Office of Water Science

Phase 1 Bioregional Assessment
Final Report

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Executive Summary

This study, the first phase in a series of studies aimed at better understanding the likely impacts of the emerging coal seam gas and coal mining development on the region will, ultimately, lead to a Bioregional Assessment for the Desert Channels Queensland region and inform future decisions regarding these developments.

This project has used known and developed datasets to identify significant water assets in the Desert Channels region that may be vulnerable to coal seam gas (CSG) extraction and/or coal mining. The project was funded by the Australian Government Office of Water Science (OWS) within the Department of Sustainability Environment Water Population and Communities, and data obtained has been used to populate databases to be used in further phases. The data has identified the surface water, groundwater and water-dependent ecological assets within the DCQ region that may be impacted by CSG and coal mining. The project has also applied vulnerabilities to these assets, in particular aquifer loss from potential and expanding CSG and coal mining operations. This was the principle product required of the project. DCQ also decided to ensure that all assets were mapped along with vulnerabilities. As the NRM group, and an investor in on-ground works, DCQ is seeking to ensure that future investment decisions utilise all available information.

While these assets are distributed across the DCQ region, the area of greatest interest for this project lies in the eastern part of the region. This is due to the geology of the area, which, due to rising and exposed formations, concentrates existing and potential CSG activity in a significant recharge area for the Great Artesian Basin. This recharge area also contains a number of important artesian springs along with the only local terminal lake systems in the region. The assets in this area have significant ecological, cultural and economic importance for the region, representing a unique series of ecosystems, with a long cultural history and supporting an important grazing industry. Many of the assets in this area are also showing signs of existing stress such as springs and bores ceasing to flow and water levels in sub-artesian bores declining. This zone easily eclipses other parts of the region as being the most vulnerable, and it is recommended that future investment be targeted towards better understanding this area of the region.

The study also found that there was a significant lack of information regarding ecological diversity in some key surface water assets. In addition, source aquifer information for a significant number of bores, and many springs, was not known. For example, within the study area, the source aquifer could not be identified accurately in 41% of bores.

The maps presented identify assets by type and status, and also indicate clear directions for future assessment and investigative work. When these maps are combined with the vulnerability mapping, they inform decisions regarding investment in priority areas and provide a guide to future data gathering. The maps also provide a tool, when used appropriately, for education of community and interested parties in the likely impact of CSG and coal mining on their assets.

Many of the vulnerabilities identified are easily managed through localised development; however, some of the assets have existing stressors caused by current levels of water use. The cumulative impact of additional stressors needs to be carefully considered, and may well extend outside a single tenement.

The vulnerability mapping is, by its nature, subjective and, therefore, the final version of the vulnerability matrix used by DCQ has been presented in the interests of transparency. Additional investigative information may cause some adjustment to the vulnerability score used on each asset, however, it should be noted that the vulnerability applied relies on the cumulative vulnerability of the likely stressors and distance of the asset, both laterally and vertically, from target CSG and coal mining formations.

Regional Overview

This project report describes the process carried out by Desert Channels Queensland (DCQ) to collate and identify key datasets for water assets considered likely to be vulnerable to coal seam gas exploration and extraction and coal mining. The project also assigned a vulnerability rating to the identified assets.

The study area for the project was the DCQ region, defined as the Queensland portion of the Lake Eyre Basin. This includes the catchments of the Georgina and Diamantina rivers and Cooper Creek. Figure 1 below shows the DCQ region and the geological features of interest, the Galilee and Cooper Basins.

Figure 1 - Desert Channels Queensland Region

The DCQ region is the most bio-diverse in the state, with seven bioregions represented. It is also the state's most arid region, which underlines the critical importance of water and water-dependent ecosystems to the health and productivity of the area. Most surface water is ephemeral or concentrated into semi-permanent or permanent water features, the latter being critical drought refugia. In addition, along the margins, springs and spring groups maintain unique ecosystems supporting plants and animals found nowhere else on the planet. Astride such a spring group in the east, is the national biodiversity hotspot, the Desert Uplands bioregion.

Rainfall decreases from east to west as the Desert Uplands, with its terminal lake systems, gives way to the highly productive Mitchell Grass Downs, the Channel Country with its anastomosing channels, then the Simpson Strzelecki Dunefields. The Channel Country floodplains of the Cooper, Georgina and Diamantina are world-class, organic, cattle fattening areas. In the northwest, the topography rises to the Mt Isa Inlier, associated with a series of geological features that have concentrated, highly prized mineral resources. Completing the bioregional picture is a swath of Mulgalands in the southeast, with an adjacent area of Brigalow South.

Agriculture is the major economic driver for the region. This is overwhelmingly grazing of natural pastures with a significant number of properties now having organic certification. The grazing industry relies mainly on groundwater from artesian or sub-artesian bores. Property sizes are large and the regional population of 14,500 (including towns) is very small compared to other regions. Towns throughout the area have been developing water assets to underpin population growth and cater for the increasing tourist market.

There is a known link between water features in the landscape and cultural heritage. This knowledge, when applied to individual assets is poorly recorded within the region and not easily assessable. This is of particular application to spring groups on the eastern margins and waterholes and wetlands in the central and western margins.

The Desert Channels region relies predominantly on groundwater from local bore fields for human use, industry, recreation and primary production, and this is often supplemented by surface water assets. Consequently, the identification of critical water assets commenced from the consideration of known impacts from CSG production and coal mining.

This project has not considered shale oil production out of the Cooper Basin. While there is strong interest in this resource, it was deemed out of scope for this project.

The DCQ region, with its highly variable and relatively low, summer dominant rainfall, has given rise to unique flora and fauna that is beautifully adapted to an ephemeral water supply. Such a water supply was not conducive to a pastoral industry or the attendant urban settlements. The Great Artesian Basin (GAB) underlies most of the region, and it is this geological feature, with its intake beds in the east, that has allowed the development of the area. While over extraction and water wastage has led to pressure declines in much of the region, with spring groups ceasing to flow, recent remedial works are beginning to redress this effect.

The Triassic and Permian formations of the Betts Creek Beds and the Aramac Coal Measures which are target formations for both CSG and coal mining development underlie the Eromanga Basin of the GAB. These Triassic and Permian formations, along with the GAB formations rise and partially outcrop in the eastern margin of the DCQ region. Unsurprisingly interest in coal mining is also confined to the eastern margins where the coal measures are close to the surface. While CSG exploration covers much of the Galilee Basin, first production is likely to be on the eastern margins.

This concentrates exploration and initial production in and around the intake beds of the GAB, close to spring groups, and in area of known, high biodiversity value. Community sensitivities are elevated due to perceived threats to water resources and a lack of understanding about CSG production methodologies and the disposal of waste water.

Geology and Mining Production Overview

The DCQ region covers 510,000 square kilometres and, understandably, has a diverse geology. For this project the two significant geological features are the Galilee and the Cooper basins. Both basins underlie the much younger Eromanga Basin that contains the formations making up the Great Artesian Basin (GAB). The Cooper Basin, located in the south of the region, is the centre of a significant oil, gas and petroleum industry. To date, the northern basin, the Galilee, which lies between the Surat and the Bowen basin, has been relatively poorly explored and utilisation of the resources is still expanding. The map below shows the extent of the Galilee basin, its important Koburra Trough and the Lovelle Depression, which are thought to contain significant coal seam gas resource reserves.

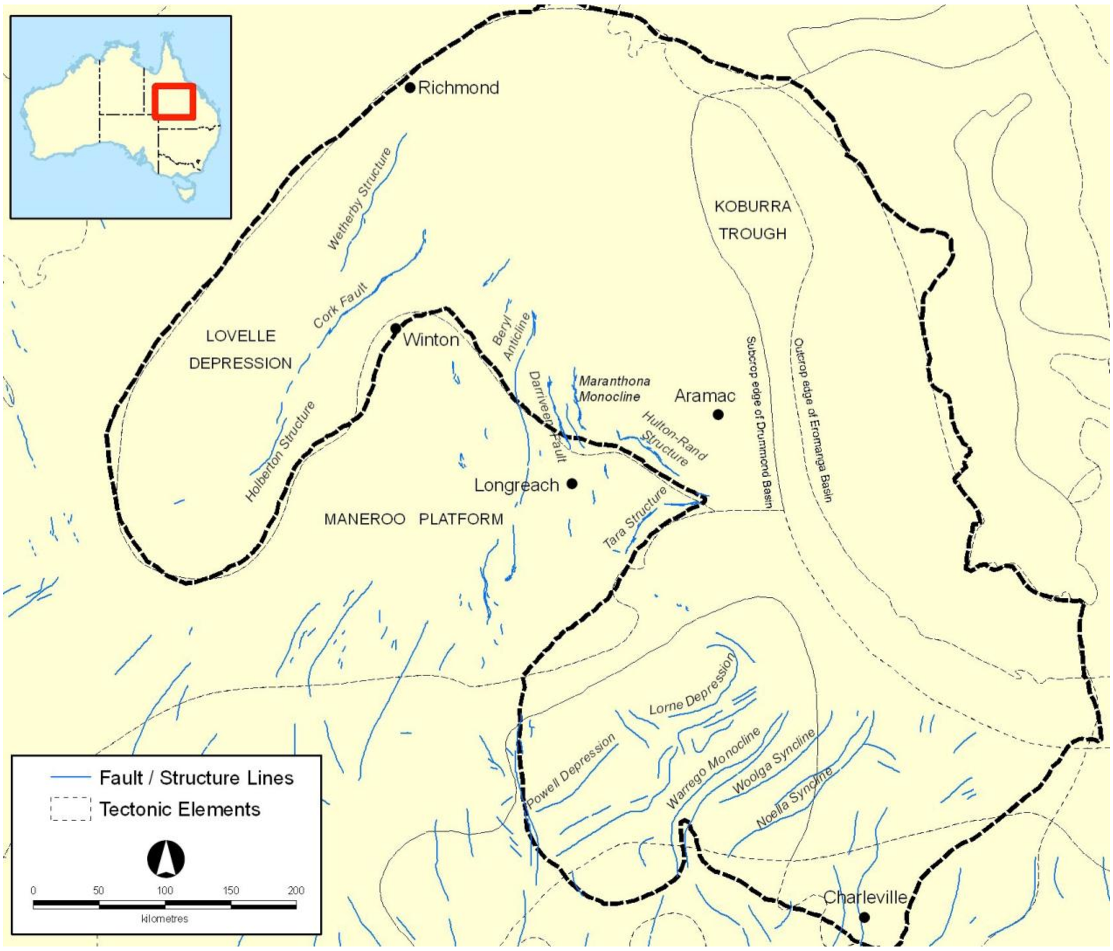


Figure 2 - Galilee Basin

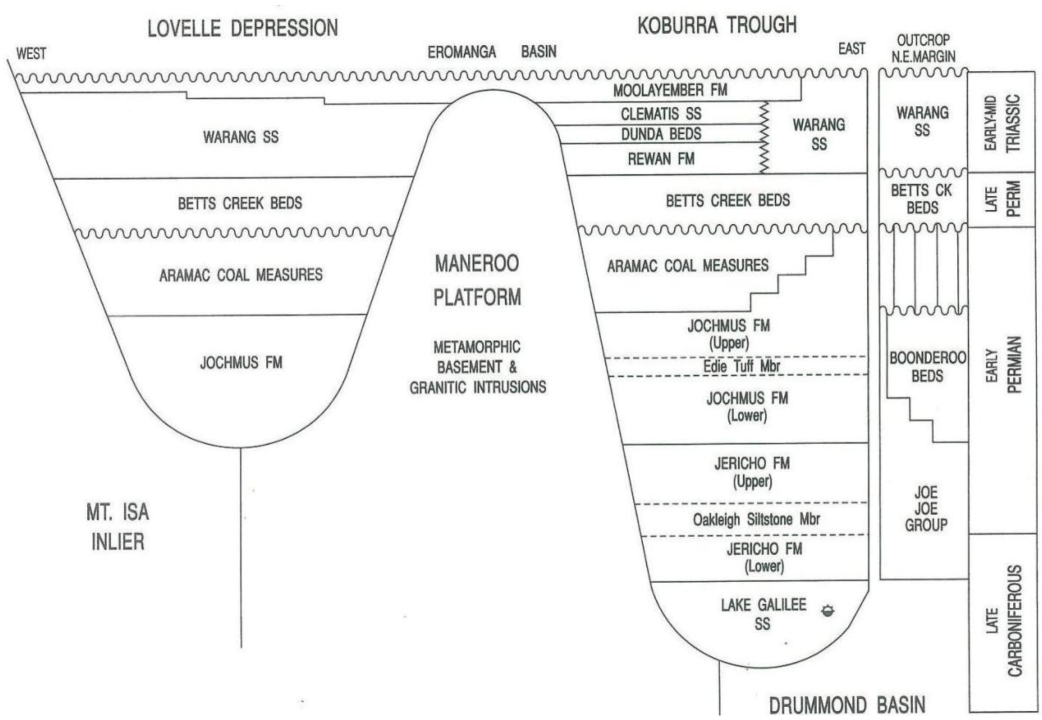
The simplified geology in Figure 3 below presented by the Galilee Basin Operators Forum identifies the target formations for CSG and coal mining activity, namely the grouped Betts Creek beds and the Aramac Coal measures. Both formations outcrop on the north eastern margins, coinciding with outcrops of the main water-bearing formations of the GAB.

It is thought that the Galilee Basin formed when a large, shallow depression formed during the late Carboniferous Age with sediments initially largely confined to the Koburra Trough. The trough location is thought to be influenced by the underlying Drummond Basin. Sedimentation during the Early Permian Age was widespread, generally fluviate and extended into the Lovelle Depression. The widespread development of peat swamps during this time resulted in the deposition and formation of the Aramac Coal measures, part of the Joe Joe Group. However, compression, uplift and erosion saw this formation completely removed in the eastern and southern parts of the Koburra Trough.

Widespread freshwater swamps and continued deposition during the Middle and Late Permian resulted in the formation of the sequence which includes the Betts Creek Beds with their contained coal measures.

The Galilee Basin is largely concealed below the Jurassic to Cretaceous sediments of the Eromanga Basin except in the northeast margins. The formations of the Eromanga Basin contain the strategically important Hutton and Hooray water bearing formations that supply the majority of primary industry, town and domestic supplies within the DCQ region. Significantly, these formations are also thought to be source aquifers for springs and spring groups, recognised internationally for their unique biota, located on the margins of the Eromanga Basin.

Water assets intersecting the water bearing formations of the Eromanga Basin have been grouped, based on their relativity to the Betts Creek beds and the Aramac Coal measures and the presence of any barriers that would limit impacts.



Source: Galilee Basin Operators Forum

Figure 3 - Galilee Basin Geology

Investigative drilling has been through several phases but, until 2000, drilling activity had been relatively light. Since 2000, and with the release of additional prospecting leases, significant exploratory and investigative work has been undertaken. The figure below shows current CSG tenures with known petroleum and CSG well drilling activity. Both the Galilee and Cooper basins are shown; of note is the heavy concentration of petroleum wells in the Cooper, and the growing number of wells in the northern Galilee Basin although this is, to date, well below the current development in the Surat and Bowen basins. The Cooper Basin currently has 951 petroleum and 3 CSG wells, while the Galilee Basin currently has 101 petroleum and 75 CSG wells.

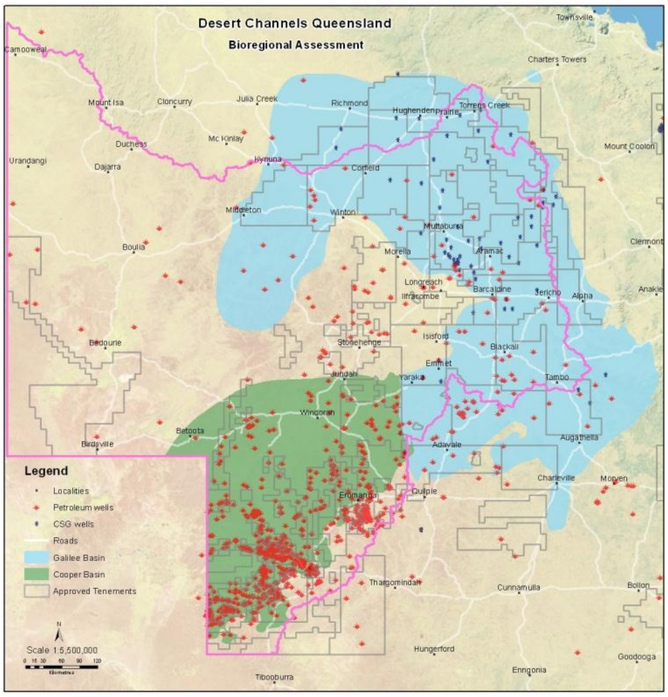


Figure 4 - DCQ Region Petroleum and CSG Investigation and Production Wells

In addition, along with exploration of CSG, coal mining prospecting and petroleum gas exploration has intensified. Coal exploration and mine pre-production activities have been underway for some time on the eastern margins of the Galilee Basin where the coal measures outcrop. This current mining activity is outside the DCQ region but the map below shows the level of exploratory interest within the region.

