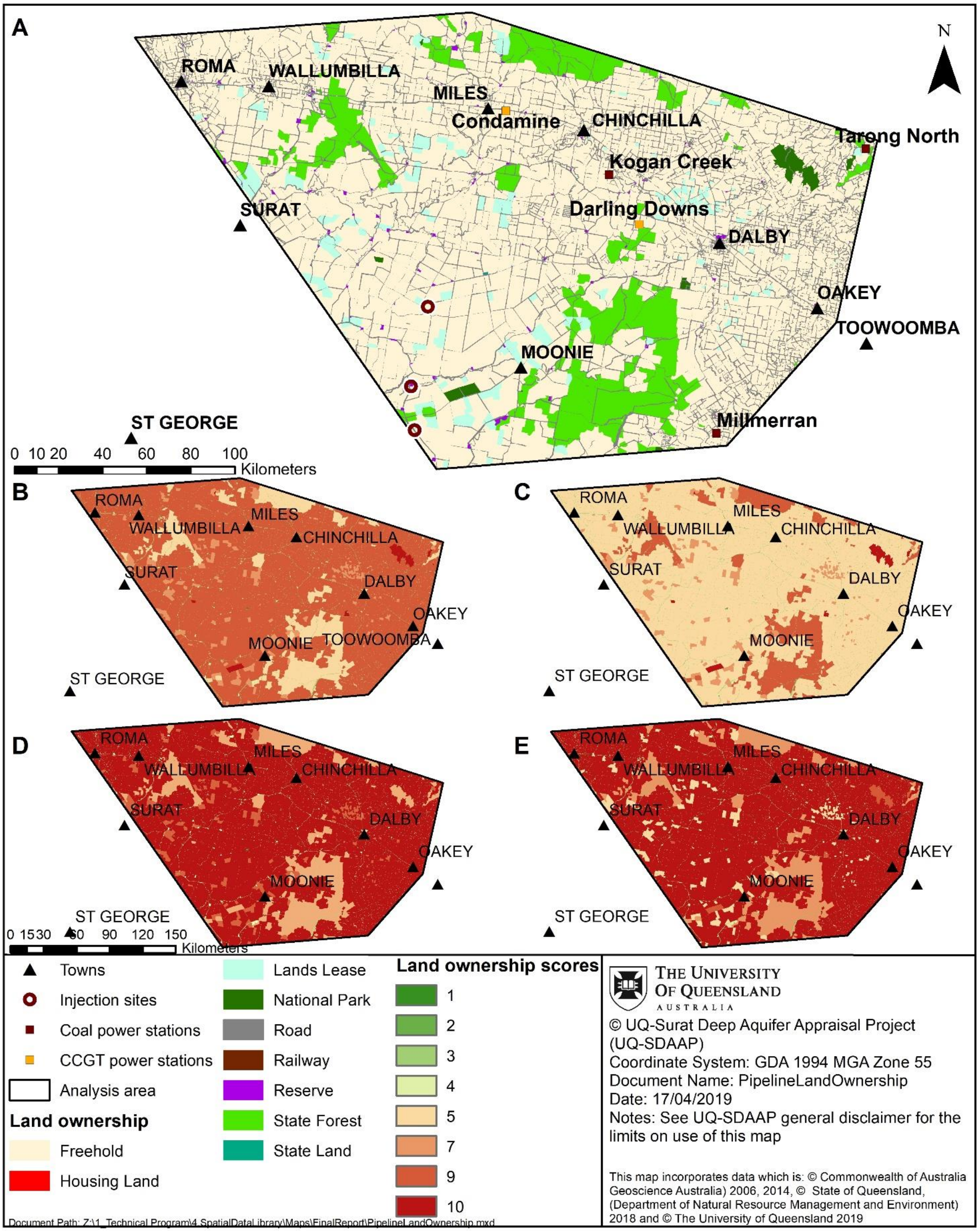
We assumed that it would be easier to lay a pipeline on an area of State land that was not set aside for a specific purpose, such as for utilities of nature conservation than on privately owned land. We therefore included land tenure (ownership type) in the suitability analysis. We used the Cadastral data – Queensland – by area of interest published on 10 July 2018 as the basis for the land ownership criterion. We removed volumetric, easement and strata cover types from the dataset, so that only one tenure cover type (base tenure) covered any given area. We used a set of principles to assign initial scores to the different land ownership factors. We considered state land, with no particular purpose, to be the most suitable for laying a pipeline and assigned it score of one. Privately held land (freehold) was given a score of nine. Land where the tenure type showed it had a particular purpose, e.g. road, national park or was a watercourse was considered the least appropriate. The other categories were assigned intermediate scores based on ownership (state or private) and whether they had a particular use as part of the tenure (Table 7; Figure 8).

The Queensland cadastral data is estimated to have a 95% confidence level in positional accuracy. The cadastral data is updated daily, so the data in the analysis area may have changed.

Table 7 Tenure types and example weightings

Tenure type	Base case score	Environment score	People-centred score	Technical score
Freehold	9	5	10	10
Other	3	3	3	3
Lands lease	7	6	9	7
State forest	5	9	5	8
Reserve	4	4	4	4
State land	1	1	1	1
National park	10	10	5	9
Railway	2	2	2	2
No Data	No Data	No Data	No Data	No Data

Figure 8 *Distribution of land ownership. (A) Data. (B) Ownership scores used in base case analysis. (C) Ownership scores used in environment analysis. (D) Ownership scores used in people-centred analysis. (E) Ownership scores used in technical analysis.*



4.8 Land use

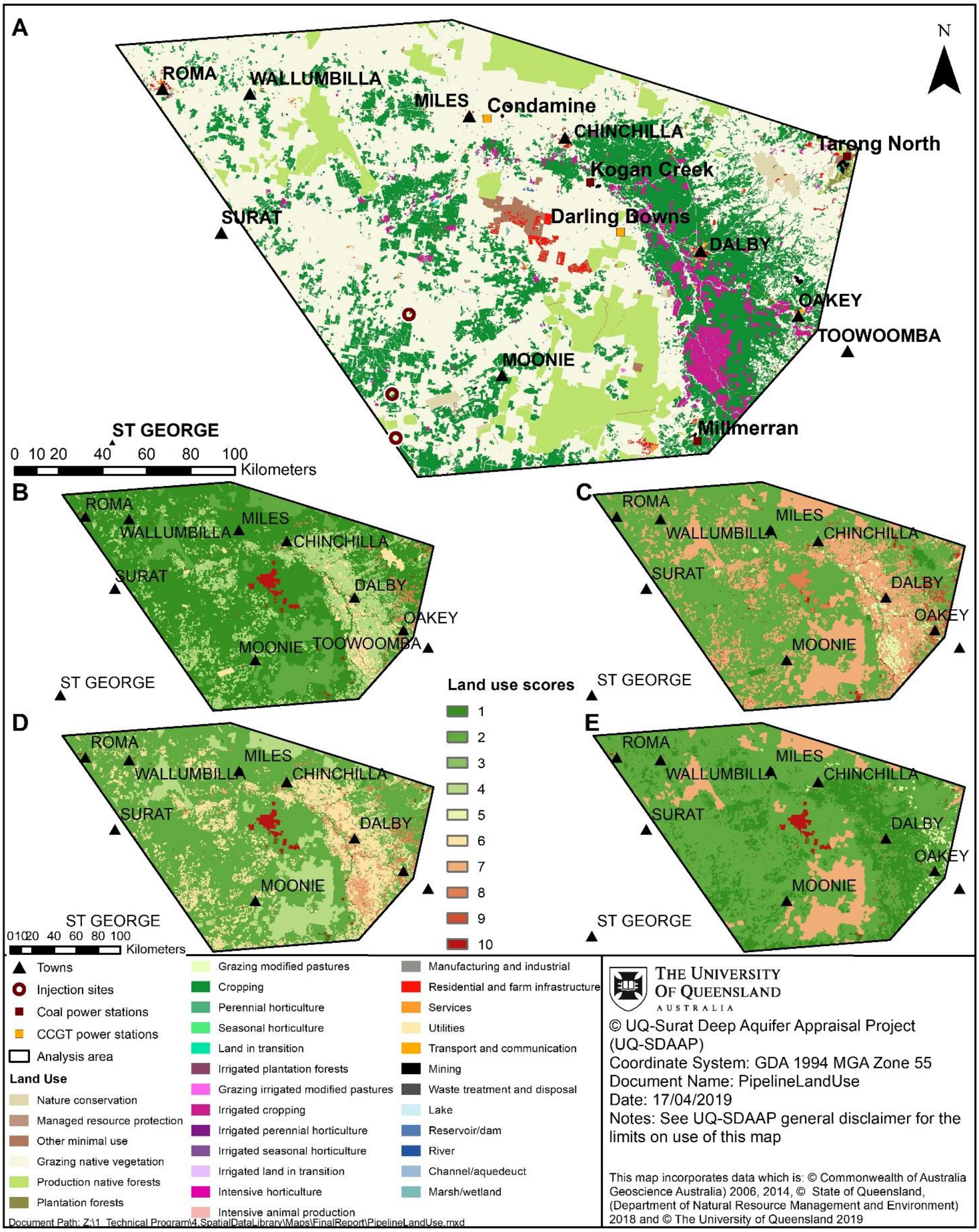
To avoid locating the pipeline on an area with high natural value like a national park, or disturbing areas with high economic value, such as land used to produce irrigated crops, we included land use in the analysis. We used the Queensland Department of Environment and Science Land use mapping series 2018 as the source of data for the land use criterion. The land use data was classified according the Australian Land Use and Management Classification (ALUMC) Version 8 (ABARES 2016). We used a set of principles to give each land use category a score (Table 8). We considered the most suitable land use for hosting a pipeline to be land with minimal use, and to which minimal changes hand been made, in this case "grazing native vegetation." We considered land with seasonal, non-irrigated or non-intensive land uses to be more appropriate than perennial, irrigated or intensive land uses. Cropping was considered more appropriate than horticulture, which was more appropriate than forestry. We considered land for intensive human use, such as residential land, or areas covered by water to be the least suitable.

The main source of uncertainty associated with the land use information is data currency. The dataset was current in 2013 (the Queensland Department of Environment and Science Land use mapping series 2018 currency map, Office of Environment and Heritage 2013) and land use in the analysis area may have changed since then.

Table 8 Land use secondary land use cateogy values.