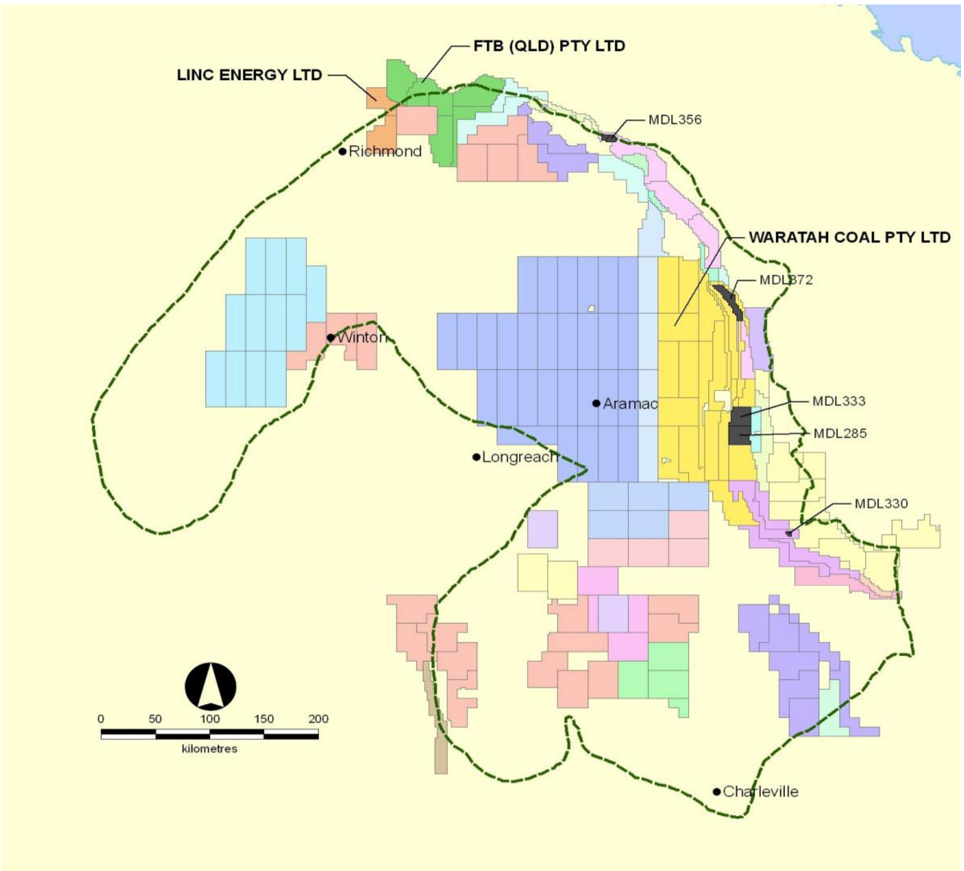


Figure 5 - Galilee Basin Coal Exploration

The stylised cross section of the GAB below represents flow paths of the Triassic formations which overly the Permian formations. The bores mapped in this report have been grouped based on the clumping of like and confined aquifers which all have a similar vulnerability.

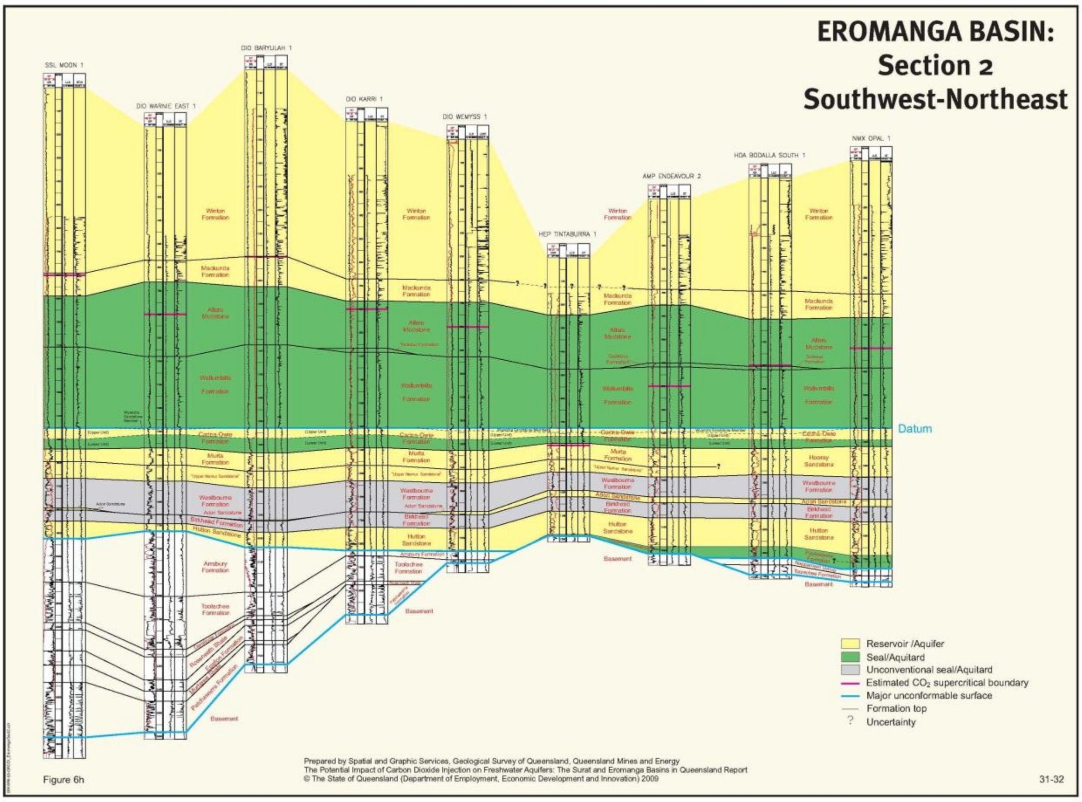


Figure 6 Great Artesian Basin Stylised Cross Section

Bioregional Assessment – Phase 1

Project products

The project has combined all known datasets and listed the information of known assets.

The project used information management and storage tools provided by the Australian Government Office of Water Science, namely:

- ANZMetLite – to create a metadata file that conforms to the ANZLIC standard for each key dataset; and
- Water Asset Information Tool – a Microsoft Access database that recorded the key attributes of each water asset identified by the project (including asset type, location, assigned values including vulnerability and key contact details).

The project team has also developed a series of maps that highlight key issues such as areas under resource threat and, therefore, increased vulnerability, and the disturbingly large knowledge gaps about many of the assets.

These maps, when combined with biodiversity information and planning data, identify obvious areas for further investment to fill knowledge gaps and for projects to sustainably manage priority areas.

Project methodology

The project identified the known impacts of CSG production and coal mining, and compared these against the likely vulnerabilities of water assets within the region. The DCQ region is not uniformly vulnerable, neither are the assets within the region.

Water assets were grouped based on source water, either surface water or groundwater, and their location either inside or outside the Galilee and Cooper basins. These assets have very different vulnerabilities and have been identified accordingly. The vulnerability of some assets, due to their geographic separation, is so low as to be irrelevant, while some assets have a very high vulnerability that needs to be carefully considered and resolved.

The level of breakdown of the water asset investigation and the scale of mapping has been an issue which has had to be resolved through the project. As data sources have been investigated, this has been further highlighted. Within the DCQ region it has been decided to map assets as close as possible down to the individual asset level. For example, due to the scarcity and value of surface water, all rock holes have been listed, but they have been spilt between permanent and semi-permanent. Similarly, all bores have been listed, although bores which are listed on datasets and have since been abandoned, are identified and mapped separately. The reason these bores have been listed is that the methodology of abandonment is unknown. Consequently, these bores represent a unique threat to water assets due to potential inter-bed leakage but, also, when mapped with spring groups that have ceased to flow, clearly outline areas of existing stress. Of significance is the overlap between areas of existing stress and CSG exploration.

To make management of the data possible for future assessment water assets were grouped into like vulnerabilities. The best example is groundwater assets, which were combined based on their age, location in the geological sequence or between aquatards, separation from CSG and coal mining target formations, source aquifer and likely threat. For example, Jurassic formations located immediately above the Triassic/Permian formations (even though there is a major unconformity) have a higher risk than cretaceous formations higher in the sequence and separated by additional barriers.

This methodology builds on known prospecting with the region, which is centred on these two basins. It highlights the potential number of assets which would require baseline assessment if production reached levels seen in other basins.

In broad terms, the project consisted of:

- Identification and collection of key base datasets;
- Identification of hierarchy of water assets to be assessed;
- Analysis of data known about each asset;
- Common grouping based on vulnerabilities;
- Creation of separate datasets for each level of water asset hierarchy and production of maps of each;
- Review and confirmation of the hierarchy and amendment if necessary;
- Creation of final dataset for each asset identified (with metadata description);
- Identification of known knowledge gaps; and
- Entry of each asset into the Water Asset Information database along with assigned vulnerability.

This process is shown diagrammatically in Figure 7 – Vulnerability Assessment Process below.

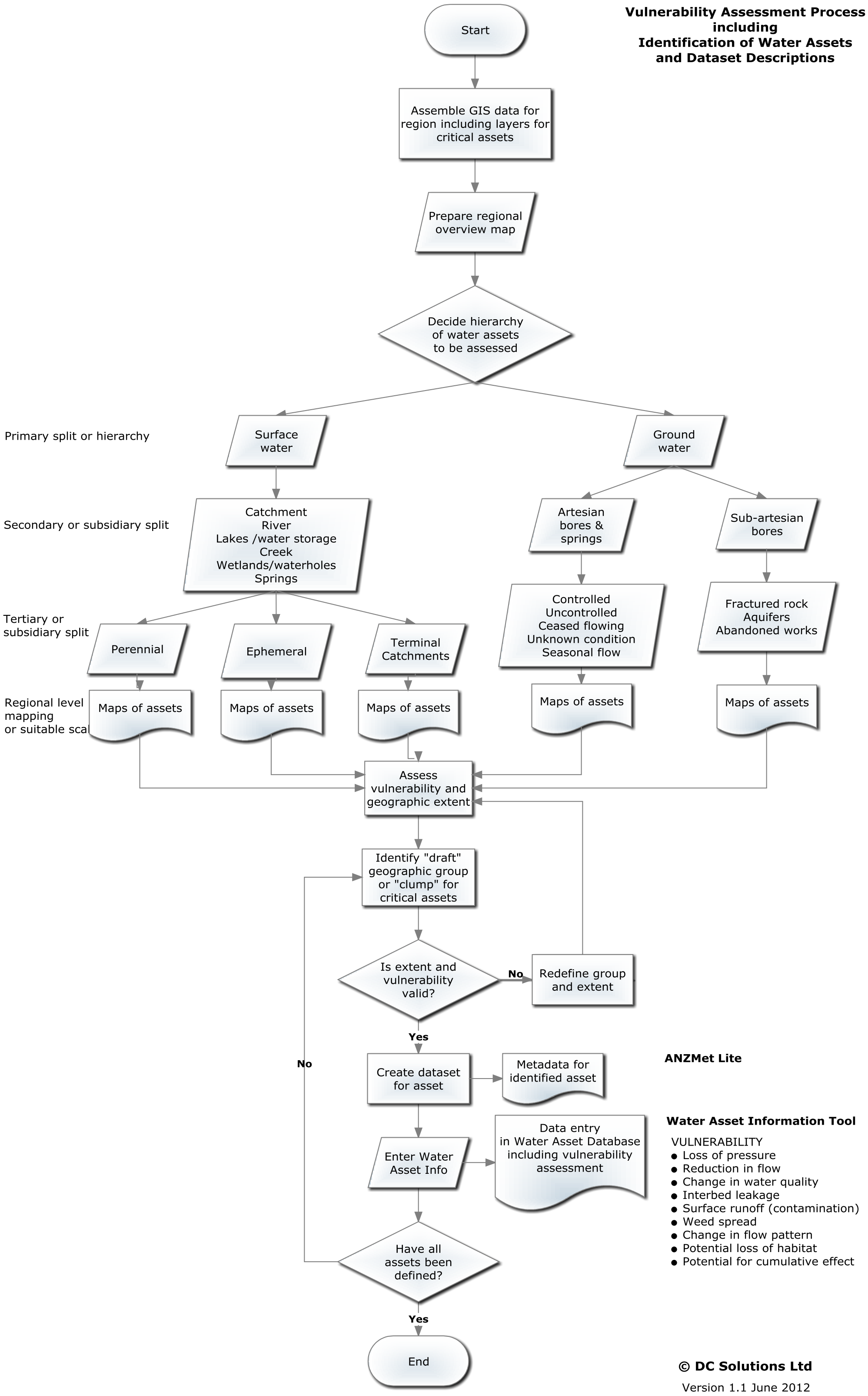


Figure 7 – Vulnerability Assessment Process

Information Identified and Recorded

Principal Datasets

The project identified a series of datasets that provide broad background information about the region. While not containing specific information about an asset, these inform discussions related to vulnerabilities. Rainfall data, for example, determines river flow information and, therefore, recharge of waterholes. When rainfall is combined with soils and vegetation information, key areas are able to be identified. This information established the baseline for the area but does not identify specific assets.

Three principal datasets identified locations for each of the major water assets:

- Queensland Government Groundwater Database (GWDB)

This database records location, type of facility, status, stratigraphy and aquifer information and water quality for both artesian and sub-artesian bores. Not all bores have all data fields populated, however, for the DCQ region over 8,000 bore records were accessed.

- Lake Eyre Basin Waterholes Study

This study, conducted by the Queensland Herbarium, identified the distribution and permanency of waterholes, springs, rockholes and lakes in the Queensland and South Australian sections of the Lake Eyre Basin. Data was collected in 2008-2009, mostly from surveys of people with long-term knowledge of certain water bodies. Wetland mapping programs in both states provided the baseline data for waterholes and lakes while springs data was compiled in 2005. The original dataset was compiled in 2009 and some of the data has subsequently been incorporated into Wetland*Info*.

- Queensland Government Wetlands Information Database (Wetland*Info*)

Wetland*Info* is a web-based database of Queensland wetlands information obtained through the joint Australian and Queensland governments' Queensland Wetlands Program. The data includes location of wetlands, springs and streams with wetlands classified according to extent, permanence and status.

Most data was fairly recent (2009), however, much of it is based on either bore logs (in the case of groundwater data) or satellite photograph based mapping with some ground-truthing. Consequently, the accuracy and reliability of the data must be considered with those factors in mind.

Nine datasets were developed which were used to identify the water dependent ecosystems and surface water and groundwater assets within the DCQ region, and to compile information required in each of the databases provided by the Commonwealth.

Each derived dataset is the product of a data query defined by the methodology described above and all are presented schematically in the figure below. The metadata file name is appended for completeness.

All data was entered into spreadsheets utilising the field names and format from the MS Access database (Water Asset Information Tool). The data was then merged into a single database once the datasets were complete. This allowed for the detailed analysis of the data concurrently, with GIS data presentation and analysis of trend information.

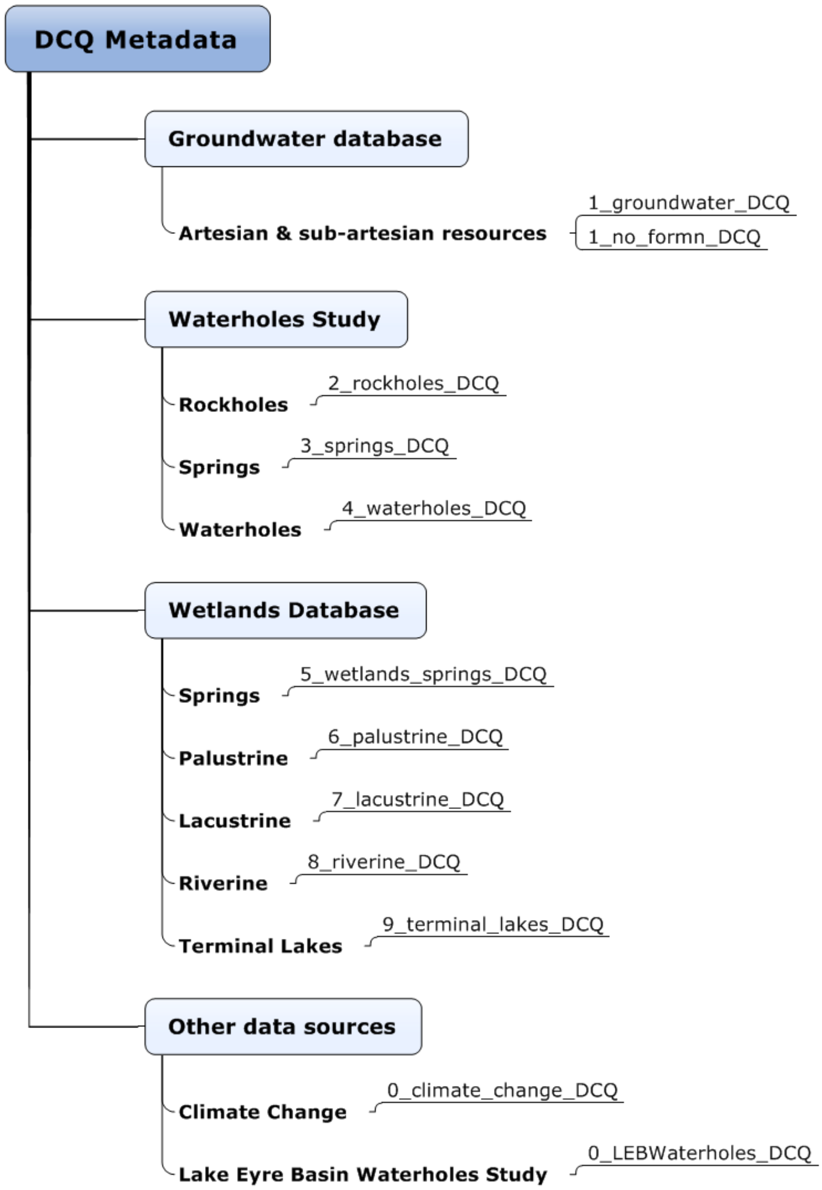


Figure 8 - Derived Datasets

For each of the assets identified in the datasets shown above, the information required by the Water Asset Information Tool was entered directly. Examples for the DCQ region are described below:

- Asset Name

The unique name of the particular asset e.g. reference number (RN) for bores, spring or rock hole name (if it exists)

- Description

A brief description (e.g. artesian bore, rock hole) of the particular asset

- Water Body Type

The type of water body the asset relates to – in the case of bores, *aquifer*; for springs and waterholes, the type of wetland created e.g. *Permanent freshwater marsh/pool*

- Map Sheet

The 1:100,000 reference map the asset is located within e.g. *Marion Downs*

- Environmental Value

The environmental value determined by the project team based on the asset and its location – e.g. for a Group 3 bore - *Low environmental value as the asset is a controlled point source of water and this water is not available to supply water dependent communities*, or for a spring - *The asset is recognised under the EPBC Act and the Nature Conservation Act 1992 and has native species dependent on discharge of groundwater from the GAB*

- Economic Value

Determined by the project team and dependent on the primary usage of the asset and/or its state - for example, bores may be *Very high economic value as the asset is the primary water source for the property, supplying stock water and domestic supply* or *Low economic value as the asset is no longer operational*. Due to their nature, springs are likely to have a lower economic value - *The asset has limited economic value with primary economic value being as a water source.*

- Social/Cultural value

These values again relate to their human use and vary, in the case of bores, from *Low value as the works have been abandoned and there is no record of cultural use of the site* to *High social value as the asset supplies property water needs, however, there is no record of cultural use,* while with springs, both the European and pre-European importance of springs in an arid environment means that springs normally have *Historically high cultural value which has been significantly reduced* or *Very high cultural values with historic use. This use is, however, poorly documented.*

- Hydrology

In many cases, hydrology can only be inferred - for example, for Group 2 bores: *Yield from these aquifers have a flow in the range 15-45 l/sec with a conductivity of around 1220 microseimens and a surface water temperature of approximately 56 degrees,* and for terminal lakes: *Terminal Lakes with recharge from ephemeral watercourses with a highly summer dominant river flow. Some documented links to groundwater recharge, however, water quality is consistent with historic evaporation of surface runoff from sedimentary formations. Very high evaporation rates cause concentration of salt, increasing conductivity results*

- Geology

With some bores e.g. Group 2, geology is known from core samples: "*These bores are intersecting Jurassic/Cretaceous sedimentary formations within the Great Artesian Basin. The formations include the major water bearing aquifers associated with the Jurassic Hooray formations and its sub groups, including the upper aquitard formations including the major unconformable surface and the formation making up the lower unconventional aquitard below". For further detail see report.* With springs, however, the geology may be inferred from its location and output: *Discharge spring from Cretaceous and Jurassic sedimentary formations for the GAB,* while with waterholes*: Naturally forming depression which has been sealed by silt layers. Waterholes are historic in age and stabilised by very low river gradients and rock outcrops.*

- Current Land Use

From the location of most of the assets, the predominant land use is *Grazing natural vegetation_Grazing natural vegetation Managed resource protection_Biodiversity,* however, for waterholes it is described as *Marsh / wetland_Marsh / wetland*

- Tenure

All assets in the region occur on *Private land other than aboriginal land*

- Condition

The condition of the assets is assigned as *Poor, Moderate, Good* based on local knowledge where possible, or on other information.

- Known Knowledge Gaps

Each asset is assigned a description of any particular knowledge gap that relates to it. These gaps are discussed further below.

- NWQMS Value

All bores are assigned the value *Primary Industri* (spelling in database) while springs and waterholes are assigned the values: *Aquatic Ecosystems Cultural and Spiritual values Primary Industri Recreation and aesthetics* because of their social, environmental and economic importance to the region.

Vulnerability Assessment

The vulnerability of the water asset is, by necessity a subjective analysis, but the process outlined below seeks to allow transparency in the way DCQ determines this key factor. Three key components are taken into account for an asset's vulnerability;

1. The potential causal factor of the development
2. Proximity to the disturbance
3. Mitigations possible

Methodology

A simplified table used by DCQ to water asset vulnerabilities is presented in Appendix 1.

The analysis was based on an assessment of the asset vulnerability to disturbance by coal seam gas and coal mining activities due to the effects of such potential causal factors as:

- For groundwater

a) Loss of pressure or loss of flow
b) Inter-bed leakage
c) Change in flow pattern
d) Change in water quality

- For surface water

a) Reduction in surface flow
b) Surface run-off (contamination)
c) Weed spread
d) Potential loss of habitat

- Proximity to disturbance

Each asset is either inside the target basins or outside. This is, however, not a clear demarcation due to lateral connectivity, in the case of groundwater through linked aquifers, or with surface water through transmission lines such as watercourses. Nevertheless, it is still possible to assume correctly that vulnerability will diminish with increasing distance from production wells.

In all cases, vulnerability has been assumed as the cumulative impact of production wells and coal mines, rather than specific site impacts.

This methodology is comparative to recent assessments in the Surat Basin where cumulative impacts were considered in initial planning stages.

- Mitigation Possible

In all cases vulnerability only translates to causal effect due to a series of failures.

The vulnerability assigned to each asset will translate into causal effects due to poor construction techniques used on production wells and unconformities being breached or porous, leading to interbed leakage.

For this reason, vulnerabilities can remain high, and mitigation is listed. Examples from the Surat and Bowen basins have demonstrated significant intersection and drawdown losses within aquifers where unconformities are breached.

There are also significant numbers of spring groups within the exploration and expected production areas. In many cases there are knowledge gaps relating to basic information such as source aquifer. At this stage there is no known mitigation except artificial recharge. For this reason, along with the unique flora and fauna associated with these springs, they are consistently listed as vulnerable.

Surface water bodies are protected, or impacts mitigated, by both the scale and the type of impact that occurs. Impacts expected from CSG activities are primarily centred on contaminated runoff and the introduction of weed species. Contamination and weed species may well be linked if waste water is discharged into watercourses, thereby changing the normal ephemeral water cycle.

In the case of coal mining, primary effects again relate to surface water contamination, but also to loss of flow due to potential diversion of watercourses to protect the mine and its ancillary sites.

All of these factors are taken into account to determine the overall potential for a cumulative effect on the asset with a vulnerability rating assigned accordingly.

Groundwater Assets

The main water beds of the GAB, the Upper Cretaceous formations and alluvium formations are well separated from the target CSG and coal bearing beds by major unconformities. While vulnerable, this vulnerability diminishes with vertical separation from the target beds. It is also recognised that the sedimentary, metamorphic and igneous intrusions of the western margins are geographically well separated and have been grouped as low vulnerability but, in reality, this vulnerability is considered non-existent.

A total of five groups were identified, with two groups comprising Great Artesian Basin elements, one group being surface formations (e.g. alluvial sediments potentially impacted) and a fourth being a catch-all between overlying confined aquifers within the Eromanga Basin and formations outside the Eromanga Basin. The fifth Group comprised those bores with no identifying stratigraphy or aquifer data. The logic is based on the geology of the Eromanga Basin, while the formations which were grouped in each category are listed in APPENDIX 2 - Bore Group Definition by Aquifer. This grouping conforms to an expected decreasing vulnerability from CSG and coal mining activities with highest vulnerability close to the target formations, and the lowest vulnerability works either laterally or vertically separated from the target formations.

The highest vulnerability assets, therefore, are active works intersecting the group of aquifers close to expected CSG and coal mining activities. This Group A series of formations have water assets which have been identified each with variable vulnerability. The highest vulnerability will be Group A assets inside the Galilee basin and which are pressure pressure-dependent. The lowest vulnerability assets are those extracting water from the Group D formations outside of the Galilee and Cooper basins due to their lateral and vertical separation from potential production wells. The total number of bores in each group is given in the table below and shown diagrammatically in the figure below and further explained in Appendix 2:

Group	Artesian	Sub-artesian	TOTAL
Group A	189	258	447
Group B	511	1037	1548
Group C	0	2054	2054
Group D	0	465	465
Group E	557	2937	3494
Total	**1259**	**6751**	**8008**

Group A Groundwater Assets

This group of Jurassic aged formations was defined as those older water bearing GAB sedimentary formations such as the Hutton Formation, which are relatively close to the likely coal and coal seam gas bearing formations. While separated by a major unconformity, and themselves confined aquifers, their limited vertical distance from the target formations makes them susceptible to loss of pressure and inter-bed leakage. These assets contain a large percentages of bores that have ceased to flow or have a declining pressure level, and are accessed heavily for primary production on the eastern and western margins of the GAB where these formations are shallow. The significant number of sub-artesian bores, combined with the number of ceased-to-flow and abandoned assets, gives a relative indication of the hydrological health of this aquifer system.

This group of assets has the highest vulnerability due to the strong overlap with, and relative proximity to, coal and CSG formations in the east and the Koburra Trough. It is highly likely that interbed leakage and pressure decline will occur if significant volumes of water are extracted from the Betts Creek and Aramac Coal measures, particularly on the eastern margins where the formations pinch.

There is a data miss-match showing in the map with the inclusion of works in the Dajarra area in this group. This is not correct and is caused by incorrect source aquifer classification.

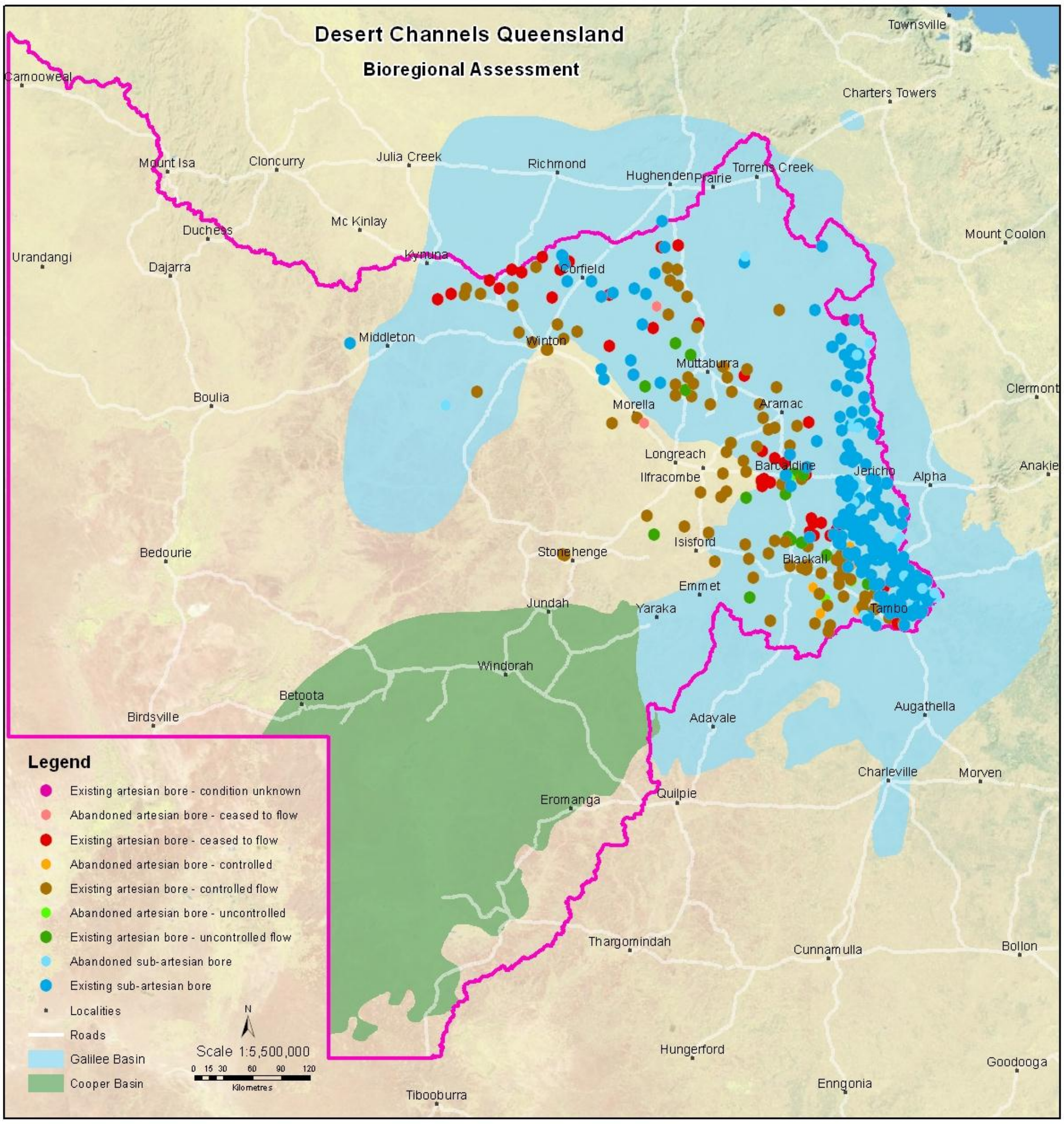


Figure 9 - Group A Groundwater Assets

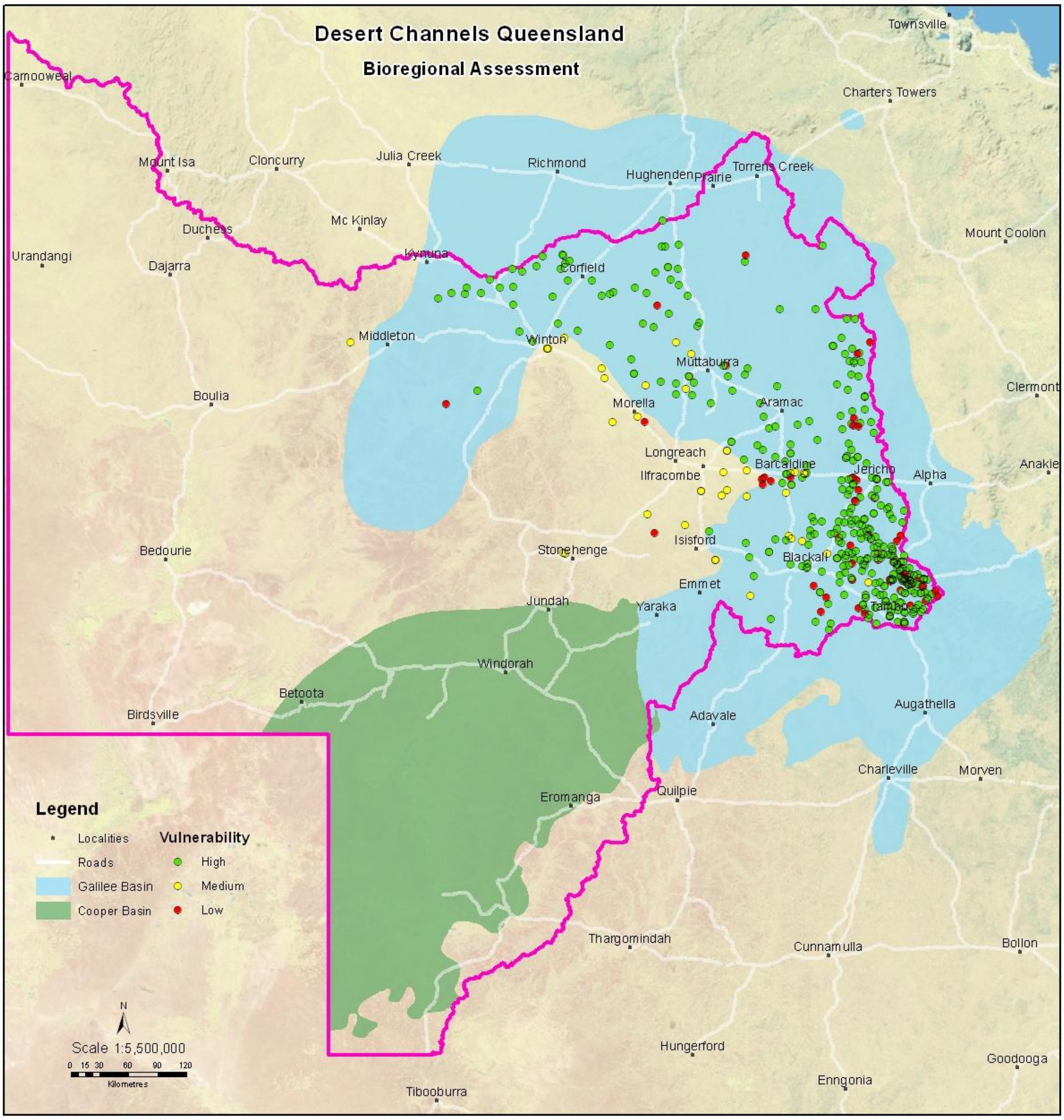


Figure 10 - Group A Assets – Vulnerability

The vulnerability map shows that the majority of assets intersecting these formations will be in the high and medium vulnerability categories, with the most likely effect being on water quantity. These categorisations correspond to works that are pressure-dependent, such as those controlled to tanks and troughs, or those under existing known stressors such as assets that have ceased to flow of have declining aquifer pressure levels.

Significant engineering works are underway through the Great Artesian Basin Sustainability Scheme to redress pressure declines and, therefore, protect flows to assets. Additional uncontrolled water extraction from linked aquifers may increase the stress on these assets.

Assets located outside the Galilee and the Cooper basins will, naturally, have a lower vulnerability due to distance from production wells.

Mitigation of the vulnerabilities will rely on construction standards used for production wells, limiting interbed leakage and monitoring drawdown effects of water extractions.

Group B Groundwater Assets

These assets are intersecting Late Jurassic to Cretaceous aged formations found higher in the sequence than Group A assets and separated by additional major uniformities. These younger and shallower main formations of the GAB (such as the Hooray sandstones) are confined and well separated from the main coal and coal seam gas formations and the lower Jurassic formations. Nevertheless, the assets are still susceptible to some interbed leakage as they are constricted and outcrop on the margins. While they have a lower vulnerability than assets in the deeper formations due to their vertical separation, the vulnerability remains medium/high on the eastern margins and close to known interbed leakage points such as the Cork Fault.

Due to their relatively shallow depth on the margins, high yields and pressure, these formations are accessed particularly on the margins where the formations shallow. As with the Group A formations, there are a significant number of sub-artesian bores located along the north/south outcrop lines of the water bearing formations and very close to the Koburra Trough. This, coupled with an existing pressure decline stressor, with large numbers of bores that have ceased to flow, makes this area of particular interest for additional investigation.