Secondary category	Base case score	Environmental score	People-centred score	Technical score
Grazing natural veg	1	9	2	2
Other minimal use	1	1	1	1
Production forestry	3	4	4	7
Plantation forestry	4	5	5	7
Seasonal horticulture	4	4	5	3
Cropping	5	4	6	1
Nature conservation	6	10	2	2
Irrigated cropping	6	6	7	2
Mining	6	2	4	5
Irrigated seasonal horticulture	6	5	7	4
Transport and communication	6	2	8	4
Irrigated plantation forestry	6	6	7	6
Perennial horticulture	7	7	6	6
Intensive animal production	8	2	8	5
Irrigated perennial horticulture	8	8	8	5
Utilities	8	3	9	7
Intensive horticulture	8	8	8	8
Marsh	9	10	3	9
Manufacturing and industry	9	3	9	8
Waste treatment and disposal	9	3	9	9
Residential	10	3	10	10
Services	10	3	10	9
Reservoir/dam	10	9	9	10
River	10	10	3	10
Lake	10	10	3	10
Channel/aqueduct	10	10	9	10
No Data	No Data	No Data	No Data	No Data

Figure 9 Distribution of land use. (A) Data. (B) Land use scores used in base case analysis. (C) Land use scores used in environment analysis. (D) Land use scores used in people-centred analysis. (E) Land use scores used in technical analysis.



4.9 Native Title

We used the Native Title Determination Outcomes dataset current on 10 November 2018 from the National Native Title Tribunal to show Native Title ownership in the processing area. The determined outcome field was used to convert the dataset to a raster showing Native Title ownership. We assigned scores to factors in the Native Title criterion based on the existence and possession type of the title (Table 9, Figure 10).

As locating CCS injection facilities on land on Native Title land would require time to negotiate access to the land, and possibly extinguish some Native Title rights over the land, we considered land where Native Title did not exist or had been extinguished, to be more suitable for the location of a pipeline (Table 9, Figure 10).

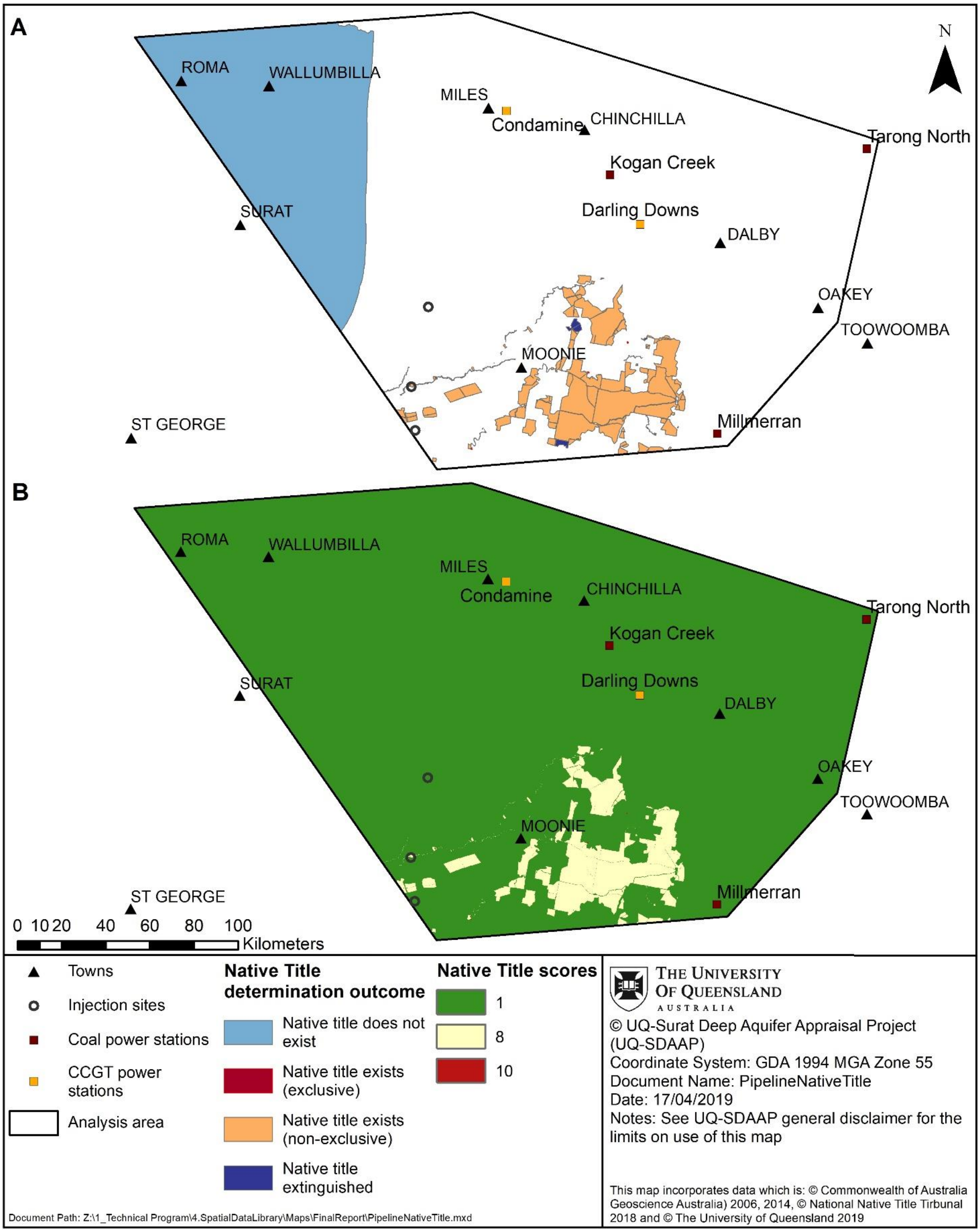
Table 9 Factor values for Native Title.

Native Title Category	score
Native Title does not exist	1
Native Title exists, non-exclusive possession	8
Native Title exists, exclusive possession	10
Native Title extinguished	1
No Data	1

While the Native Title Registrar (Registrar) has exercised due care in ensuring the accuracy of the information provided, it is provided for general information only and on the understanding that neither the Native Title Registrar nor the Commonwealth of Australia (Commonwealth) is providing professional NNTT Geospatial Corporate Data Model Version 1.26 14 October 2016 National Native Title Tribunal Page 5 of 27 advice. Appropriate professional advice relevant to your circumstances should be sought rather than relying on the information provided. In addition, you must exercise your own judgment and carefully evaluate the information provided for accuracy, currency, completeness and relevance for the purpose for which it is to be used.

As the interpretation of any particular native title determination area provided is based upon the best information available to the Registrar at the time of creation, any effective analysis must include reference to both the relevant determination of native title made by the Federal Court of Australia and the entry made in relation to that determination on the National Native Title Register maintained by the Registrar.

Figure 10 Distribution of Native Title determination outcomes. (A) Data. (B) Native Title scores used in analysis.



4.10 Existing easements

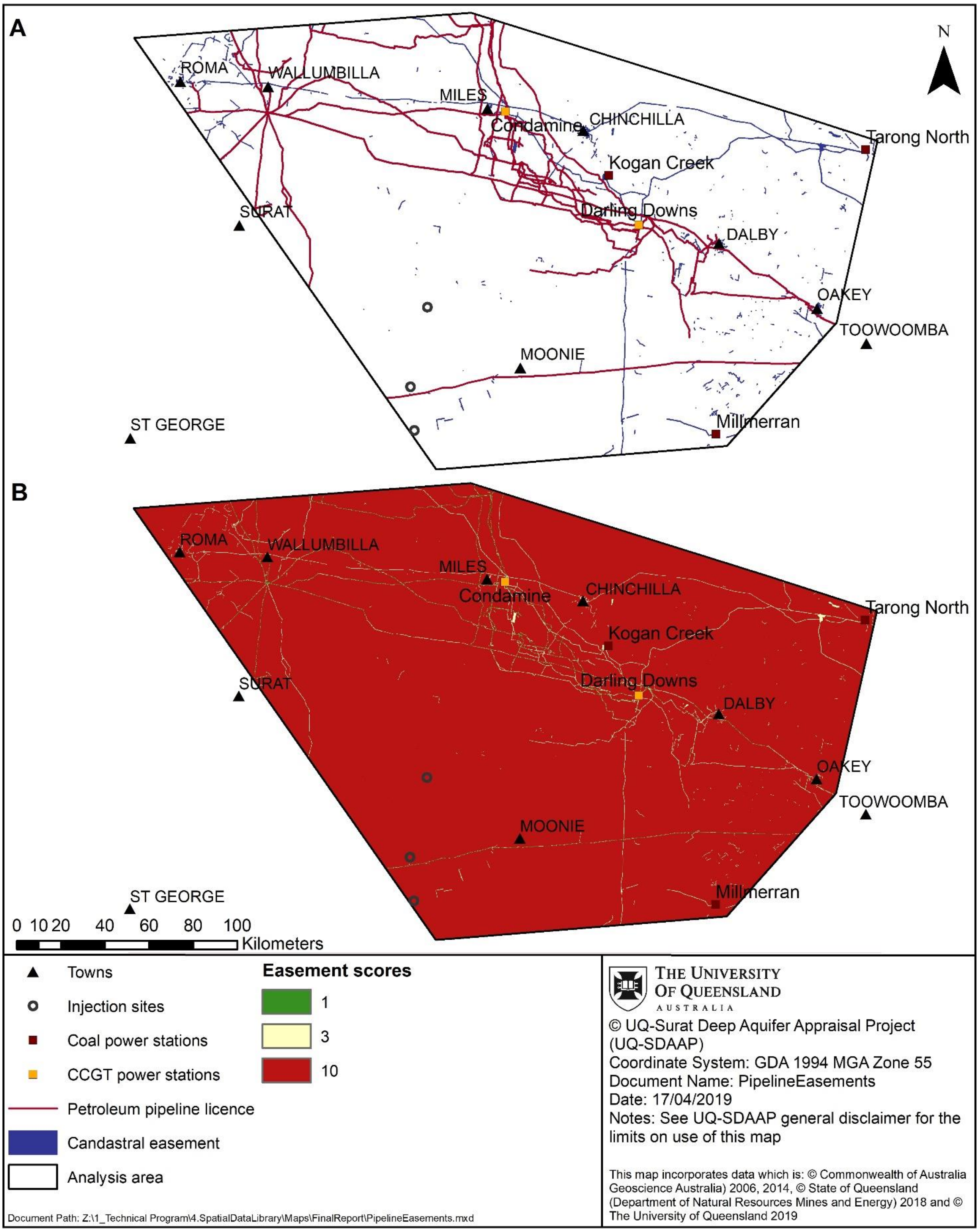
We included the location of existing easements, as Queensland State policy states that the *preferred* way of securing land for a pipeline is to use an existing easement (State of Queensland 2018). We used the Cadastral data – Queensland – by area of interest published on 10 July 2018 and petroleum pipeline licences from the Department of Natural Resources Mines and Energy 2018, Exploration and Production Permits – Queensland data current on 16 October 2018 as the basis for the existing easements criterion. We removed base, volumetric and strata cover types from the cadastral data so that only areas with easements were shown – see Table 10 and Figure 11.