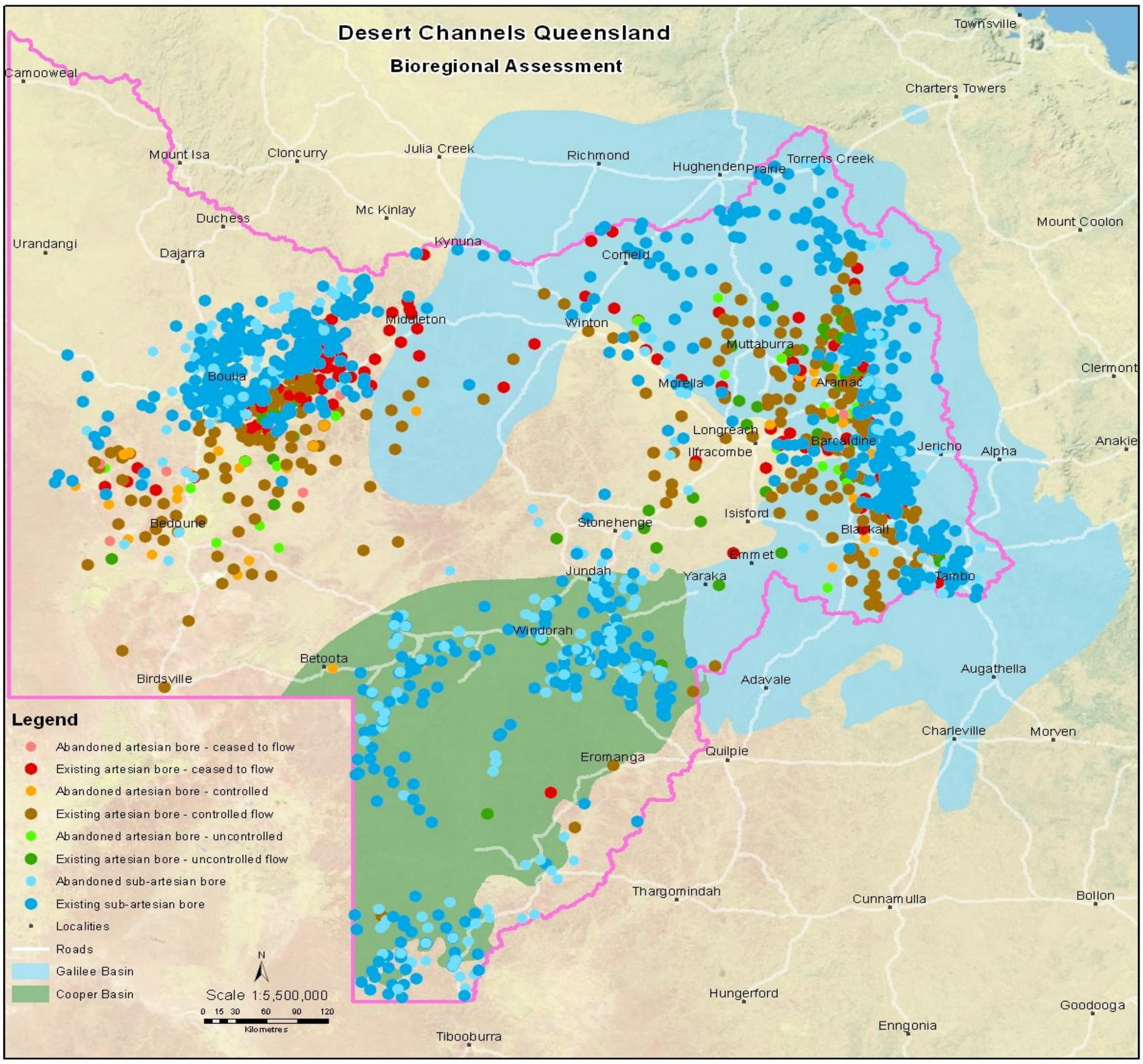


Figure 11 - Group B Groundwater Assets

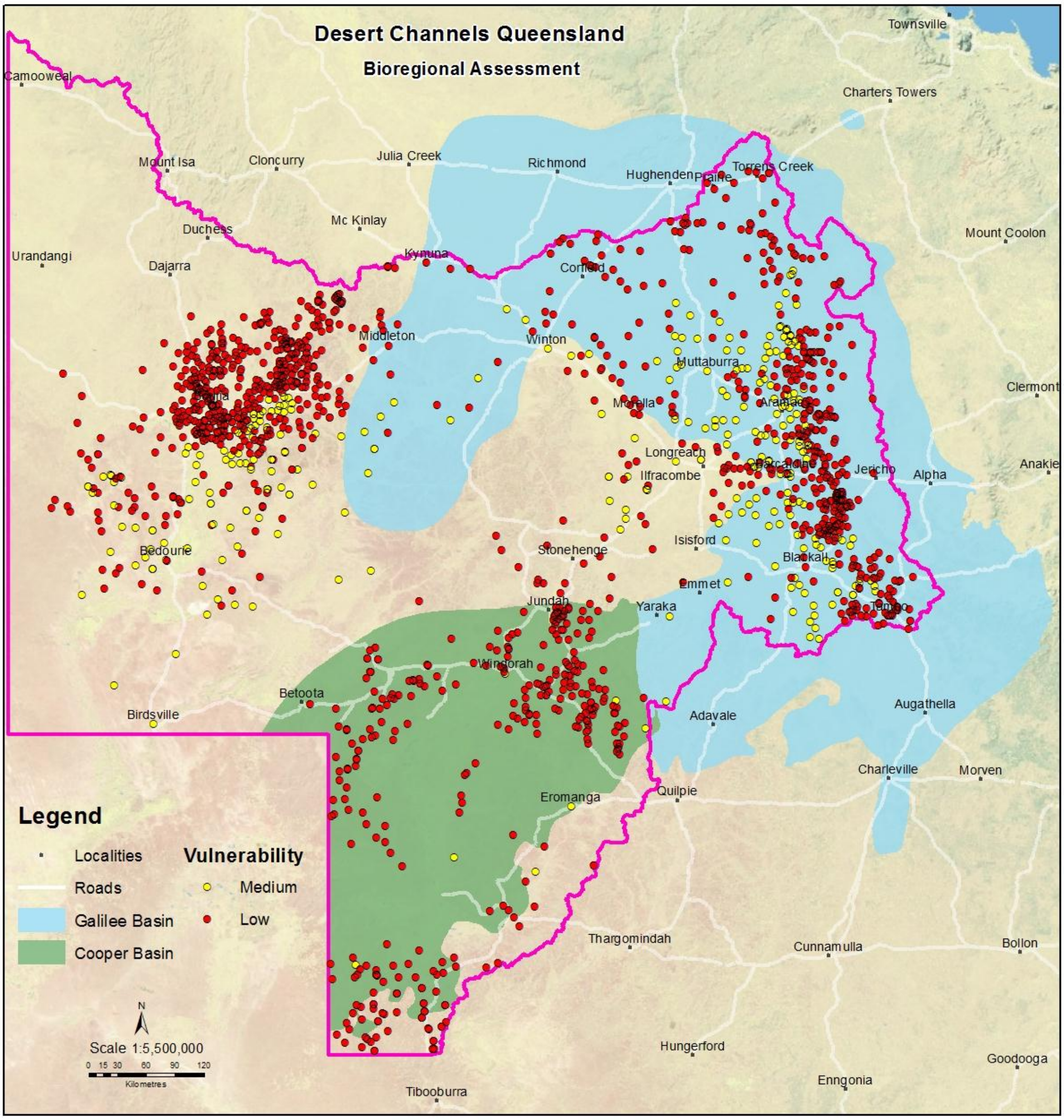


Figure 12 - Group B Assets – Vulnerability

The vulnerability map shows that the majority of assets intersecting these formations higher in the geological sequence, and further from production formations, will be in the medium and low vulnerability categories with the most likely effect being on water quantity. The medium categorisation corresponds to assets which are pressure-dependent such as those controlled to tanks and troughs and assets with know stress. The lower vulnerability assets are assets with no known current stress, or assets located outside of the target basins.

Significant engineering works are underway through the Great Artesian Basin Sustainability Scheme to redress pressure declines and, therefore, protect flows to assets. Additional uncontrolled water extraction from linked aquifers may increase the stress on these assets.

Mitigation of the vulnerabilities will rely on construction standards used for production wells, limiting interbed leakage and monitoring drawdown effects of water extractions.

Group C Groundwater Assets

Group C consists of formations that, because of their type or depth, are considered to have only a low vulnerability to CSG or coal mining operations. Examples are the confined cretaceous Winton and Mackunda formations. These formations overlie the Toolibuc formation (a possible shale oil target formation) and, while having a very large geographic extent, are generally very low yielding, and generally have very poor water quality which continues to decline with extraction. Recharge of these formations is poorly understood and works can have a relatively short life. The formations can be up to 300 m thick, but aquifers within the formations generally start at about 60 m depth, are very thin, low yielding and to gain sufficient yield even for stock watering, the asset generally has to extract water from multiple aquifers. This construction trend tends to exacerbate water quality issues.

Nevertheless, the assets remain strategically important in the Eromanga Basin because, as the main water bearing formations of the Eromanga Basin deepen towards the centre of the basin, they move out of the economic range of most landholders. These landholders, therefore, are highly dependent on assets intersecting these formations. The lack of alternative water supplies, bores with low yields, coupled with a low rainfall region, makes landholders with these assets particularly uneasy.

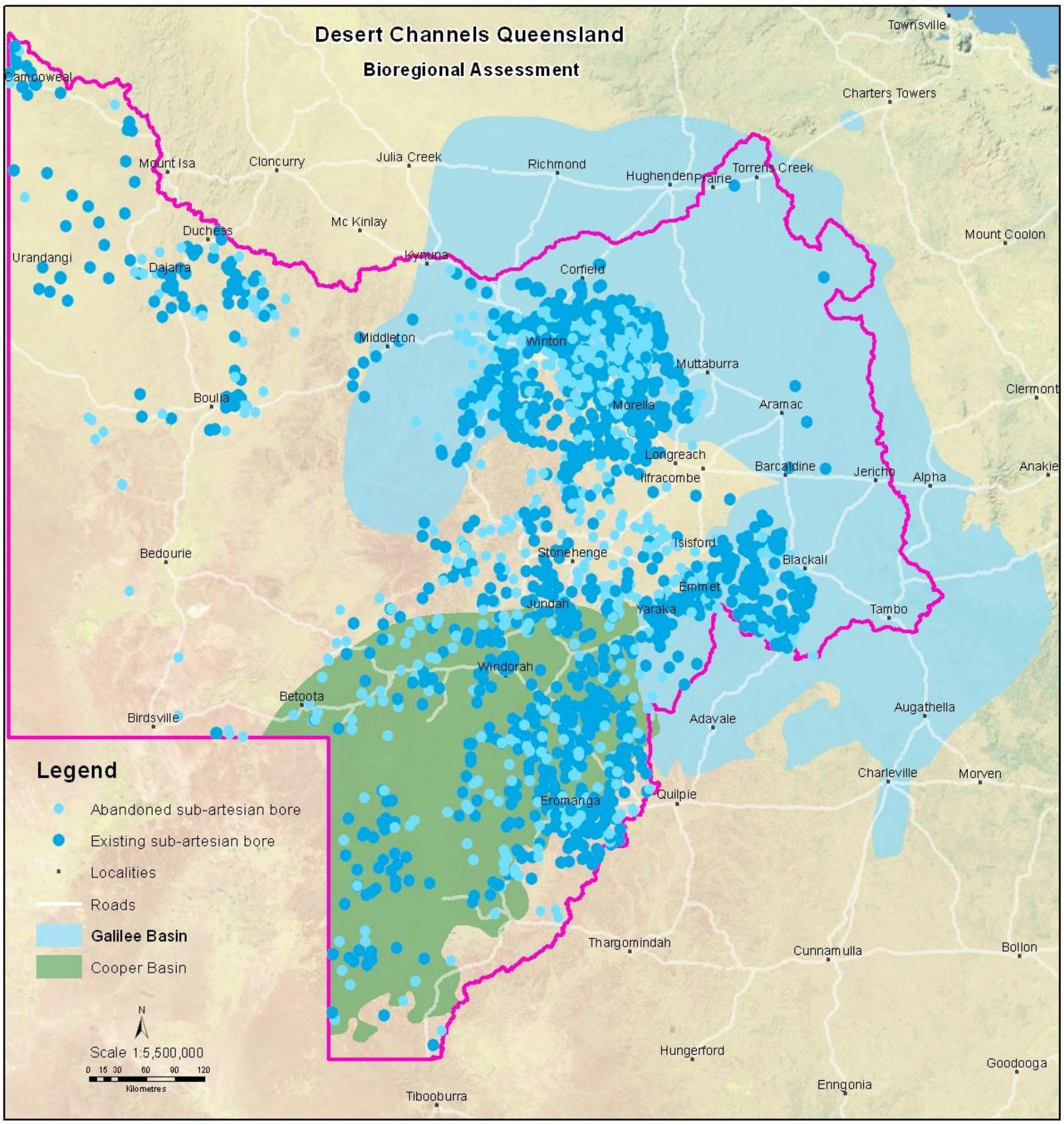


Figure 13 – Group C Groundwater Assets

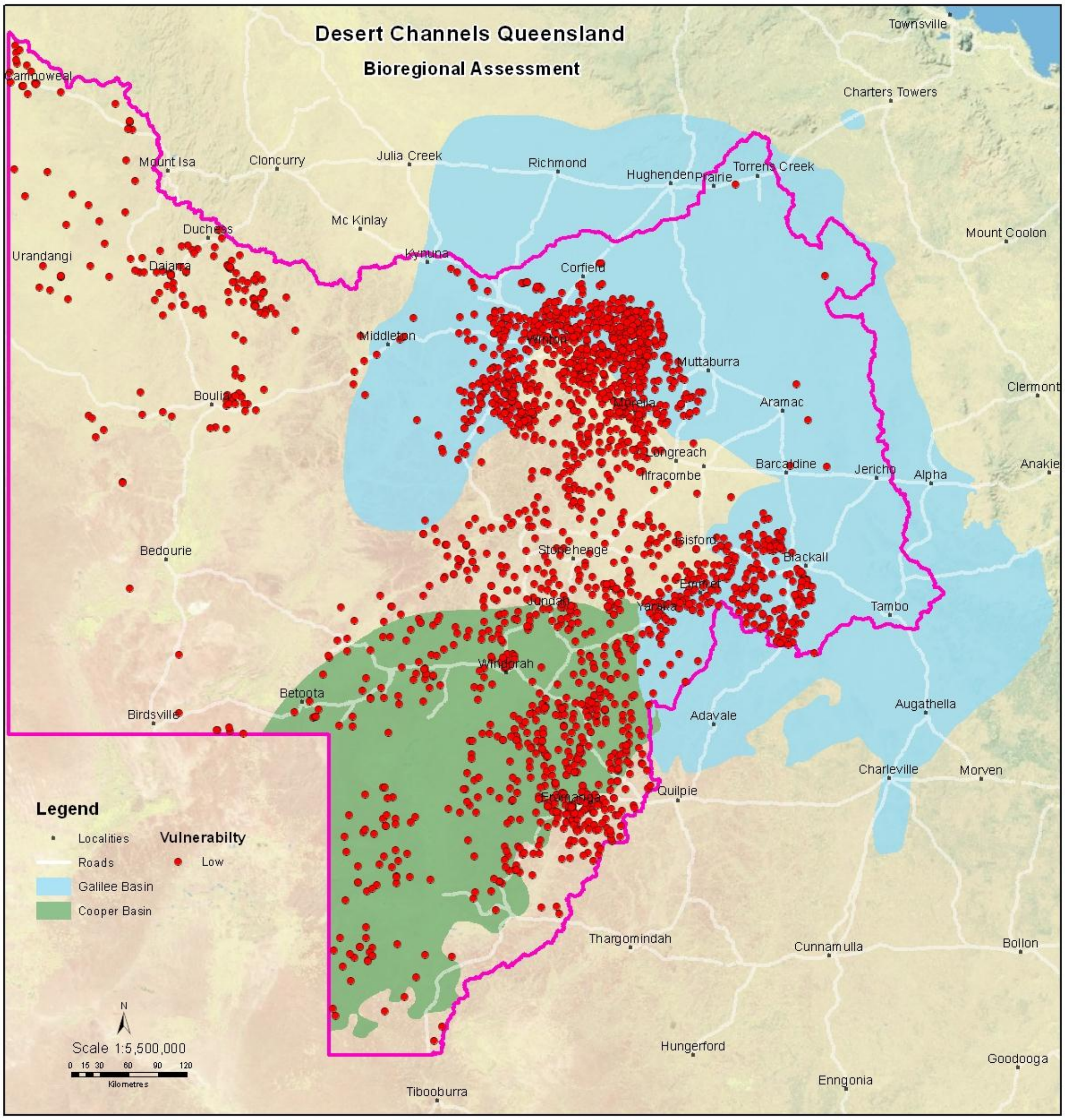


Figure 14 - Group C Assets – Vulnerability

These assets, intersecting formations high in the geological sequence or laterally separated from the likely production areas, have all been mapped as low in vulnerability from CSG and coal mining activities. These works are separated from the likely production formations by significant numbers of confined aquifers, multiple aquitards and unconformities. Interbed leakage from deeper beds to recharge these formations has not been established and, therefore, a low vulnerability has been assigned. The complex nature of the geology means that a linkage cannot be discounted and it is accepted that many of the assets in these formations are under stress due to water quality decline. However CSG and coal mining activities are unlikely to affect these assets.

Mitigation of the vulnerabilities will rely on construction standards used for production wells, limiting interbed leakage and monitoring drawdown effects of water extractions.

Group D Groundwater Assets

Assets in this grouping intersect shallow tertiary and quaternary formations, close to watercourses and vulnerable to water quality changes within alluvial aquifers. These assets are not vulnerable to water extraction from the CSG and coal mining formations, but represent the transition from assets with vulnerabilities due to ground water extraction, to those assets vulnerable to changes to surface water flow patterns, quantity and quality. Within the CSG and coal mining target areas, the majority of aquifers are confined to the far eastern margins. This is principally due to the geology of the Desert Uplands and the major drainage catchment of the Alice River which carries a heavy fluviate load of sand and gravel and, therefore, presents opportunities for shallow unconfined formations. Yields from these formations can be high but is highly dependent on recharge.