The Queensland cadastral data is estimated to have a 95% confidence level in positional accuracy. The cadastral data is updated daily, so the data in the analysis area may have changed. The easement layer in the cadastral database also does not represent the full set of easements as any easements not shown on plans when the digital cadastral database was created are not shown. Any easement left of plans are however unlikely to be easements suitable for the location of CO_2 pipelines.

Table 10 Easements scores.

Category/raster value	score
Petroleum pipeline easement	1
Cadastral easement	3
No Data/No easement	10

Figure 11 Distribution of easements. (A) Data. (B) Easement scores used in analysis.



4.11 Regulated vegetation management

We included information about regulated vegetation to avoid locating the injection site in an area where tree clearing would be necessary. We used the Vegetation management - regulated vegetation management map version 2.08 published on 05/11/2018 (Department of Natural Resources Mines and Energy, State of Queensland 2018) to represent vegetation regulated by the *Vegetation Management Act 1999* (Qld). The regulated vegetation management category was used to convert the dataset to a raster.

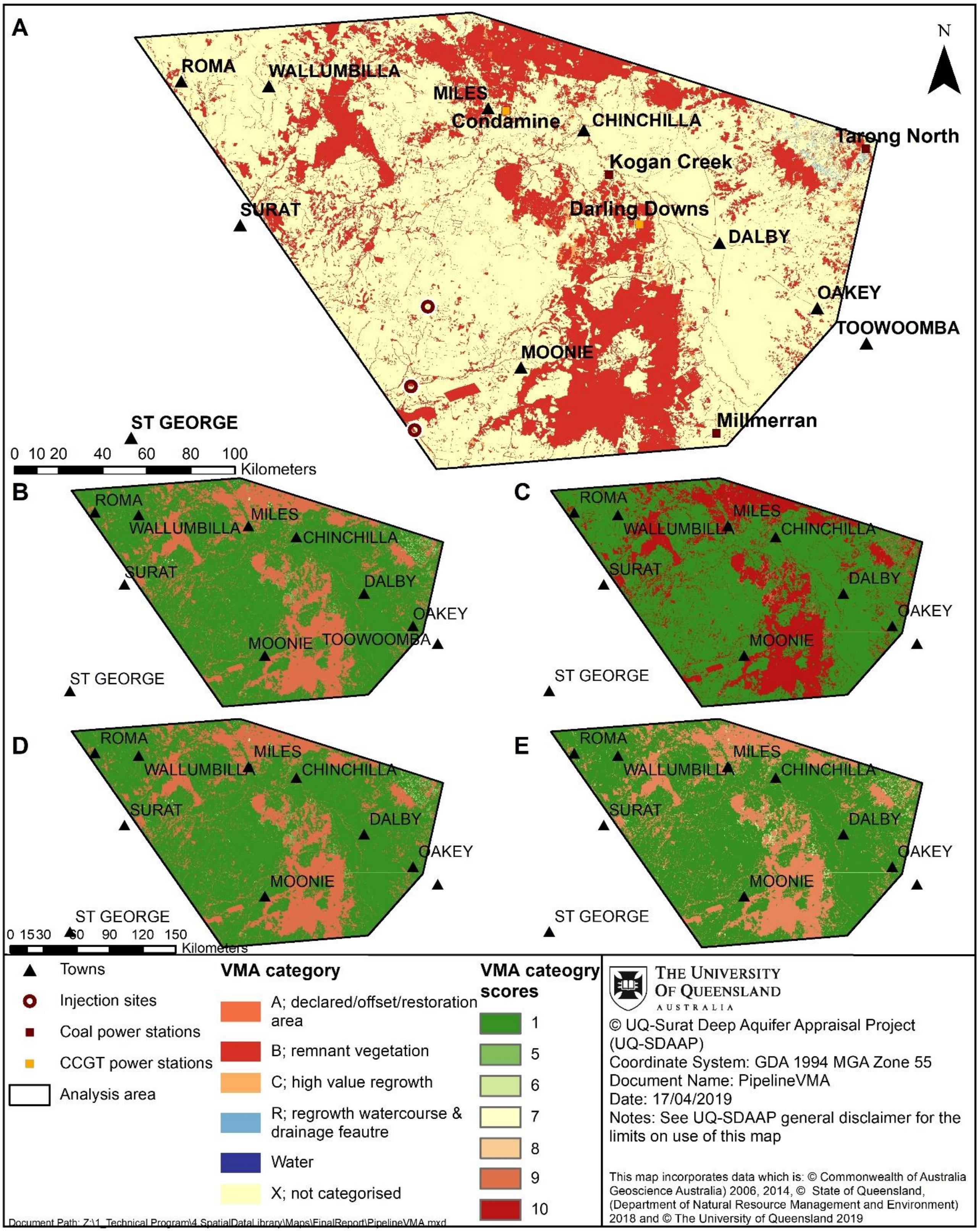
We considered land not classified under of the *Vegetation Management Act 1999* (Qld) (category X, s20AO) to be most suitable for the location of CCS injection surface infrastructure, so we gave that factor a score of one. We considered the two least suitable factors to be areas covered by water, and areas with remnant vegetation (category B, s20AM VMA), assigning those factors a score of 10 and nine respectively. We gave areas defined under s20AL of the *Vegetation Management Act 1999* (category A) as declared, offset, exchange, unlawfully cleared or subject to a restoration or enforcement notice a score of seven, as we considered that having a statutory declaration or notice over the area would add risk to the use of that land. High value regrowth (category C, s20AN VMA) was assigned an intermediate score of five, and regrowth watercourses and drainage features (category R, s20ANA) a score of six (Table 11; Figure 12). We increased the scores for the analysis prioritising perceived environmental values, so that water and remnant vegetation had the highest cost/score of 10 and all other categories of regulated vegetation had a score of nine. We also increased the score for high value regrowth to eight and declared/offset/restoration areas to eight for the technical analysis to reflect the additional cost felling trees as well as the cost of any negotiations required to cut down trees subject to regulation.

The regulated vegetation management map is the map certified under the *Vegetation Management Act 1999* as showing the vegetation category areas. It acts as the authoritative map for the location of regulated vegetation, however it is updated monthly to reflect changes in categorisations made under processes in the *Vegetation Management Act 1999*. Data currency is therefore the main uncertainty associated with the data.

Table 11 Vegetation Management Act (1999) cateogires and scores.

VMA Category	Base case score	Environmental score	People-centred score	Technical score
Remnant vegetation (B)	9	10	9	9
Not categorised (X)	1	1	1	1
Regrowth watercourse & drainage feature (R)	6	9	6	6
High value regrowth (C)	5	9	5	8
Declared/offset/restoration area (A)	7	9	7	8
Water	10	10	10	10
No Data	No Data	No Data	No Data	No Data

Figure 12 Distribution of Vegetation Management Act 1999 regulated vegetation categories. (A) Data. (B) Regulated vegetation category scores used in base case analysis. (C) Regulated vegetation category scores used in environment analysis. (D) Regulated vegetation category scores used in people-centred analysis. (E) Regulated vegetation category scores used in technical analysis.



4.12 Other areas 'avoid'

We included information on the location areas where access without permission from a specific authority is prohibited, such as military bases. We also included the location of mining leases and areas where surveys under the *Nature Conservation Act 1992* (Qld) (NCA) or state planning policy matters of state environmental significance (MSES) should be conducted (Table 12). While it is likely that flora and fauna surveys will need to be conducted for the length of a pipeline route, particularly if it is not within an existing pipeline easement, the locations where surveys need to be conducted under the NCA or as MSES represent locations where protected species have been recorded, and are therefore more likely than surrounding areas to have a species that needs to be protected. Areas where access without permission is prohibited were considered the least suitable and assigned a score of 10 for all analyses except the environmental prioritisation, where we gave it a score of eight. We gave areas with a mining lease a slightly lower score of eight for the base case, people-focused and technical analyses and a score of three for the environmental analysis – see Table 12 for initial values.

We used Geoscience Australia's TOPO 250K Series 3 National Topographic Data – Framework "Prohibited Areas" (2006) to represent areas where entry without permission is prohibited. The GEODATA TOPO 250K Series 3 contains information from a range of sources including satellite imagery, GEODATA TOPO 250K Series 2 and other 1:250 000 scale map. Any inaccuracies from the source datasets may have been incorporated into the GEODATA TOPO 250K Series 3 dataset. An additional uncertainty arises from the currency of the data. The data in GEODATA TOPO 250K Series 3 was current in 2006 and is updated infrequently It is possible that some new prohibited areas will have been added to the analysis area.

We used the mining leases shapefile from the Department of Natural Resources Mines and Energy 2018 Exploration and Production Permits – Queensland data current 16 October 2018 to represent mining lease areas. Exploration and Production Permit boundaries are updated daily. The main uncertainty related to the mining leases dataset is therefore the currency of information used.

We represented areas where surveys under the *Nature Conservation Act 1992* (Qld) (NCA) must be conducted by the Nature Conservation Act Protected Plants EVNT Flora Survey Trigger Map Spatial Layer Version 6 (Department of Environment and Science 2018). The dataset was derived from a subset of known records of the location of endangered, vulnerable or near threatened plants with and the records have varying precision. It should be used as indication that a survey should be conducted and what may occur in area when conducting a survey (Department of Environment and Science 2018).

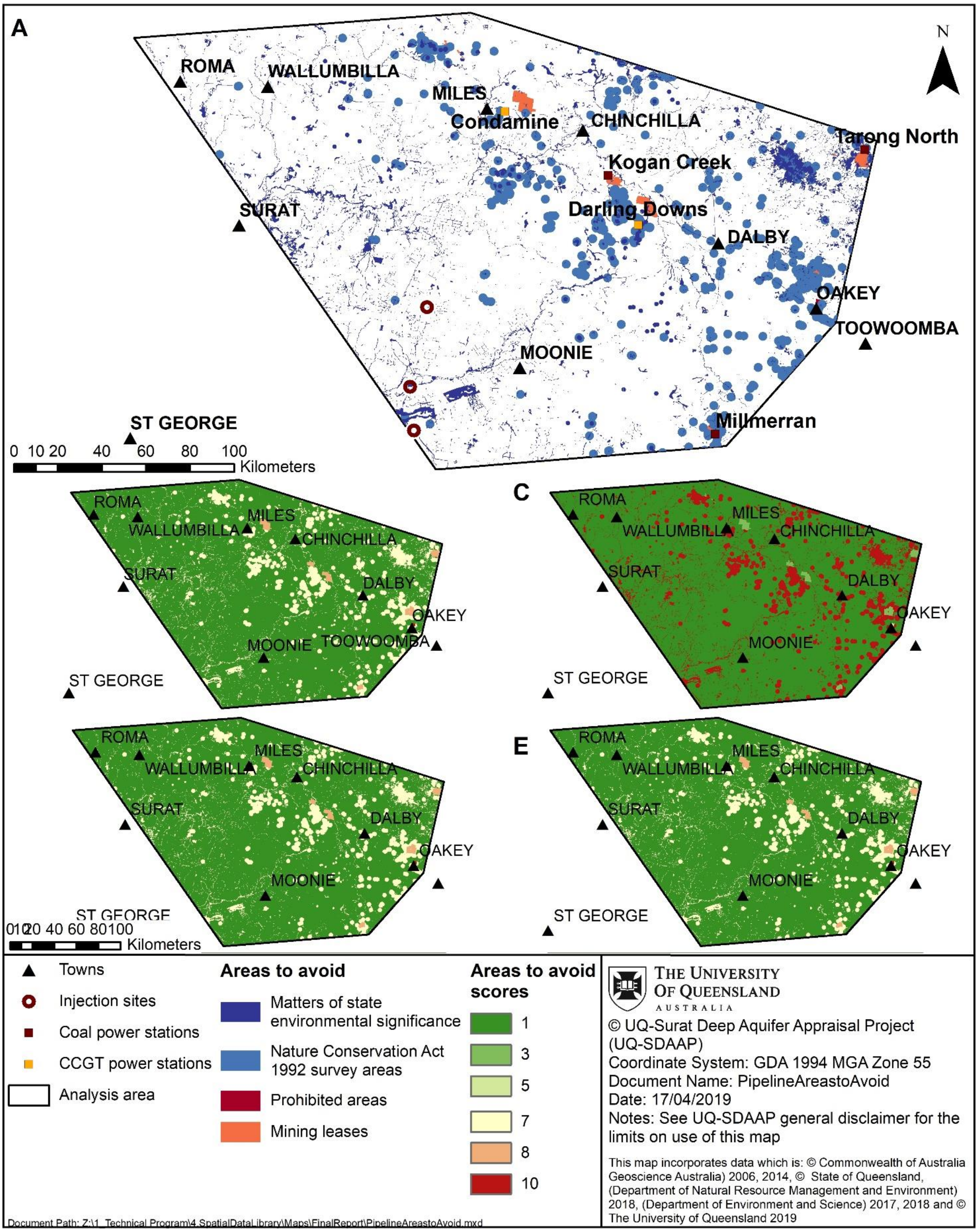
Areas where state planning policy matters of state environmental significance (MSES) exist were represented by matters of state environmental significance – Protected area – nature refuges, Wildlife Habitat – threatened and special least concern animal, high ecological significance wetlands, and regulated vegetation- category B endangered or of Concern shapefiles from the Department of Environment and Science (2017). The MSES data layers provide an indication of where the perceived environmental values represented in the MSES are expected to occur and should be considered as a guide for where to conduct site surveys rather that an indication that the environmental value is present.

Table 12 Areas to avoid categories and scores.

Category	Base case score	Environmental score	People-focused score	Technical score
mining lease	8	3	8	8
prohibited areas	10	5	10	10
NCA	7	10	7	7
MSES	7	10	7	7

No data	1	1	1	1

Figure 13 Distribution of areas to avoid. (A) Data. (B) Areas to avoid scores used in base case analysis. (C) Areas to avoid scores used in environment analysis. (D) Areas to avoid scores used in people-centred analysis. (E) Areas to avoid scores used in technical analysis.



5. Exploratory Results

Figure 14 shows the pipeline routes produced by the initial base case analysis, Figure 15 the notional pipeline routes produced by the prioritising 'environmental value's analysis, Figure 16 shows the notional pipeline routes produced by the 'people-centred' analysis and Figure 17 shows the notional pipeline routes produced by the prioritising 'technical requirements'.

Figure 18 to Figure 23 show the elevation profiles of the notional pipeline routes produced by the four different pipeline scenarios; base case, EV, PC and "technical" prioritising for each pipeline segment. Table 13 compares the notional pipeline route lengths for the different pipeline scenarios. The base case analysis had the shortest pipeline route and one of the best (flatter) elevation profiles, even in comparison to the technical analysis. Table 14 compares the stream crossings

Table 15 compares the road, pipeline and rail crossings and Table 16 compares the powerline crossings for the four pipeline scenarios. The EV scenario had the least number of stream crossings, but the highest number of road, pipeline, rail and powerline crossings, while the PC scenario had the highest number of stream crossings and the technical analysis had the lowest number of road, pipeline, rail and powerline crossings.

Figure 14 Pipeline routes from base case analysis.

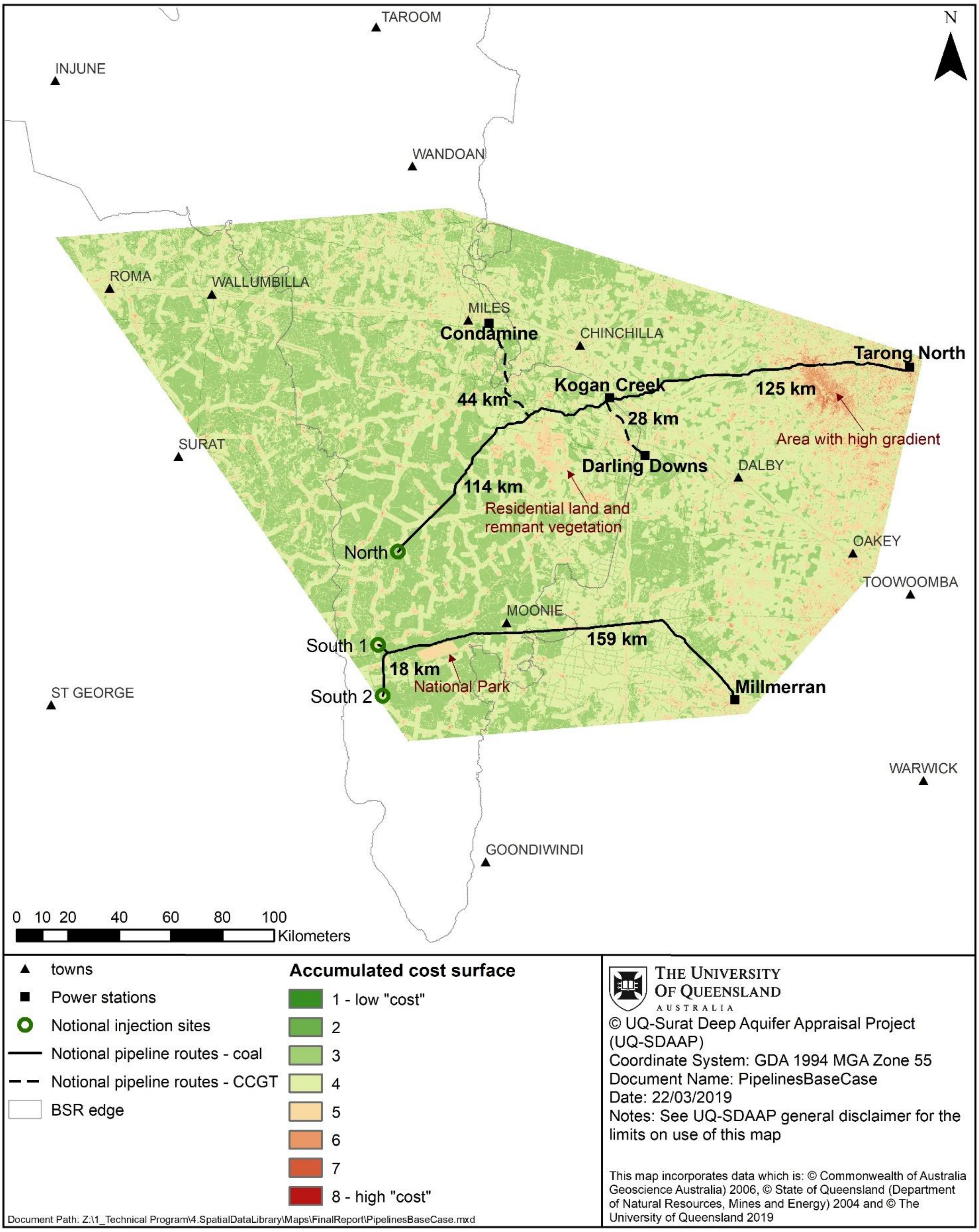


Figure 15 Pipeline routes from environment analysis.