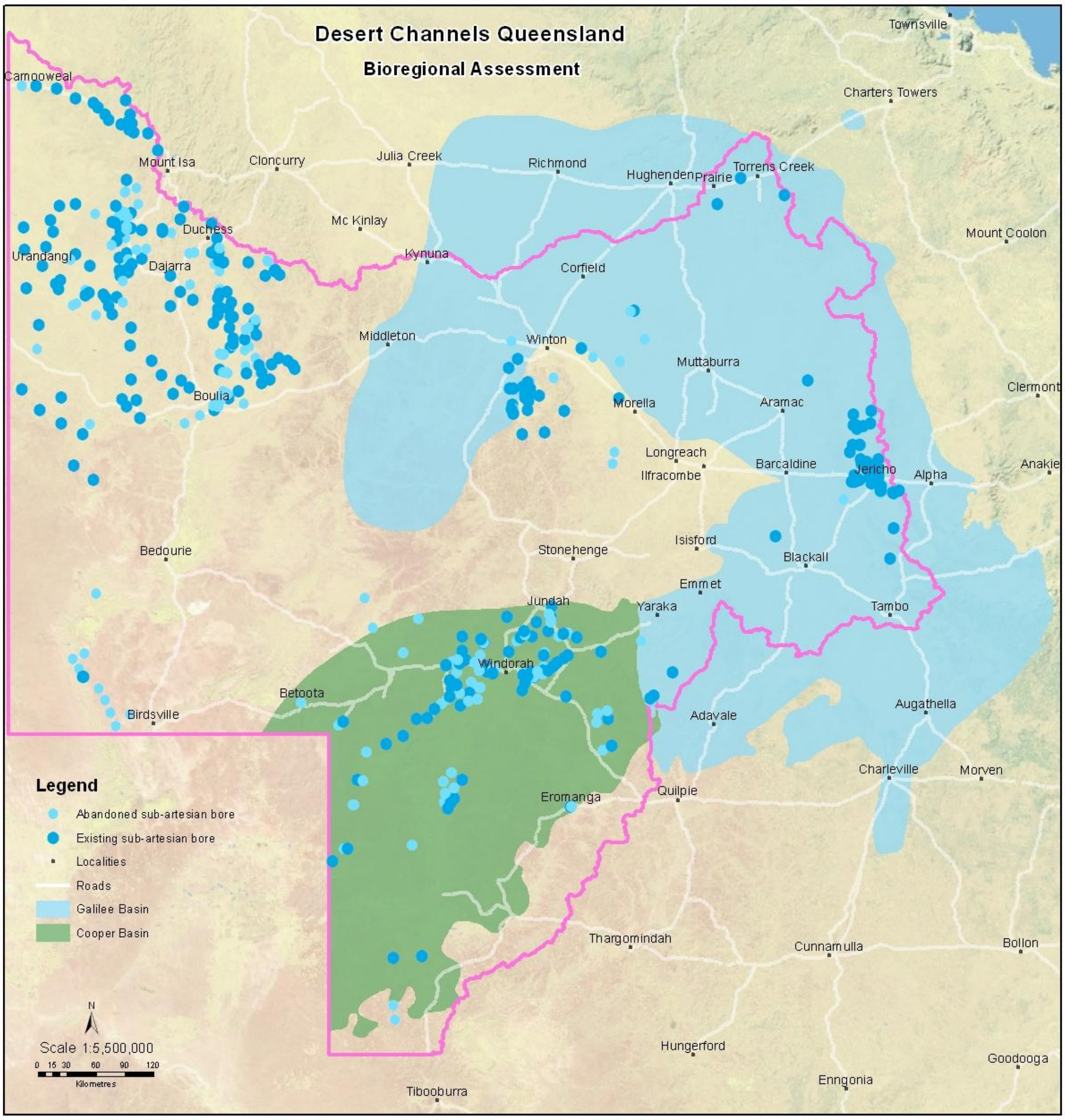


Figure 15 - Group D Groundwater Assets

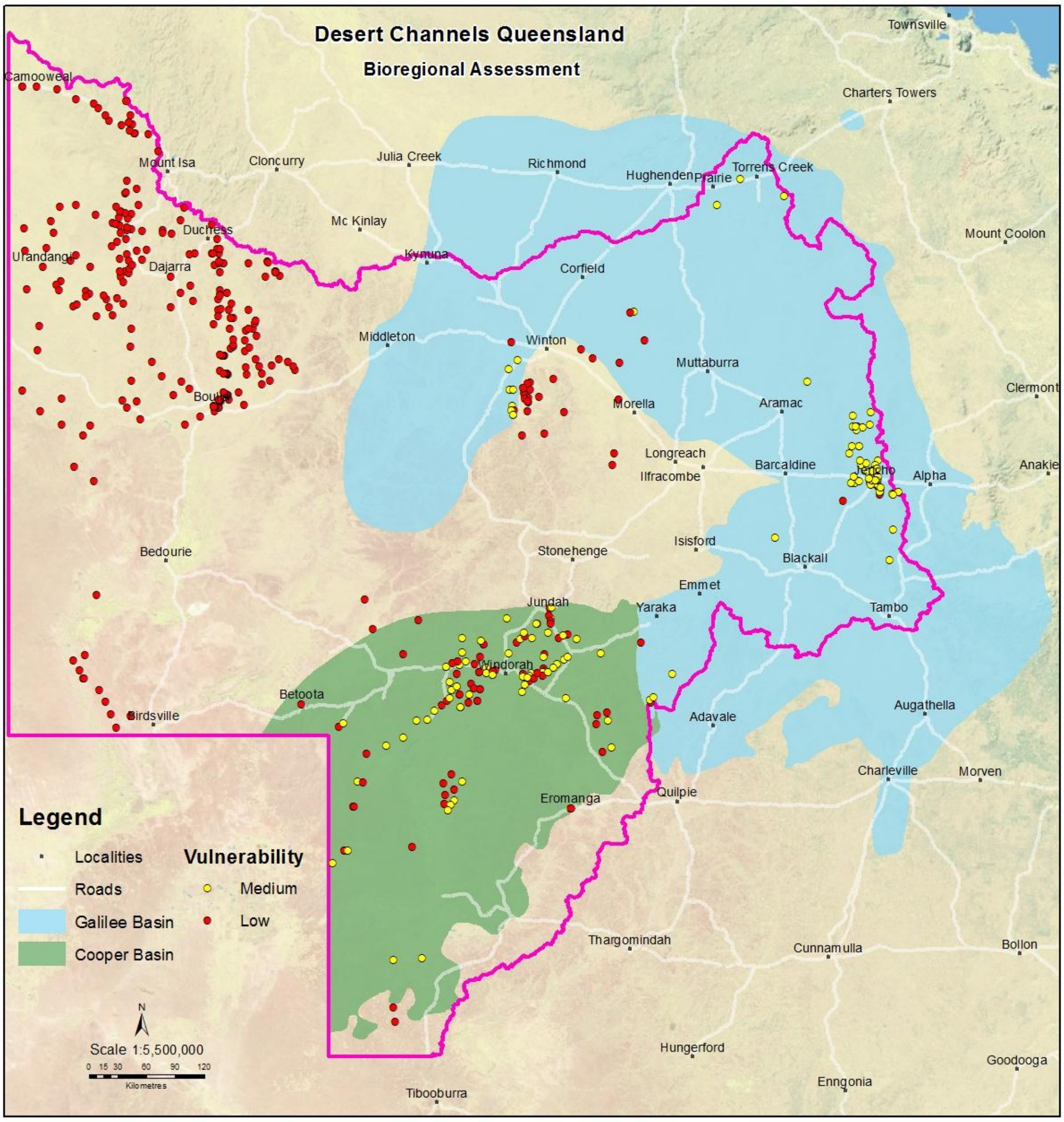


Figure 16 - Group D Assets - Vulnerability

The vulnerability map shows the assets intersecting very shallow geological formations and unconsolidated beds. These works have no linkage to deeper groundwater but are susceptible to changes in surface water patterns, contamination and water quantity.

Works within the Galilee and Cooper basins have the highest vulnerabilities and the concentration of assets in the Jericho area, close to establishing coal mining activities and CSG exploration are of significant interest.

Mitigation of the vulnerabilities will rely on construction standards used for production wells, limiting any uncontrolled discharge, water quality of any discharge and ensuring that surface water flows and patterns are not altered.

Group E Groundwater Assets

This grouping of water assets represents a significant knowledge gap as it consists of a large number of works without information on the aquifer or formation accessed. These works range in depth, are significant in number, and many are located within areas of interest. Overall, 41% of the bores in the database have no information regarding source aquifers. This is a significant data gap.

Due to the lack of detailed information about these works the vulnerability has had to be raised. However, through additional information being incorporated, it may be possible to better identify source water bodies and potentially lower the vulnerability of the assets.

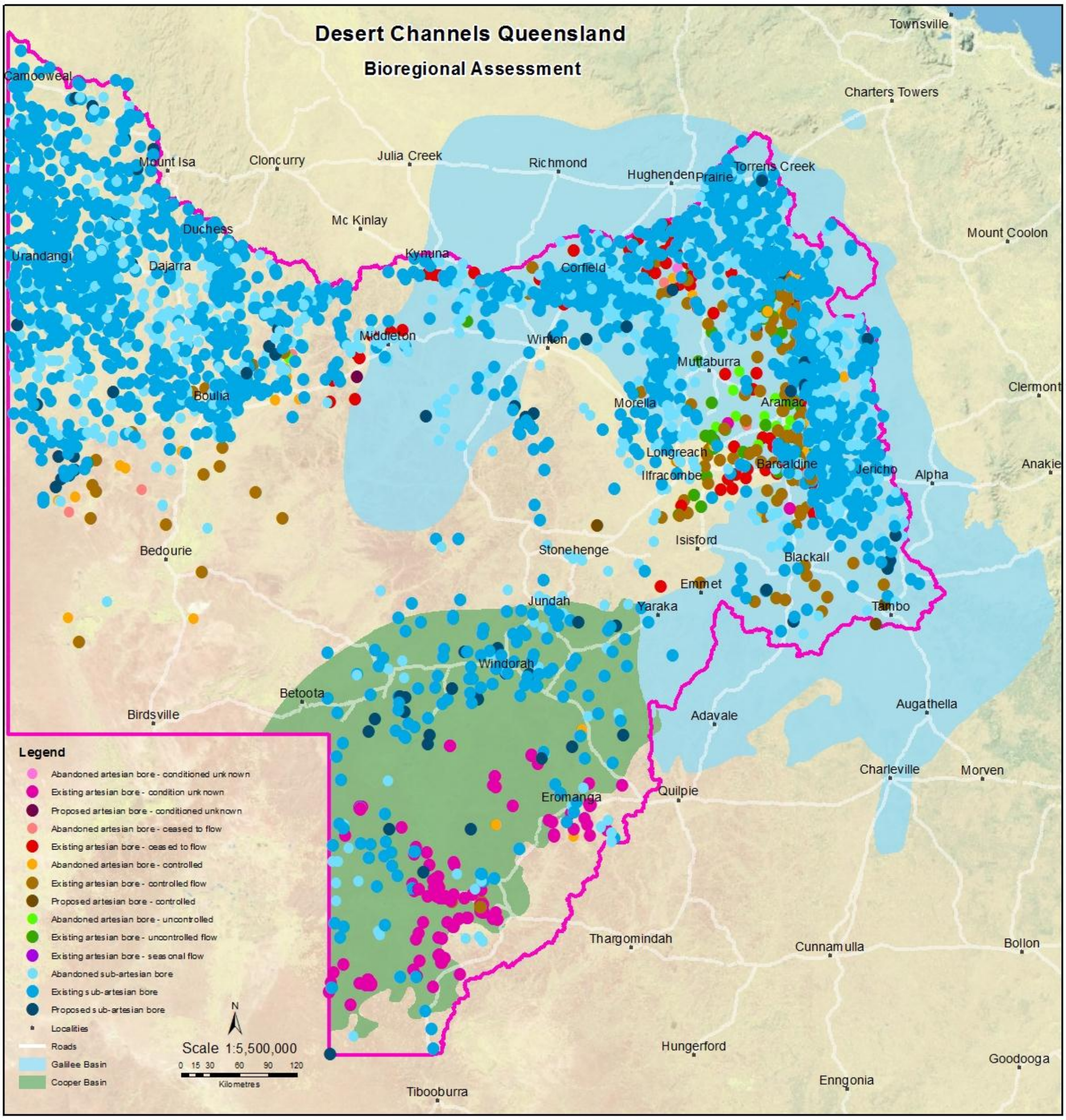


Figure 17 - Group E Groundwater Assets

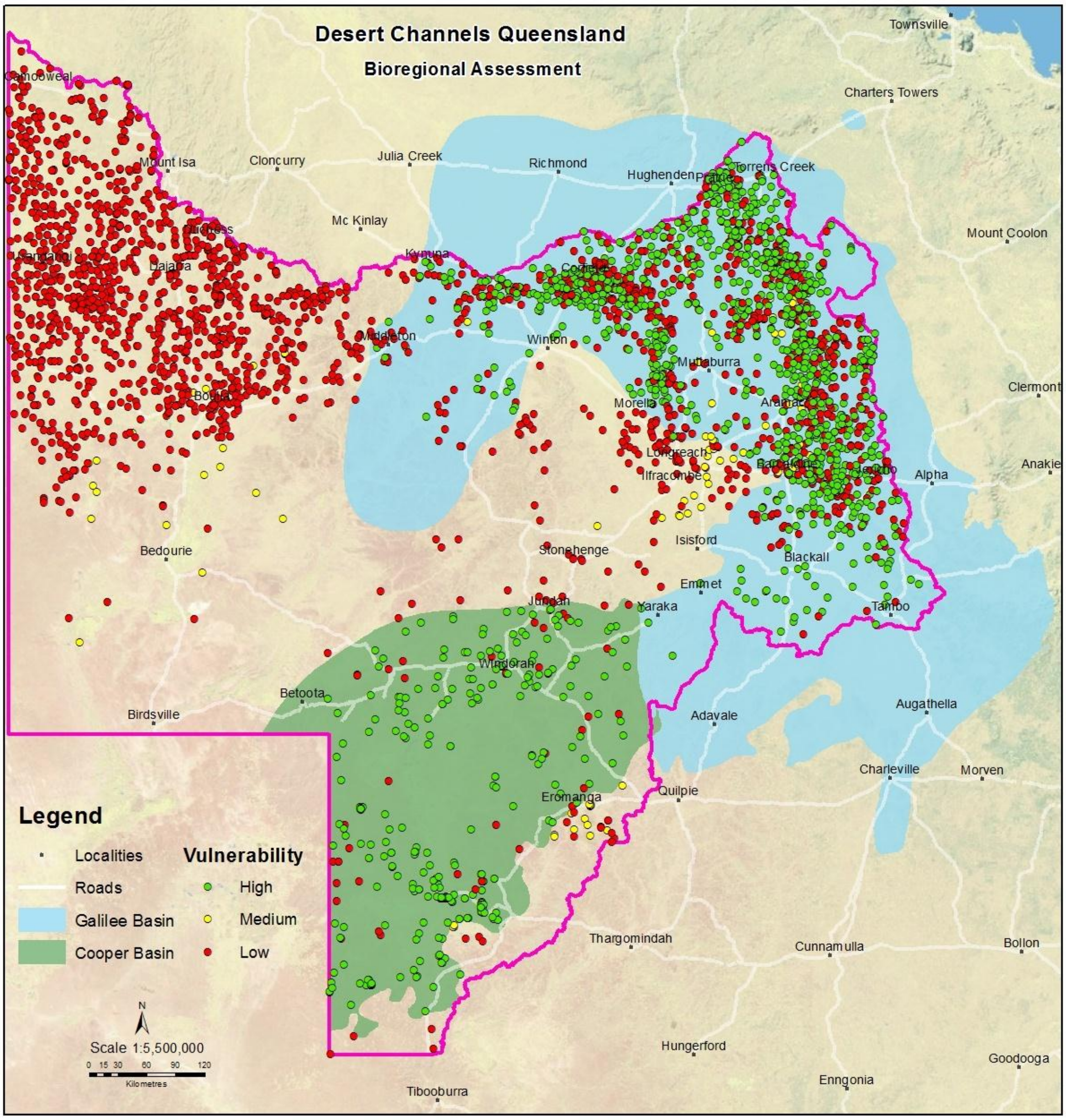


Figure 18 - Group E Assets – Vulnerability

This map, shows the vulnerability of works where critical source aquifer information is missing. These works will always have an elevated vulnerability, particularly where they are pressure-dependent and inside the Galilee and Cooper basins. Further investigatory work with these assets may better categorise the assets into the above groups (A-D), thereby better mapping their vulnerability.

Obtaining more information about the heavy concentration of assets within the Galilee Basin must be an initial high priority for further work. This additional information, particularly for works that are pressure-dependent or under stress, will allow for a better understanding of the true impacts of CSG and coal mining activities on these assets. The pressure-dependent assets (those listed as medium to high vulnerability), particularly the artesian pressure-dependent assets, will naturally fit into Group A or B due to their location in the landscape and the underlying formations in the area. The lower vulnerability assets are assets with no known current stress and are likely to be in Group C and could be discounted from initial further investigatory work.

Mitigation of the vulnerabilities will rely on construction standards used for production wells, limiting inter-bed leakage and monitoring drawdown effects of water extractions once source aquifer is known.

Spring Assets

There are three basic type of springs noted in the region. Riverine springs, supporting important riverine habitat, and recharge and discharge springs supporting highly endemic biota with international recognition.

As expected, the recharge and discharge springs are associated with landform and slope changes where formations are exposed or pressure surfaces cause water flow. There is a strong concentration of springs on the eastern margin associated with slope and landform changes. Of particular interest is the north-south line of springs (east of Aramac / Barcaldine) that align with shallowing aquifers of the Eromanga Basin, and changes in landform from the Desert Uplands to the rolling downs. These springs are known collectively as the Barcaldine Supergroup (Silcock (2009)). The combination of a number of inactive springs and ceased-to-flow bores points to changes that have occurred in GAB flows and pressure levels over time. The distribution of these assets (and the biodiversity supported by many of them) points to an area of particular interest for further work.