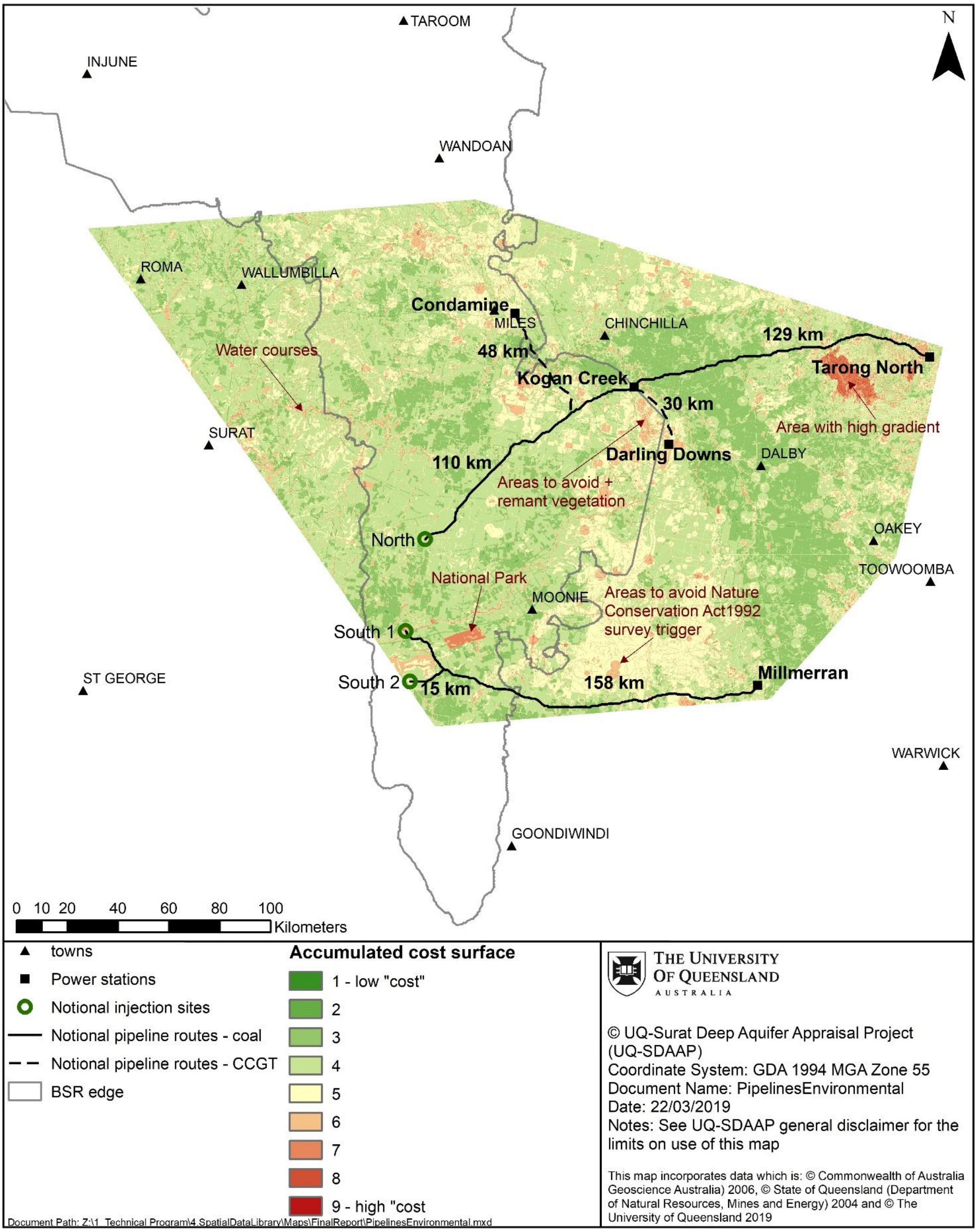


Figure 16 Pipeline routes from people-centred analysis.

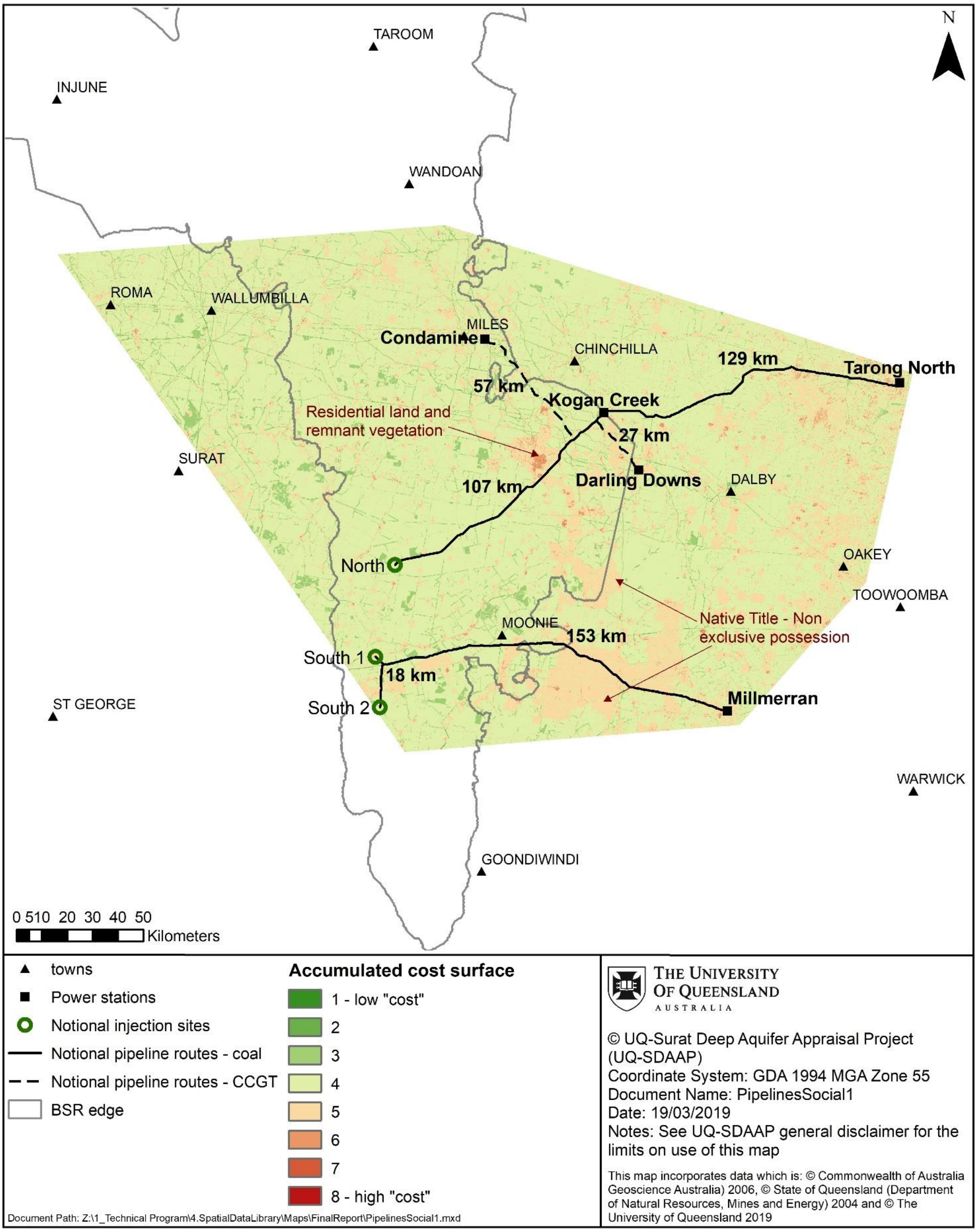


Figure 17 Pipeline routes from technical analysis.

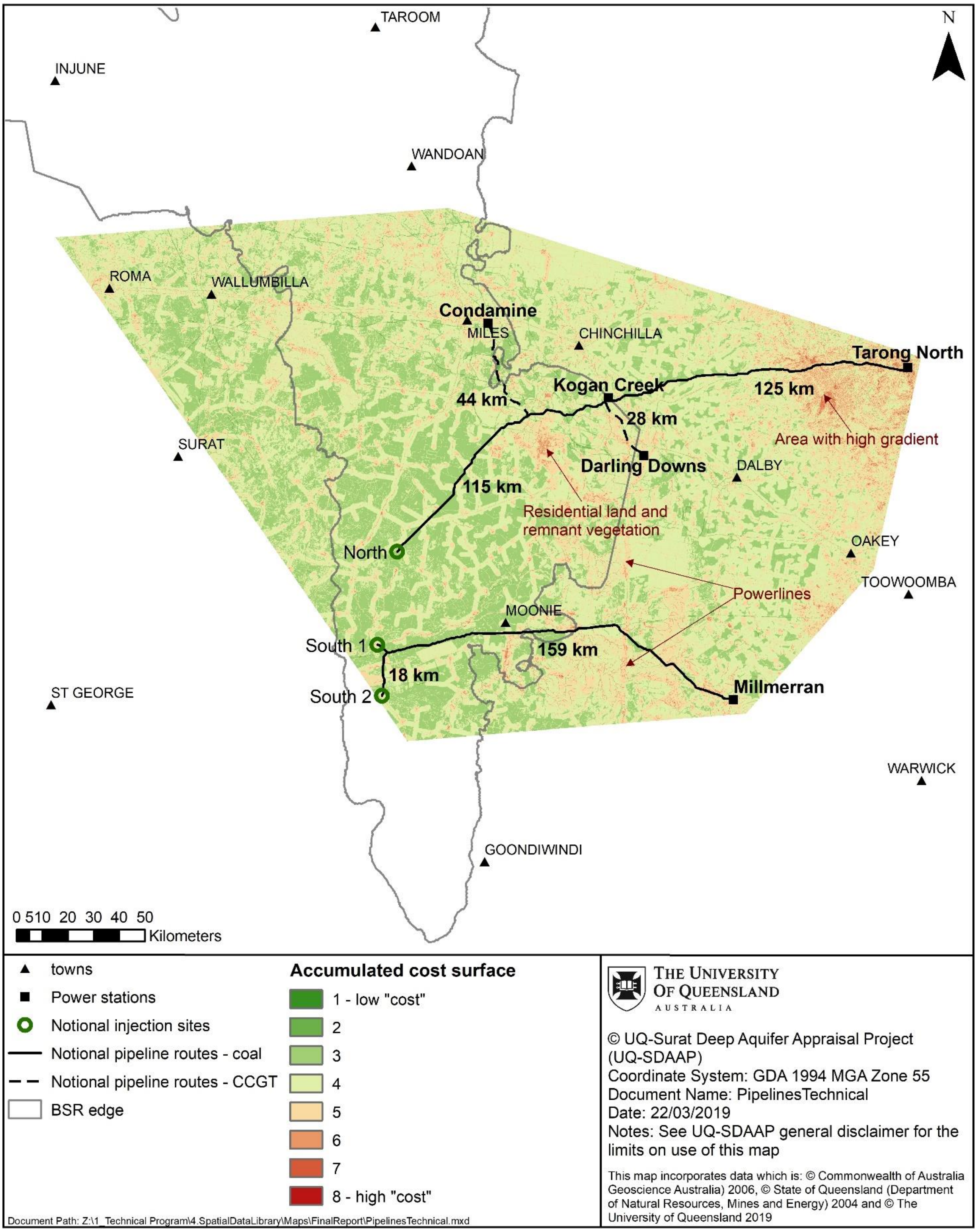


Figure 18 *Elevation profiles for the Kogan Creek to notional northern injection site pipeline. (A) Base case. (B) Environmental. (C) People-centred. (D) Technical method.*