The key knowledge gap for springs relates to the lack of any information regarding the source aquifers. Consequently, springs have been assigned a high vulnerability to any development that may affect any aquifer.

It is also known, but poorly documented, that these assets have a long cultural history. Further work is required to fully understand this association.

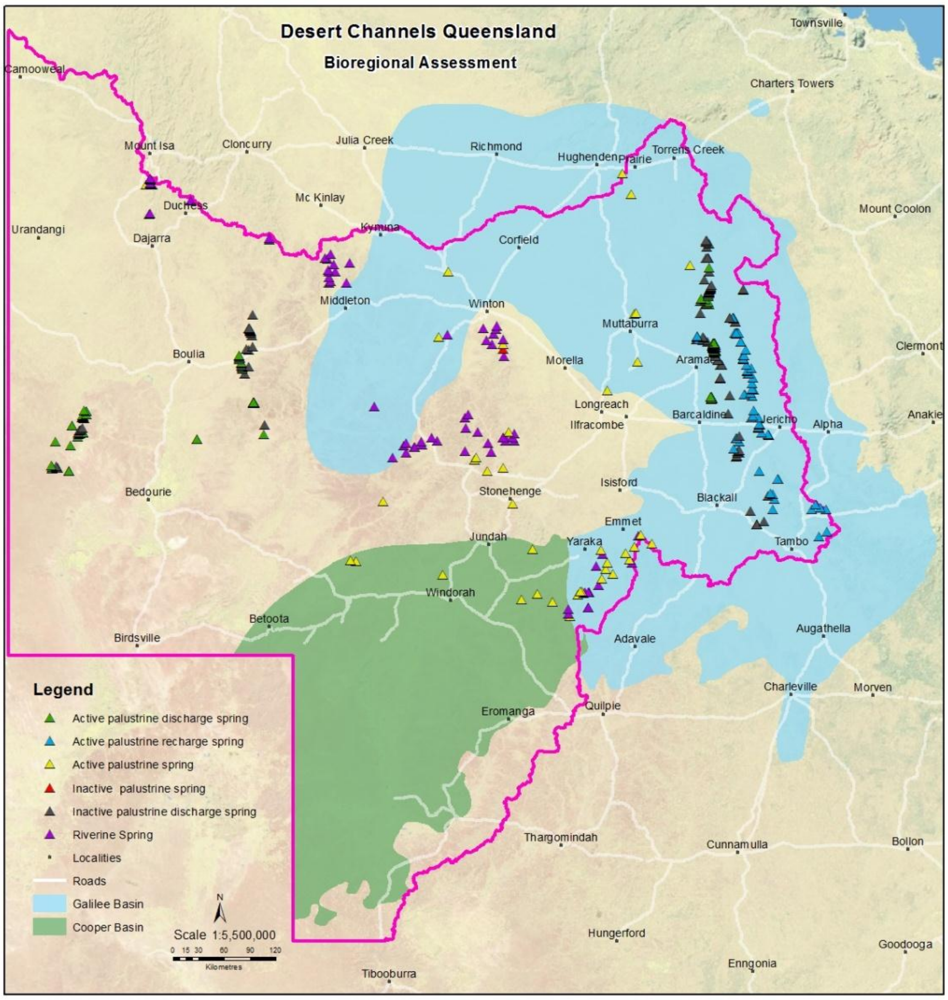


Figure 19 – Spring Assets

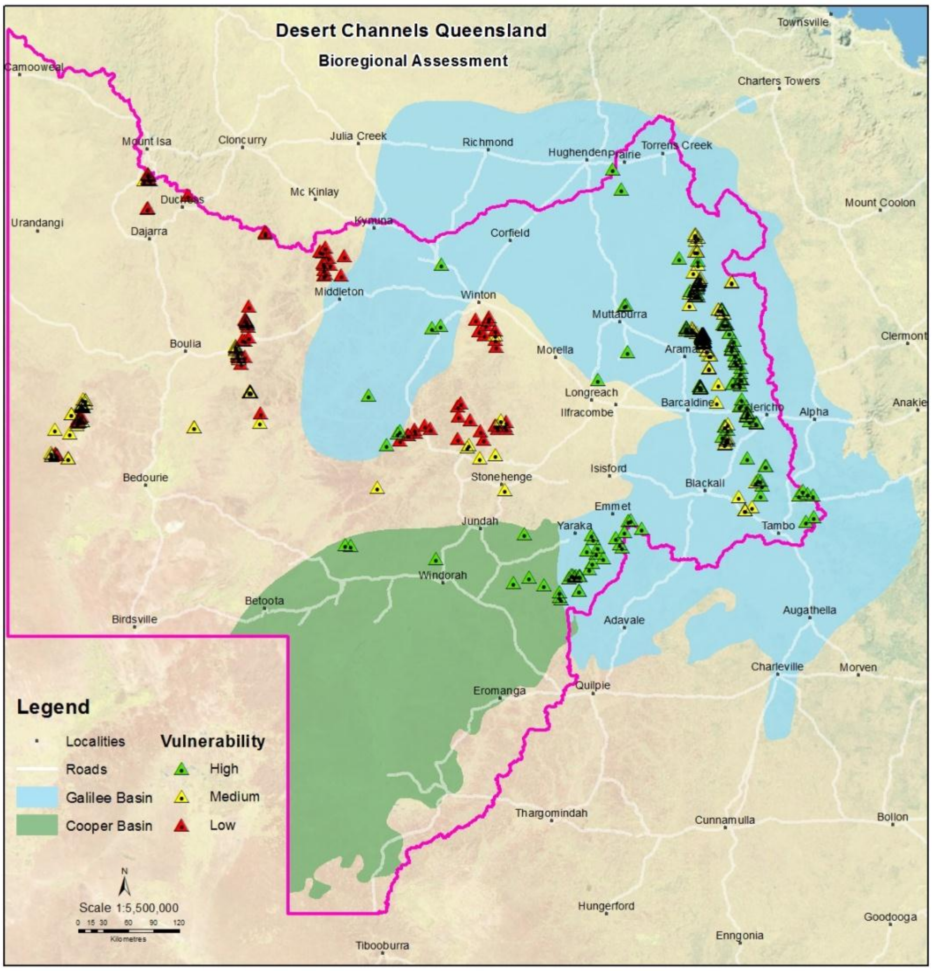


Figure 20 - Spring Assets – Vulnerability

The vulnerability map shows that the majority of highly vulnerable assets are located within the Galilee Basin as would be expected from the underlying geology. These springs, many of which have knowledge gaps related to source aquifer, are unique ecological features with significant legislative recognition and protection.

The highest vulnerability rating has been applied to assets where knowledge gaps exist, are surrounded by springs that have ceased to flow and are within the Galilee Basin. Many of these assets are also very close to the Koburra Trough and its expected intensive development.

The vulnerable nature of the habitat has caused the elevated rating and, while water quantity from the source aquifer drives the spring health, the main effect mapped is that related to habitat. Assets which have ceased to flow and habitat has been lost have a lower vulnerability rating.

Significant engineering works are underway through the Great Artesian Basin Sustainability Scheme to redress pressure declines and therefore protect flows to assets such as springs. Additional uncontrolled water extraction from linked aquifers may increase the stress on these assets.

Mitigation of the vulnerabilities will rely on construction standards used for production wells, limiting inter-bed leakage and monitoring drawdown effects of water extractions.

Surface Water Assets

As outlined above, the study also investigated surface water assets in terms of their vulnerability to development impacts. The ephemeral nature of many of the surface water assets means that while they may have low vulnerability to the direct impacts of CSG development, they are likely to be vulnerable to impacts such as contamination from surface run-off, change in flow patterns and weed spread. The maps below identify the areas at risk from these potential impacts.

Rockholes

Rockholes form primarily in sandstone or other rocky ranges and form semi-permanent and permanent water bodies following rainfall. While most rockholes are ephemeral, retaining water for up to several months, a small but important minority are permanent, with consequent importance to flora, fauna and historic cultural and social usage. The distribution of rockholes shown is described fully in Silcock (2009). With the exception of the cluster in the northern Grey Range (shown as the cluster south of Yaraka) most rockholes are outside the primary area of interest and hence are considered of low vulnerability.

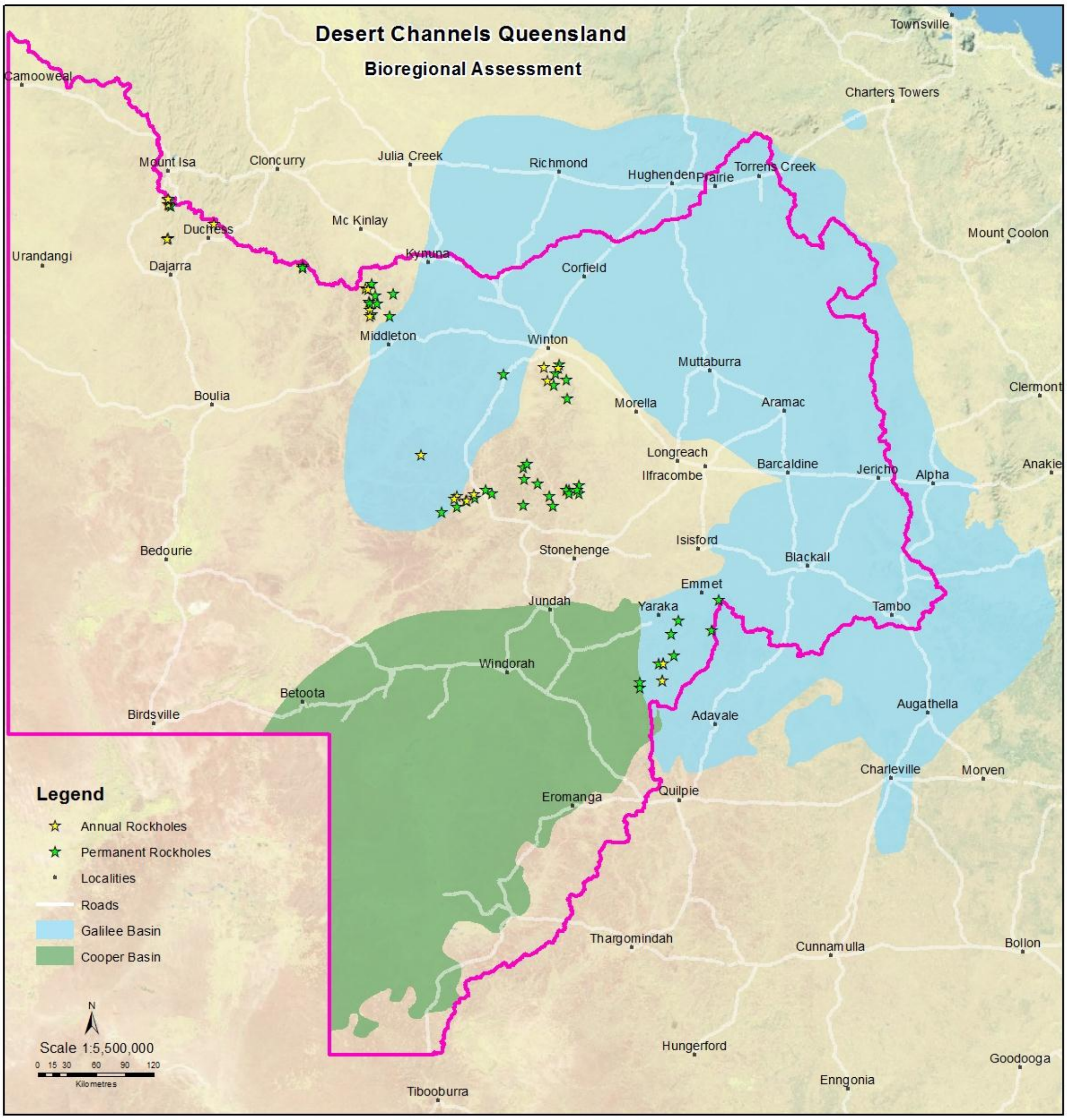


Figure 21 – Rock Hole Water Assets

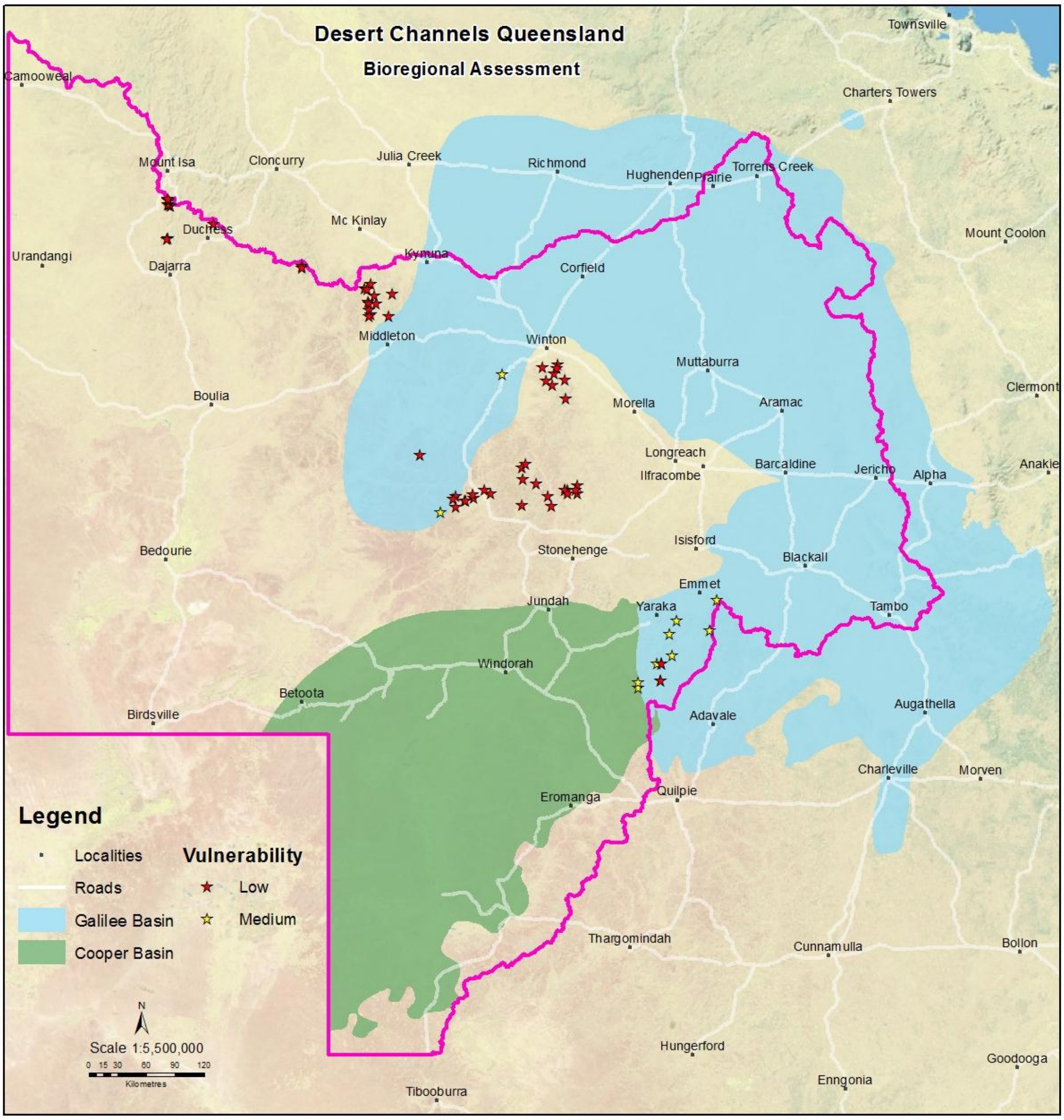


Figure 22 - Rock hole Assets – Vulnerability

The most vulnerable rockholes will be those that are permanent and within the Galilee Basin and, therefore, may be susceptible to loss of water quantity through diversions. These assets have long cultural histories and support unique biota.

Source water is by overland flow and it is expected that mitigation will be relatively easy, as would protection from contamination.

1. Lacustrine Water Bodies

Lacustrine water bodies are defined as primarily floodplain lakes with a surface area greater than 8ha. These water assets can be semi-permanent, usually forming following flood events, or permanent. With the exception of the terminal lakes system in the northeast part of the region (lakes Galilee and Buchanan) most of the lacustrine water bodies are located outside the primary area of interest or in the lower section of the Cooper Basin. As ephemeral systems, those located within the Galilee and Cooper basins are potentially vulnerable to changes in surface flow and run-off contamination, and are rated as high vulnerability to those threats. Lake Galilee and the surrounding terminal lakes are considered separately due to their unique ecology.

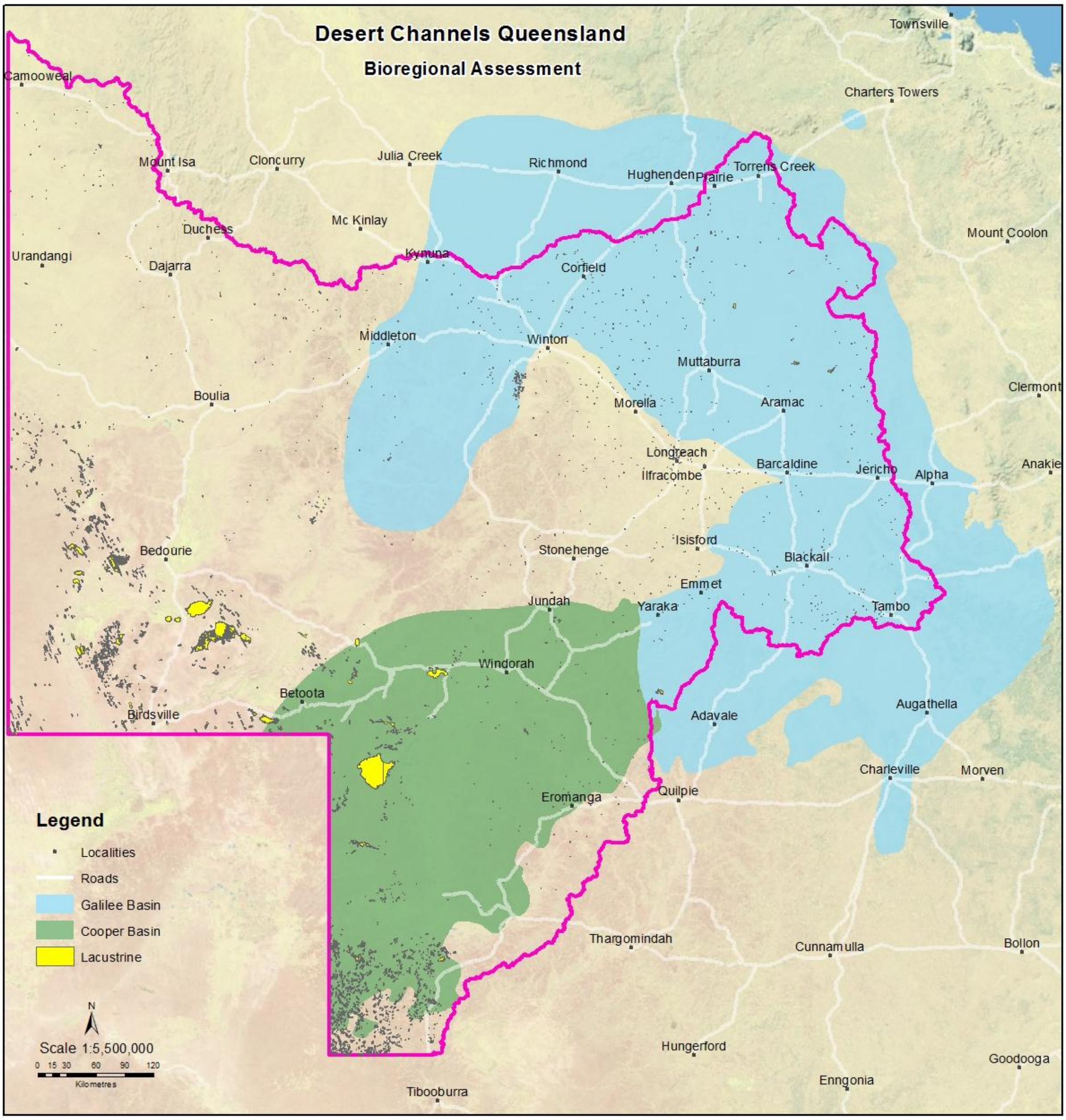


Figure 23 - Lacustrine Water Assets

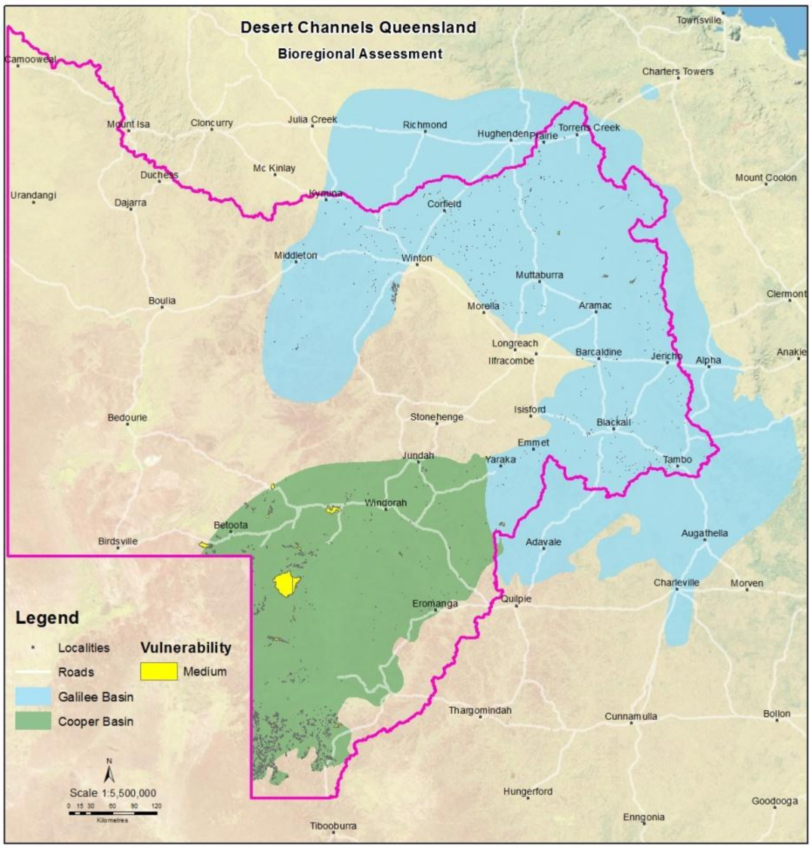


Figure 24 - Lacustrine Assets – Vulnerability (Medium)

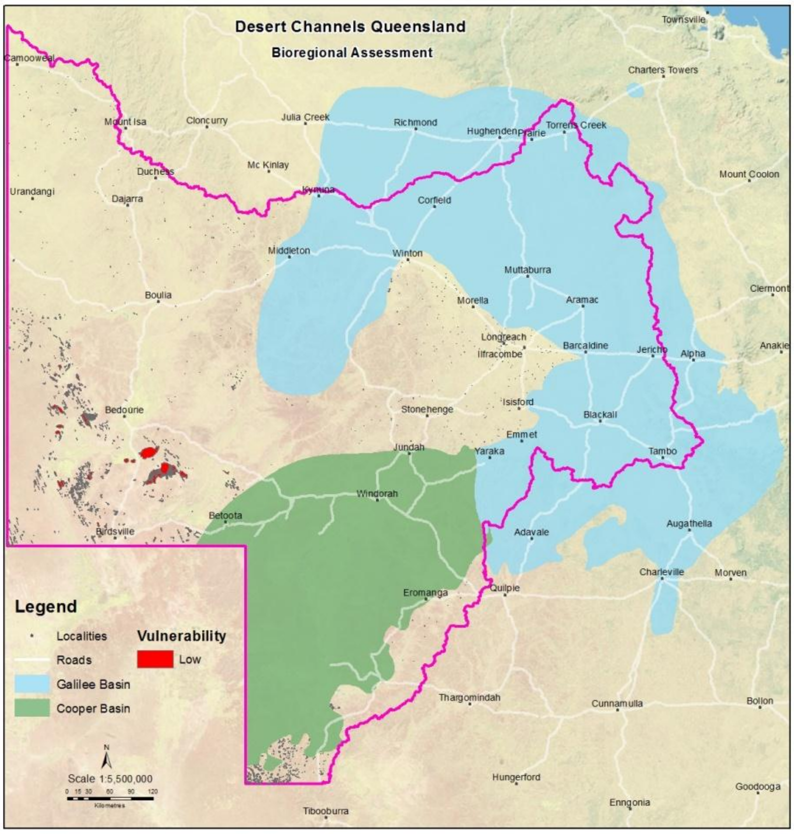


Figure 25 - Lacustrine Assets – Vulnerability (Low)

The vulnerability mapping has been applied broadly, with assets inside the Galilee and Cooper basins having a higher vulnerability than those assets outside the basins. These water assets represent a refuge for species during extended periods of limited or no surface water flow. The relative impact of CSG and coal mining is expected to be small, and only through diversion of surface water, changes in flow patterns and potential contamination. Examples of contaminated discharge from the Surat Basin suggest surface water contaminated discharge releases from the CSG industry are relatively small in volume and localised.

Disposal of waste water also represents a threat, and possibly a greater threat than loss of water quantity and contamination, by additionally changing flow patterns and potentially offering favourable conditions for weed growth.

2. Palustrine Water Bodies and Wetlands

Similar to the Lacustrine Wetlands described above, Palustrine water bodies are defined in [Palustrine Wetlands] in WetlandInfo and are primarily vegetated non-channel environments of less than 8 hectares. They include billabongs, swamps, bogs, springs, soaks etc., and have more than 30% emergent vegetation. As Figure 25 below shows, they are mainly within the flood plain of the major streams of the area known as the Channel Country, a major grazing and beef producing region. As ephemeral systems they are potentially vulnerable to changes in surface flow and run-off contamination and are rated as high vulnerability to those threats within the Galilee and Cooper basins.

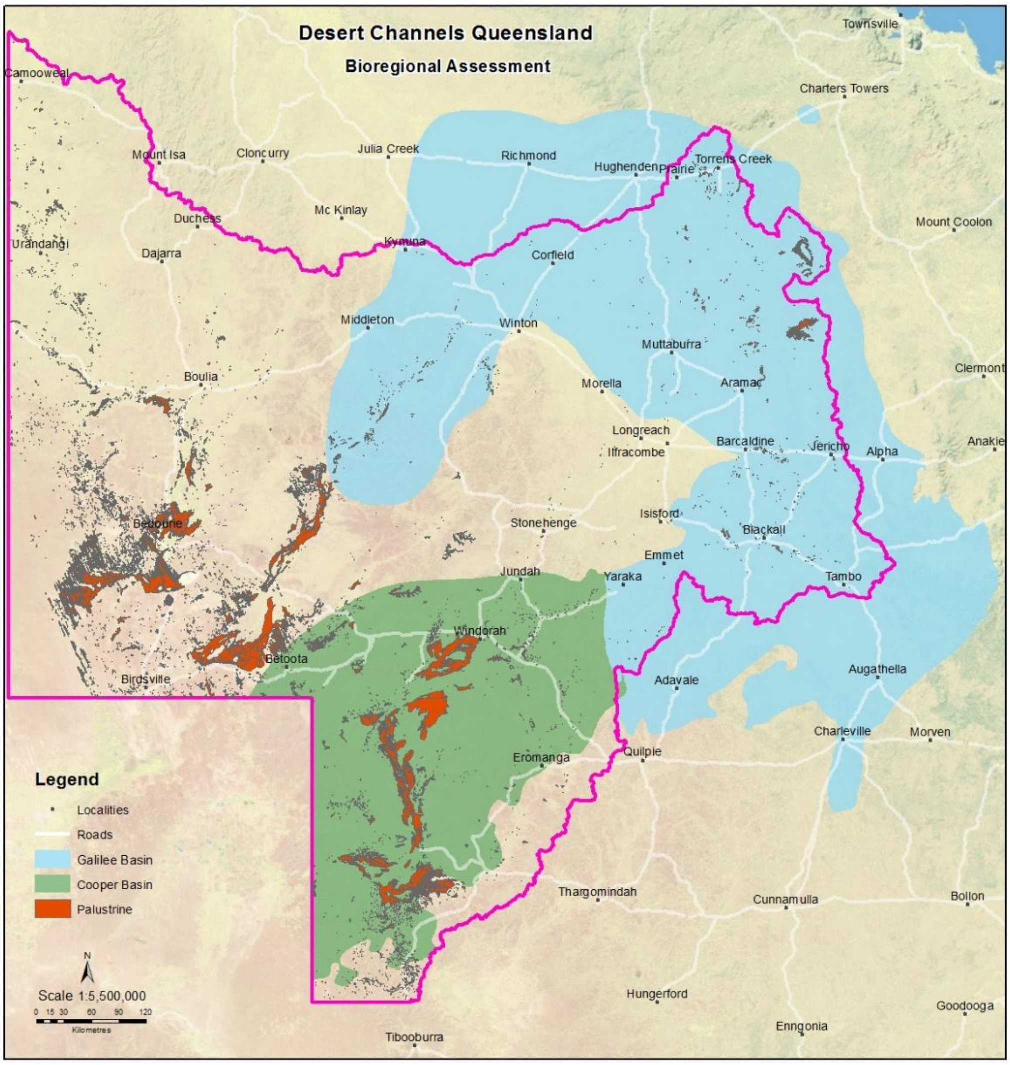


Figure 26 – Palustrine Water Assets

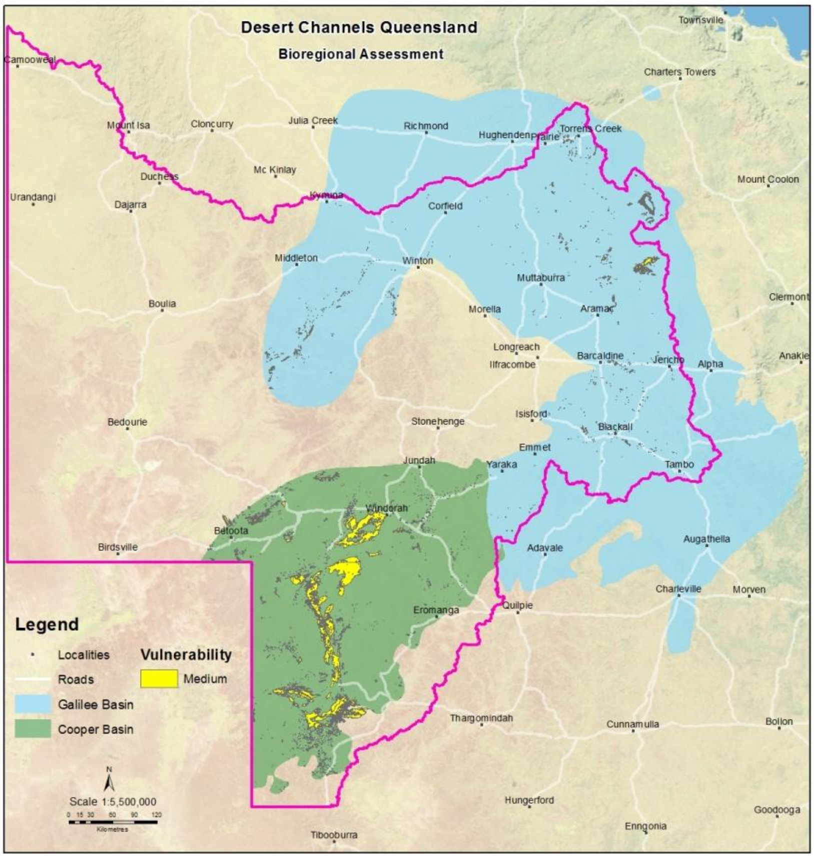


Figure 27 - Palustrine Assets – Vulnerability (Medium)

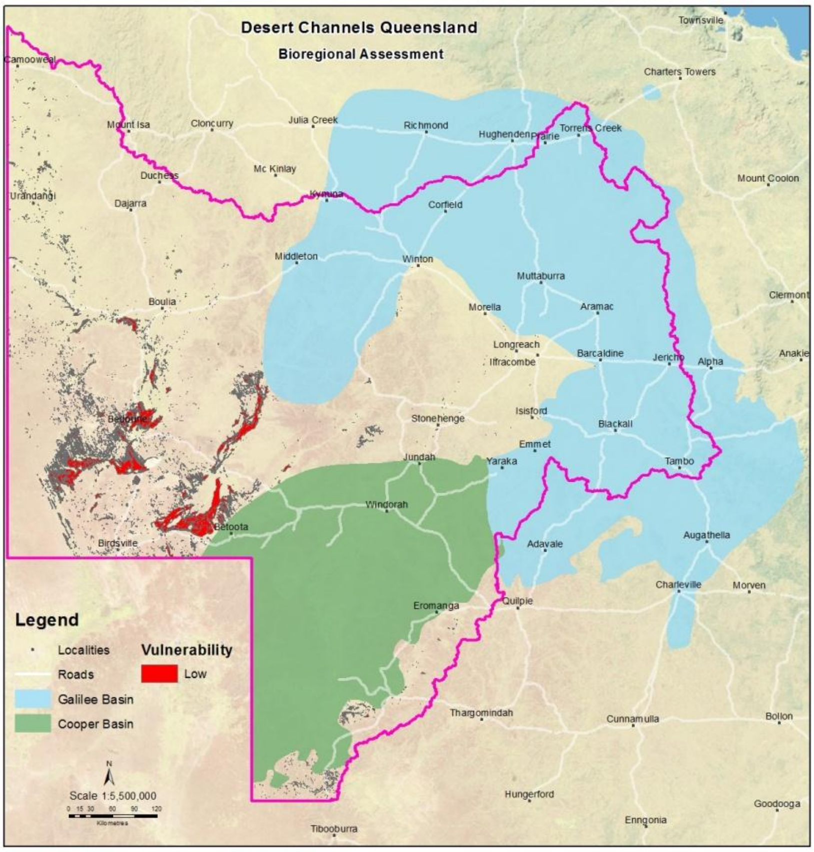


Figure 28 - Palustrine Assets Vulnerability (Low)

The vulnerability of these assets is the same as lacustrine water assets, with the highest vulnerability assets within the Galilee and Cooper basins. While smaller in size and volume than lacustrine water assets, these assets will be subject to the same effects.

As with lacustrine assets, these water assets represent a refuge for species during extended periods of limited or no surface water flow. The relative impact of CSG and coal mining is expected to be small and only through diversion of surface water, changes in flow patterns and potential contamination.

Disposal of waste water also represents a threat and, possibly, a greater threat from loss of water quantity and contamination by additionally changing flow patterns and potentially offering favourable conditions for weed growth.

3. Riverine Water bodies and Wetlands and waterholes

Similar to the Lacustrine and Palustrine Wetlands described above, riverine waterbodies are defined in WetlandInfo Riverine. However, the unique nature of the inland streams has resulted in a specific model being developed to suit the hydrology and topography across the Lake Eyre Basin. By definition, riverine wetlands are all wetlands and deepwater habitats within a channel. The channels are naturally or artificially created, periodically or continuously contain moving water, or connecting two bodies of standing water. As Figure 28 below shows, they are mainly associated with the major streams. As ephemeral systems they are potentially vulnerable to changes in surface flow and run-off contamination and are rated as high vulnerability to those threats.