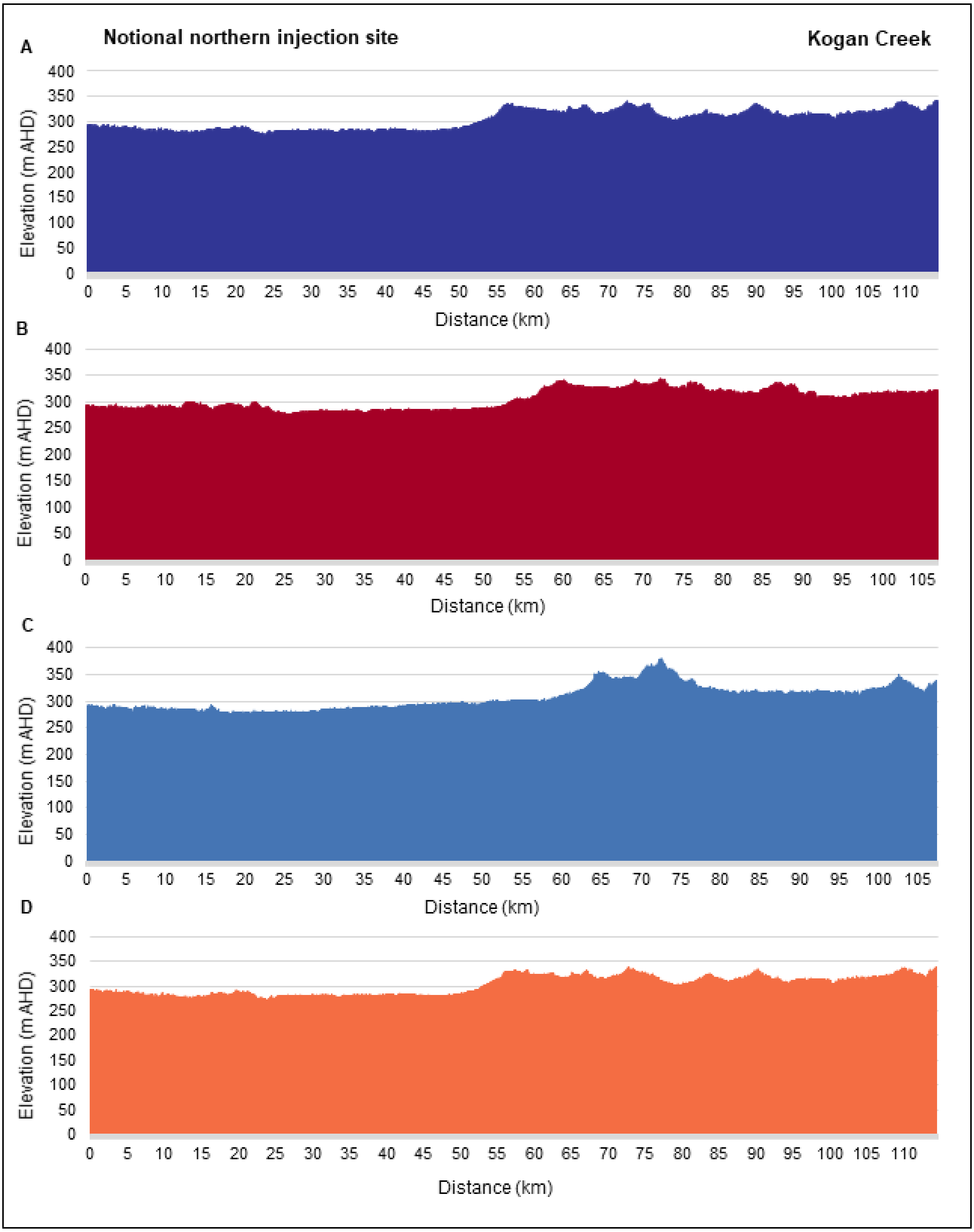


Figure 19 Elevation profiles for the Condamine to Kogan Creek pipeline. (A) Base case. (B) Environmental. (C) People-centred. (D) Technical method.

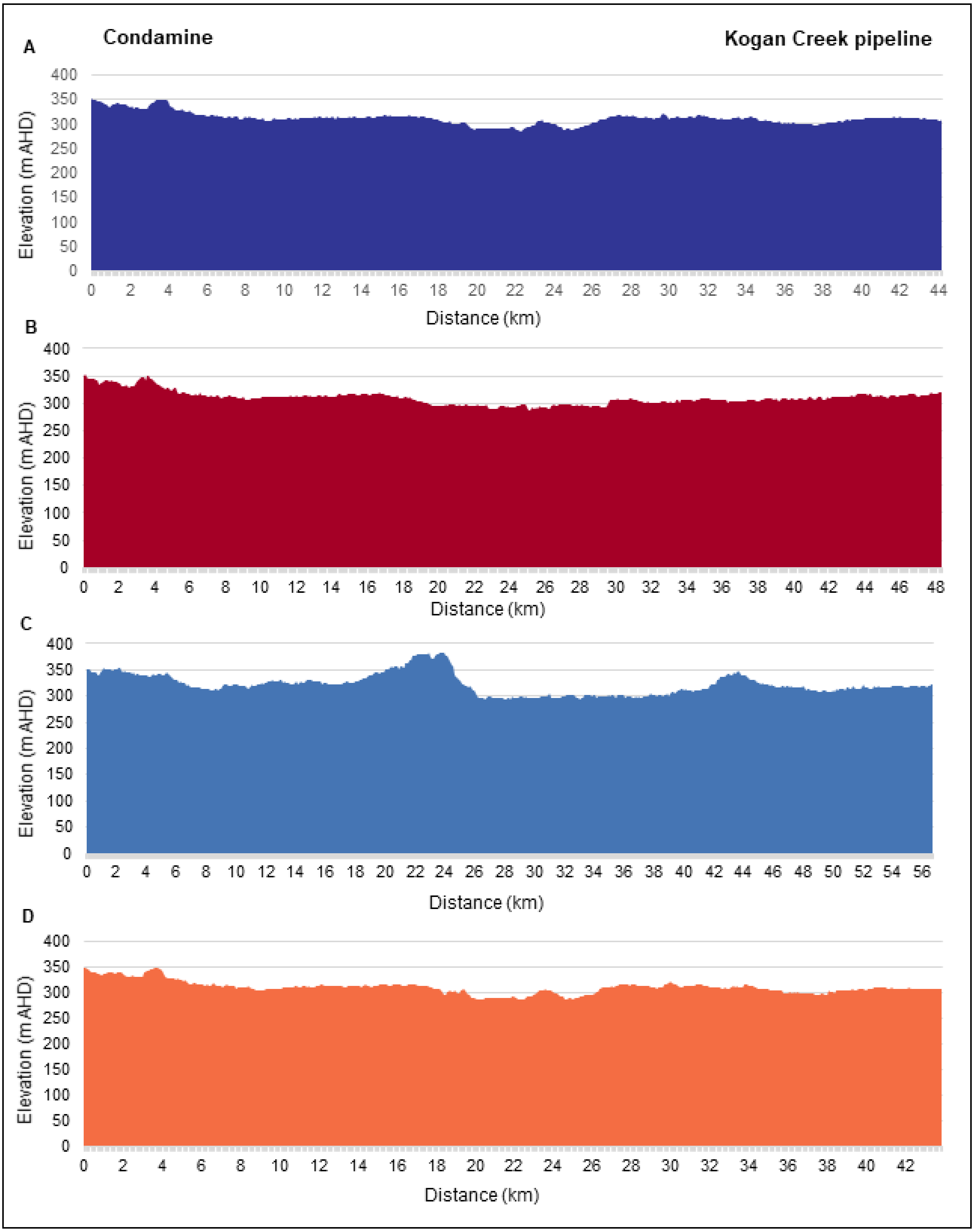


Figure 20 Elevation profiles for the Darling Downs to Kogan Creek pipeline. (A) Base case. (B) Environmental. (C) People-centred. (D) Technical method.

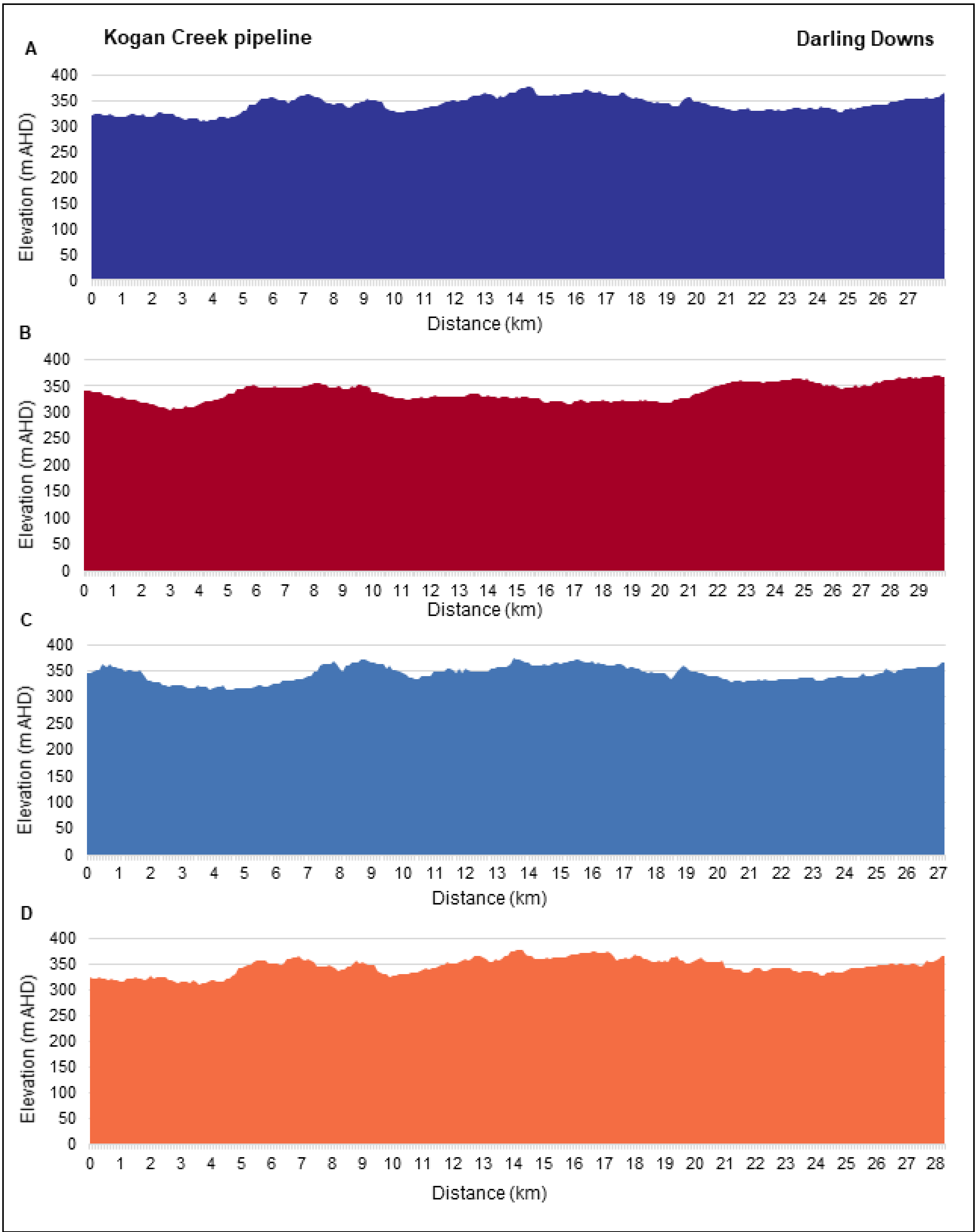


Figure 21 Elevation profiles for the Tarong North to Kogan Creek pipeline. (A) Base case. (B) Environmental. (C) People-centred. (D) Technical method.

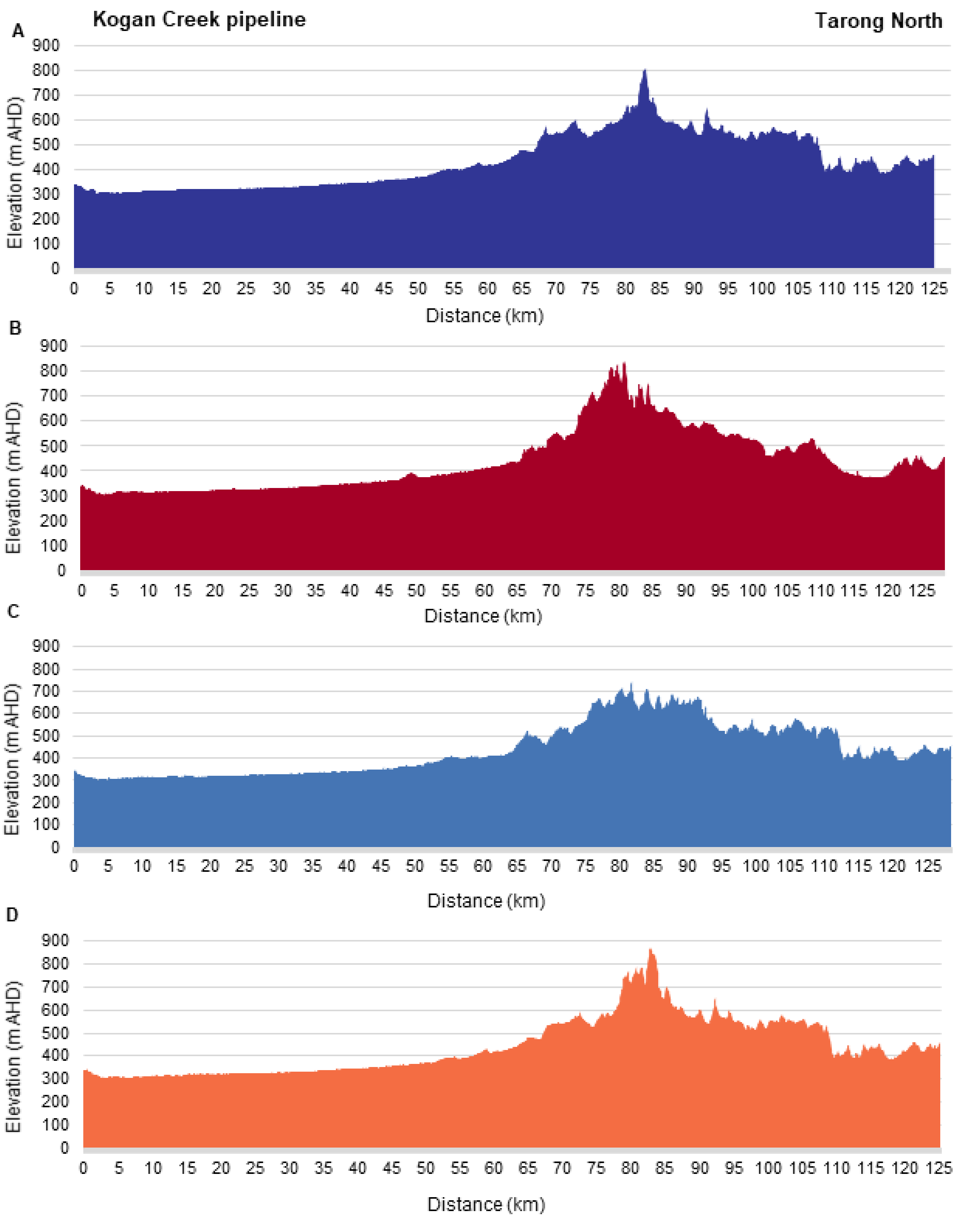


Figure 22	Elevation profiles for the Millmerran to notional southern injection site 1 pipeline. (A) Base case. (B) Environmental. (C) People-centred. (D) Technical method.

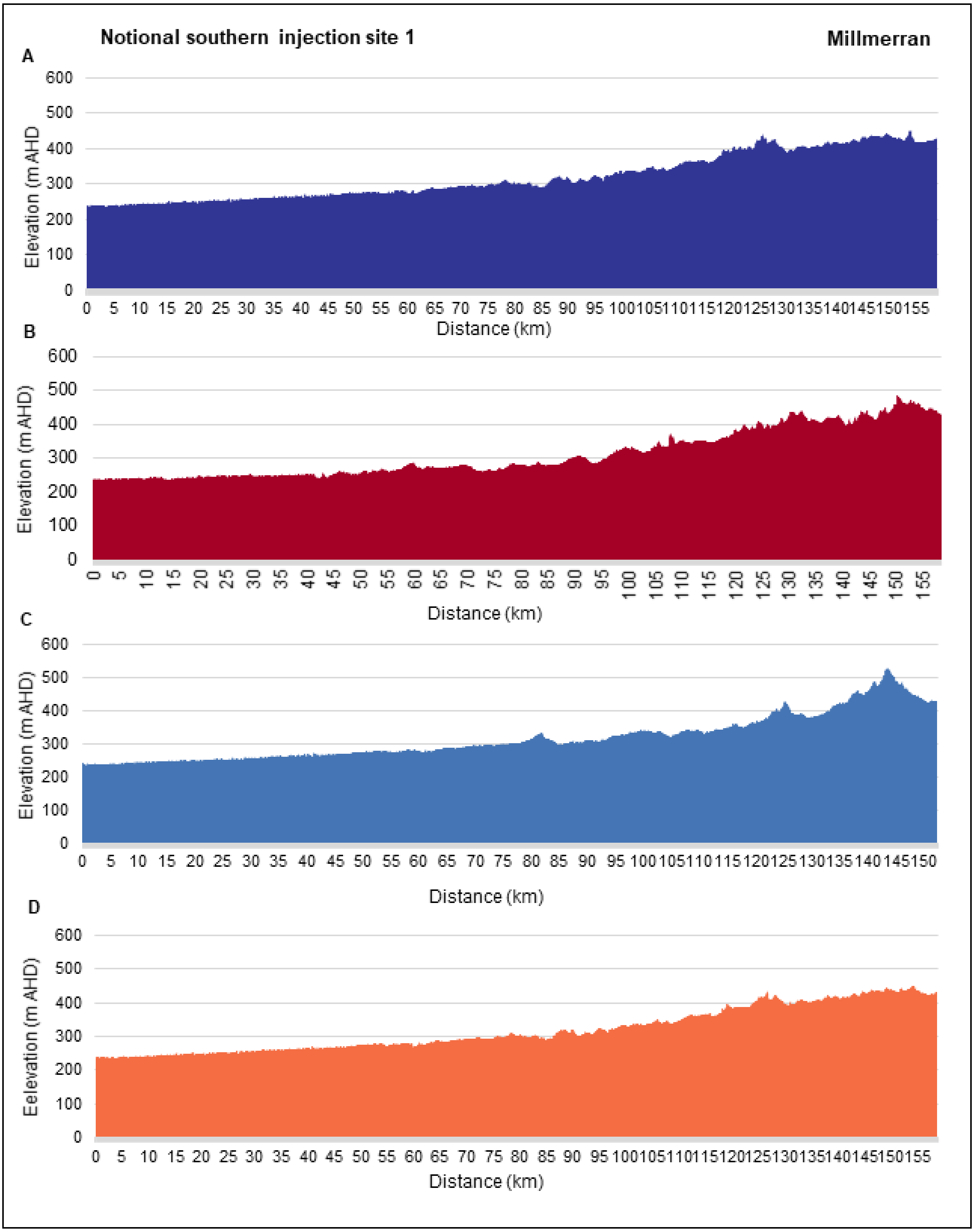


Figure 23 Elevation profiles for the Millmerran pipeline to notional southern injection site 2 pipeline. (A) Base case. (B) Environmental. (C) People-centred. (D) Technical method.

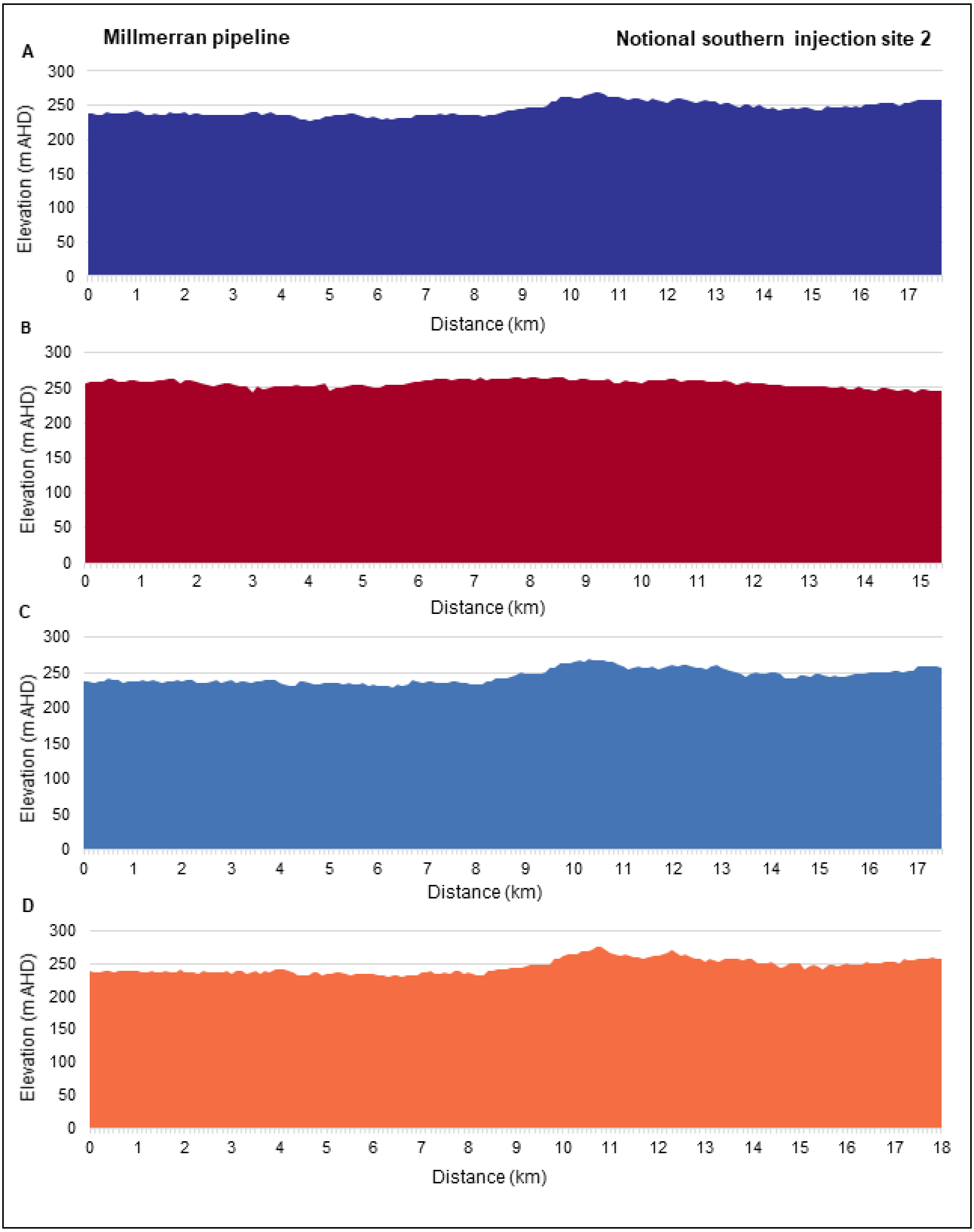


Table 13 Pipeline route length (km).

Pipeline route	Base Case	Environment	People-centred	Technical
Kogan Creek to notional northern injection location	114.4	110.4	107.5	114.5
Condamine to Kogan Creek pipeline	44.2	48.4	56.7	43.8
Darling Downs to Kogan Creek pipeline	27.8	29.8	27.2	28.3
Tarong North to Kogan Creek	124.8	128.5	128.6	125.2
Millmerran to notional southern injection site 1	159.1	158.4	152.5	158.8
Connection between southern injection sites	17.7	15.3	17.5	18.0
Total length	488	490.8	490	488.6

Table 14 Pipeline route stream crossings.

Pipeline route	Base Case	Environment	People-centred	Technical
Kogan Creek to notional northern injection location	19	21	27	18
Condamine to Kogan Creek pipeline	17	19	23	17
Darling Downs to Kogan Creek pipeline	17	8	14	17
Tarong North to Kogan Creek	93	66	111	79
Millmerran to notional southern injection site 1	40	54	46	42
Connection between southern injection sites	3	0	3	3
Total crossings	189	151	224	176

Table 15 Pipeline route road, powerline and rail crossings.

Pipeline route	Base Case	Environment	People-centred	Technical
Kogan Creek to notional northern injection location	24	31	29	23
Condamine to Kogan Creek pipeline	10	11	11	7
Darling Downs to Kogan Creek pipeline	7	13	7	6
Tarong North to Kogan Creek	34	43	29	34
Millmerran to notional southern injection site 1	32	47	42	32
Connection between southern injection sites	5	1	5	4
Total crossings	112	146	123	106

Table 16 Pipeline route powerline crossings.

Pipeline route	Base Case	Environment	People-centred	Technical
Kogan Creek to notional northern injection location	6	6	6	6
Condamine to Kogan Creek pipeline	2	4	6	2
Darling Downs to Kogan Creek pipeline	4	4	4	4
Tarong North to Kogan Creek	13	16	17	13
Millmerran to notional southern injection site 1	4	9	4	3
Connection between southern injection sites	2	1	2	2
Total crossings	31	40	39	30

6. Discussion

6.1 Differences between routes produced by four different analyses

The pipeline routes produced by the base case and technical constraints analysis are very similar. This is most likely because the two highest weighted criteria were the same for both. Other criteria weightings were also similar. The occasional deviations between the two routes are mostly due to the route produced by the technical constraint's analysis, crossing fewer streams or following roads. The sparseness of the homestead locations used to represent dwellings meant that they did not have a big impact on pipeline routes.

For some pipeline routes such as the Tarong North to Kogan Creek route, the base case analysis also produced routes that had less elevation change than the technical constraints analysis. This is probably because although the base case and technical constraints analysis had slope as the highest priority/cost criterion, the base case placed a higher priority on avoiding national parks, and in this instance, a national park also covers some of the steepest terrain that the Tarong North to Kogan Creek pipeline had to cross.

Detailed pipeline engineering was outside the scope of UQ-SDAAP, but **the Tarong North to Kogan Creek route for a high density, supercritical CO_2 pipeline requires further study because of large elevation changes.**

The biggest difference between the pipeline routes produced by the four analyses is the pipeline connecting Millmerran to the notional southern injection sites produced by the EV scenario. Rather than travelling north and joining the easement of the Moonie to Brisbane and Jackson to Moonie oil pipeline like the pipeline routes produced by the other analyses, the EV pipeline scenario travels west before turning north to the southern notional injection sites. The pipeline therefore avoids travelling through a state forest and instead travels through cropping land, which was given a lower cost/value in the environmental analysis. While the EV route has a similar length to other pipeline routes, it is may not be a preferable route as it does not take advantage of an existing easement that extends for the majority of the pipeline length needed.

The difference between the routes produced by the people-centred analysis and the base case analysis were mostly due to the difference in weighting and factor values for the land ownership and land use criteria. For example, the Tarong North to Kogan Creek pipeline produced by the people-centred analysis tends to travel along roads rather than crossing through freehold land and avoids cropping areas when travelling through freehold land. The Millmerran to notional southern injection sites pipeline also travels along an easement recorded in the cadastral database before crossing the state forest to join the Moonie to Brisbane and Jackson to Moonie oil pipeline easement. The easement recorded in the cadastral database is an easement for powerlines. For technical reasons it would be an unsuitable easement to use for a CO_2 pipeline because of the potential for an induced current in the pipeline. The base case, technical constraints and people-centred analyses all produced pipeline routes between Millmerran and the notional southern injection sites that crossed the state forest to reach the Moonie to Brisbane and Jackson to Moonie oil pipeline easement. Non-exclusive possession Native Title exists over the state forest. The people-centred analysis produced a pipeline route that had a longer length through the state forest, despite Native Title having the third highest weighting. This demonstrates how the important the relative weightings can be for determining pipeline routes, as the weightings have a multiplicative effect on factor scores (Esri 2018d; Malczewski 2000).

The different analyses in this report produce results showing what route a CO_2 pipeline might take depending on what the highest priorities are for determining its location, e.g. cost or minimising social or environmental impacts. The results also highlight how prioritising different criteria produce trade-offs. For example, the shortest pipeline between Millmerran and the notional south injection site one was produced by the people-centred analysis, however less of its length was within the existing pipeline easement. The pipeline route produced by people-centred analysis would therefore require more surveys to be conducted for the part of the route not within the existing easement. This example clearly represents the trade-off between the cost in length of the pipeline vs other associated costs in construction of the pipeline. It is also an example of where having actual cost data for pipeline construction would aid in the production of least cost path analyses that are tied to real costs rather than estimates of relative cost.

The overall approach of the notional pipeline route analysis described in this report is also suitable for use in community consultation, that may form part of an appraisal plan. The different pipeline scenarios, base case, EV, PC and "technical" illustrate various trade-offs need to be made when deciding where to build a pipeline.

It is recommended that a similar approach would be suitable for communicating and exploring pipeline routeing choices with stakeholders (Seel et al. 2014).

In each case, the length of the routes identified by each analysis only vary slightly. Since length is a major cost driver, this means that uncertainty in pipeline cost from this source will be minimal. There are other cost-driving factors, such as stream crossings and elevation profile which vary between routes.

Optimisation would be required in the context of a detail EIS and community engagement process.

6.2 Uncertainties associated route scenarios

We sourced all datasets for the least cost pathway analysis from government databases. While we had access to a wide range of relevant data, having different data sources means that the analysis is based on data of greatly varying currency and update frequency. For instance, the Queensland Digital Cadastral Database (Department of Natural Resources Mines and Energy 2018) and Exploration and Production Databases (Department of Natural Resources Mines and Energy 2018) are updated daily. If there are any changes in the analysis area, the results of the analysis will quickly be out-of-date. In contrast, the GEODATA TOPO 250K (Geoscience Australia) is updated infrequently and the version we use herein is 10 years old. It is therefore unlikely to contain a record of all the features our analysis was interested in, as new houses may have since been built, and some may have been omitted from the database.

The resolution of the DEM used to create rasters for the analyses has a resolution of 3 arc seconds, roughly 90 m. In some instances, the distances used to create categories in the analysis, for examples distances from roads have therefore been larger than the distances that would be used on the ground. The least-cost paths that we produced should therefore be considered more as a guide as to the general path, or a corridor through which the notional CO_2 pipeline would pass, rather than an exact indication of where the notional pipeline would be laid. It will be important to consider additional uncertainties related to spatial accuracy which may also arise from re-projection of the data.

The routes produced using the overall analysis approach described in this report are dependent on the data used as an input. Due to the uncertainties associated with the data, any notional pipeline route described in this report will therefore need to be ground-truthed at the next phases of the project. That phase may also include additional data (such as information on soil properties) that would be relevant to include in a pipeline route analysis. Any changes to the data or additional criteria may change the notional routes produced if the analysis, or a similar analysis, were to be repeated.

6.3 Recommendations for further appraisal data collection

Due to the nature of data available, some factors that would have an influence on cost-effective pipeline routes have not been included in this analysis. Some factors have been included, but with older or incomplete datasets.

Given the age of the data used for the location of presumed dwellings, we recommend that more detailed and up-to-date information on the location of presumed dwellings, as well as other buildings, be collected. The location of dwellings and other farm infrastructure such as sheds will also need to be confirmed to ensure that disruption to people's lives and livelihoods during further data collection and construction of a pipeline is minimised. Land use should also be ascertained during the appraisal program, so that up-to-date information on land use can be used for updated pipeline route consultation and planning.

As the depth and type of soil can have a large effect on the cost of digging trenches for pipelines, it is recommended that this data is collected during any pipeline route appraisal work for inclusion in later analyses.

The analysis also does not contain any information on indigenous cultural heritage or significance. We recommend that data from the Aboriginal and Torres Strait Islander Cultural Heritage Database and Register be included along with any information obtained through consultation with indigenous owners in further analyses to determine potential pipeline routes.

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