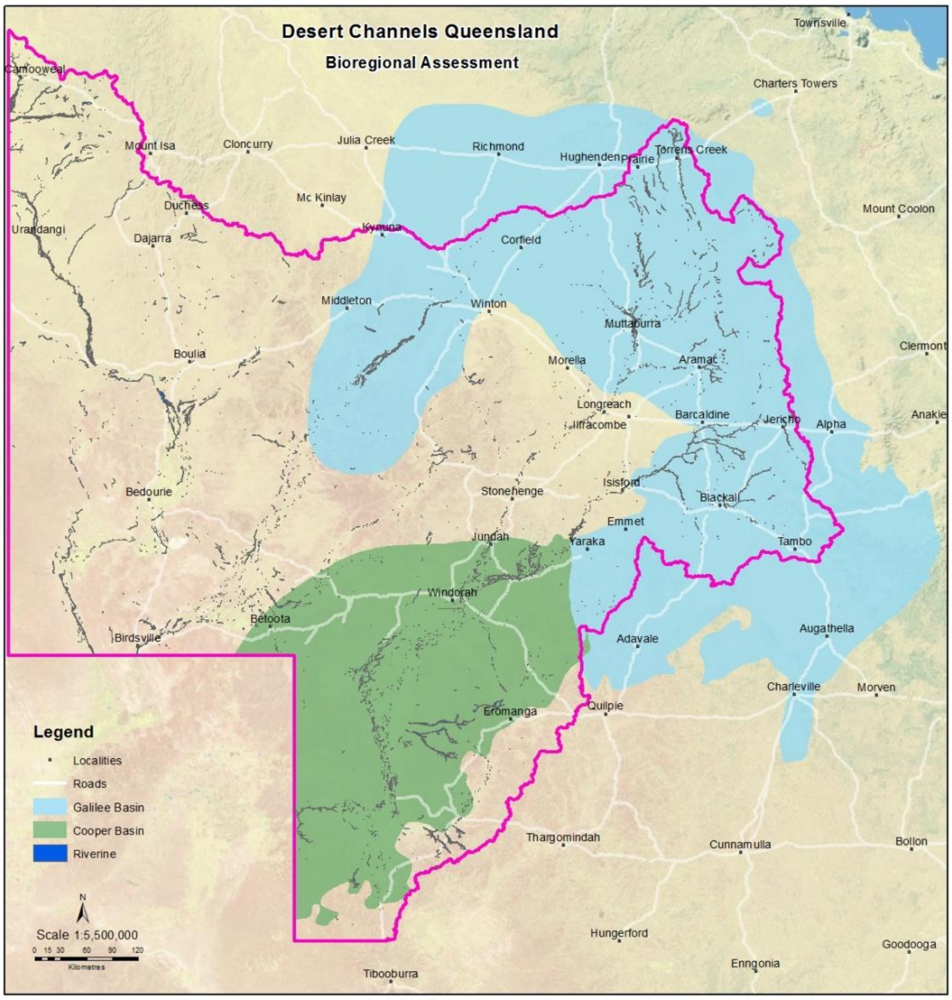


Figure 29 - Riverine Water Assets

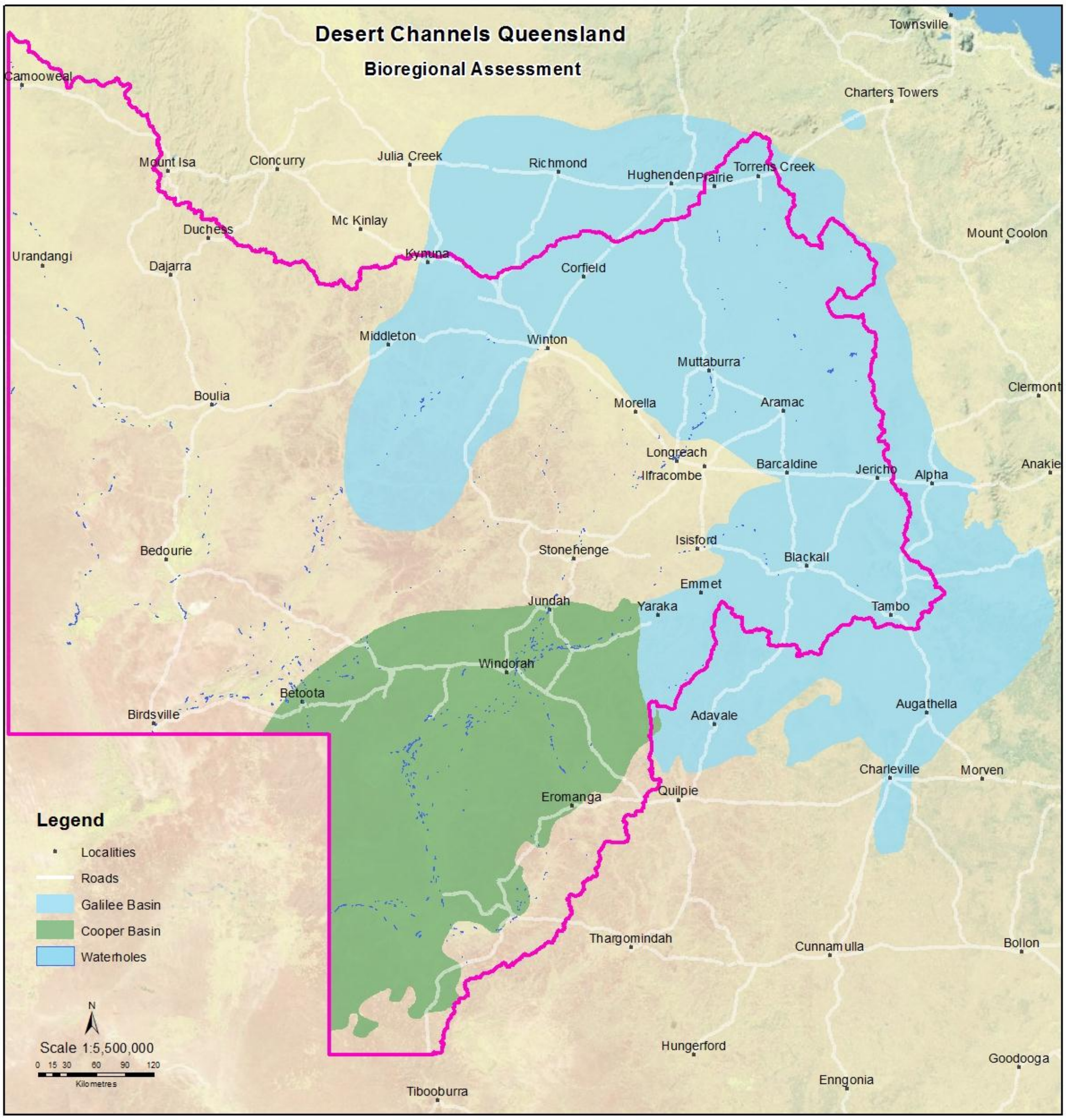


Figure 30 - Waterhole Assets

The waterhole map shown above, while clearly conforming to water channels of major watercourses also shows the flow path for biological movement within the region. These waterholes, which have been identified as permanent water bodies, represent a biological refuge in drought and a seed source for re-colonisation. In addition, these water bodies support riverine communities as well as transient and migratory visitors. These waterholes also have strong cultural and social histories that, in many cases, remain current.

As expected, the majority of waterholes are in the lower reaches of the Cooper Creek; however, there are highly significant waterholes on the Thomson River (such as the Longreach Weir), the Barcoo River and the Diamantina River, which are all inside the Galilee Basin.

These waterholes are critical assets to both the community and the environment and are highly vulnerable to contamination. The distance from production wells and any discharge will reduce vulnerability, but as the waterholes are flushed by ephemeral flows, dilution of contaminates may not occur quickly.

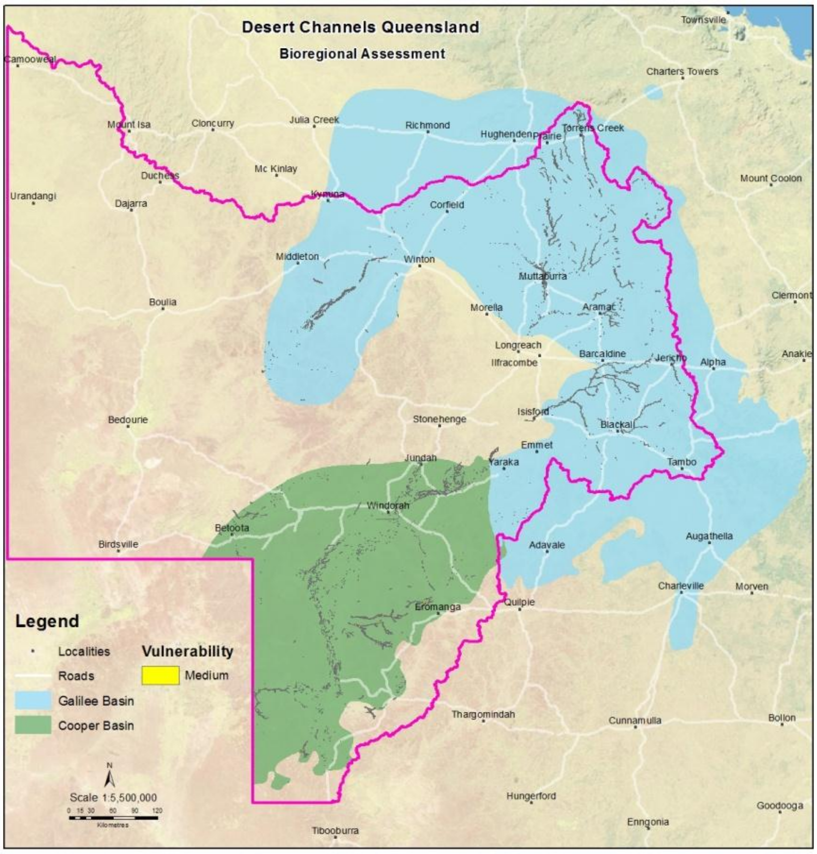


Figure 31- Riverine Assets – Vulnerability (Medium)

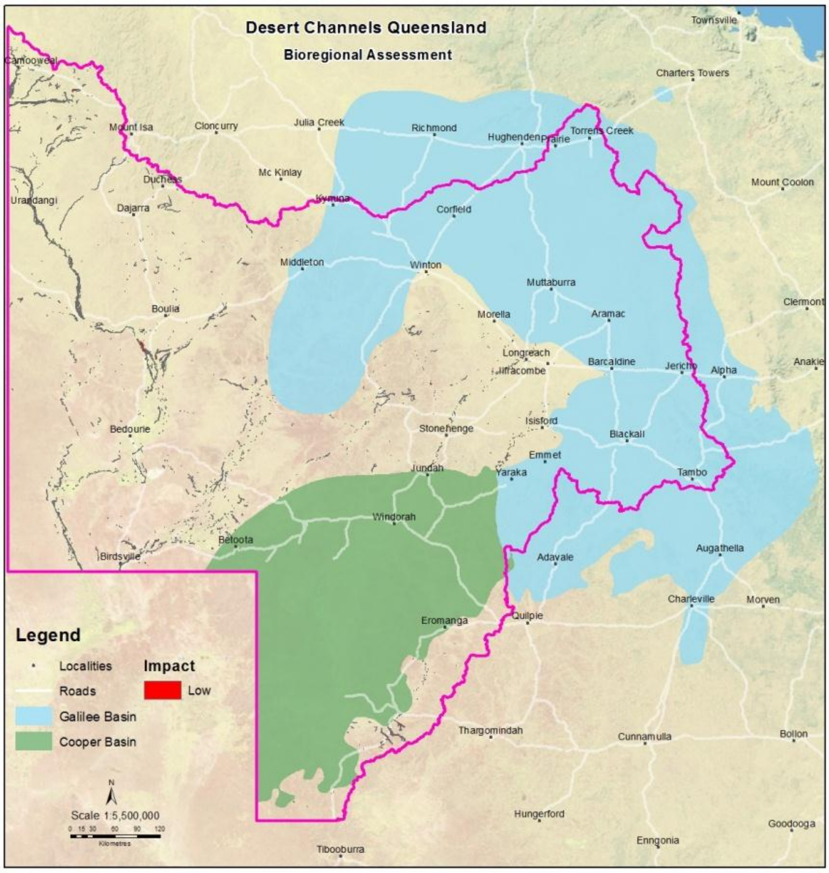


Figure 32 - Riverine Assets – Vulnerability (Low)

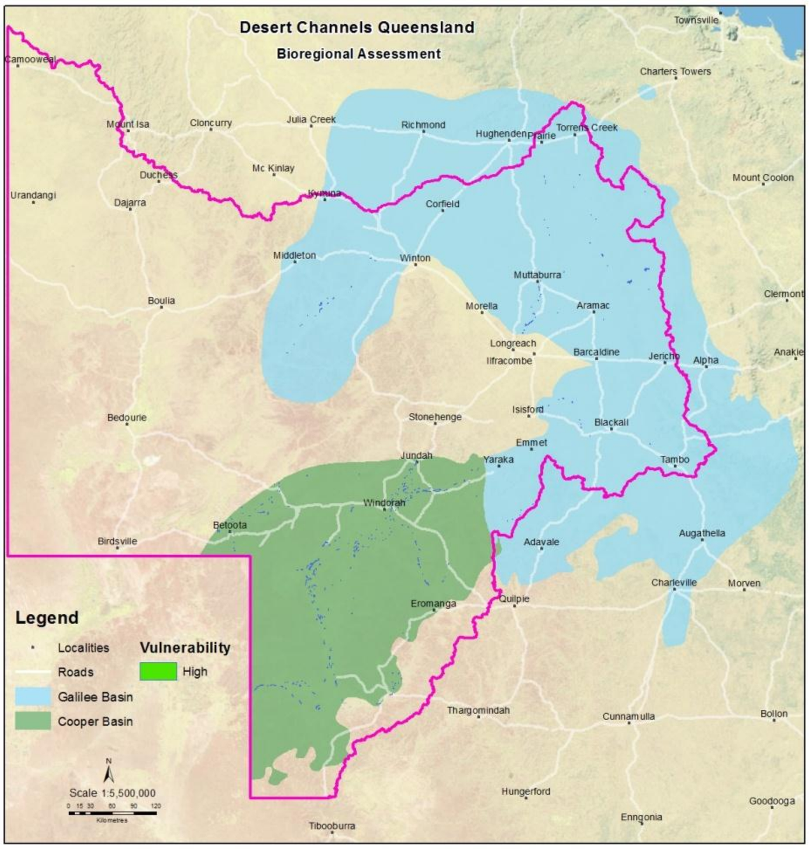


Figure 33 - Waterholes Assets – Vulnerability (High)

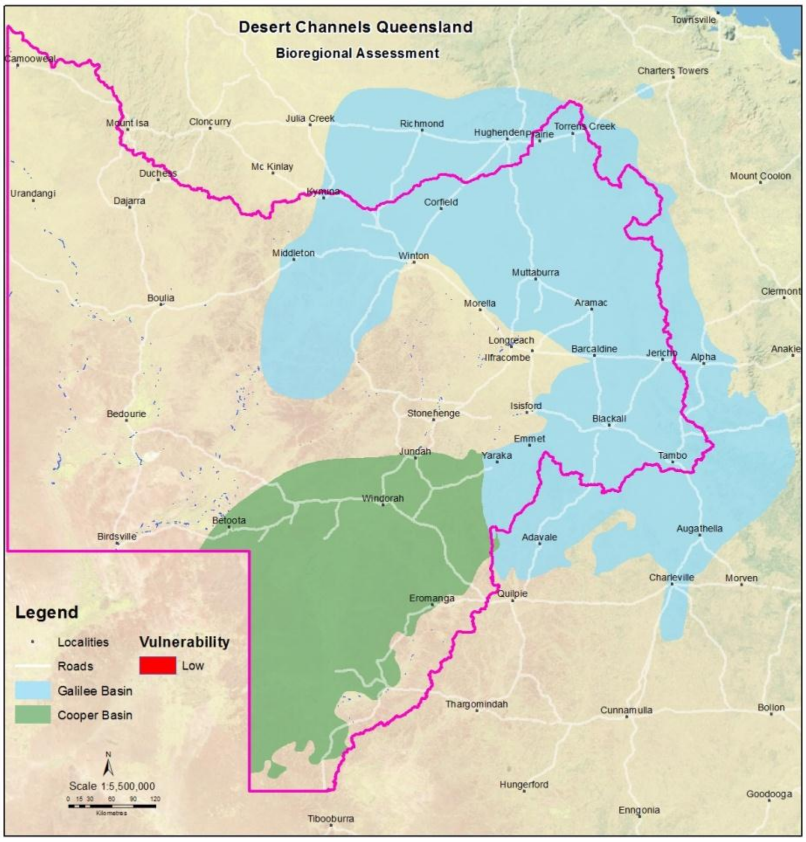


Figure 34 - Waterholes Assets – Vulnerability (Low)

Riverine environments, and waterholes associated with watercourses, as mapped here, will be affected by any changes in flow patterns and quantities.

The highest vulnerability will occur within the Galilee and Cooper basins, with assets outside of these basins having a low vulnerability due to their distance from, and lack of connectivity to, production sites. The exception may be assets on the Thomson River below Longreach and the Barcoo River below Isisford due to potential upstream effects.

Assets within the basins will be susceptible to changes in flow patterns, water quantity and contamination. This is particularly critical for the mapped waterholes that are permanent, represent the critical refuge for a large range of species and would not be easily flushed if contamination occurred.

Mitigation revolves around ensuring that water quantity and, in particular, flow patterns are maintained.

4. Localised Terminal Lake Assets

The Desert Channels region contains a cluster of terminal lakes in the eastern part of the region and this is shown below. These terminal lakes, with their associated saline adapted ecologies are very fragile ecosystems. They have been identified separately due to the special recognition afforded through respective legislation. The nature of these lakes means they are vulnerable to changes in surface flow, weed infestation, mechanical damage and any contamination from surface run-off. The above figure also shows the proximity of the lake systems to springs in the region. These lakes lie within the Desert Uplands bioregion, and form an important part of the regional ecosystem.

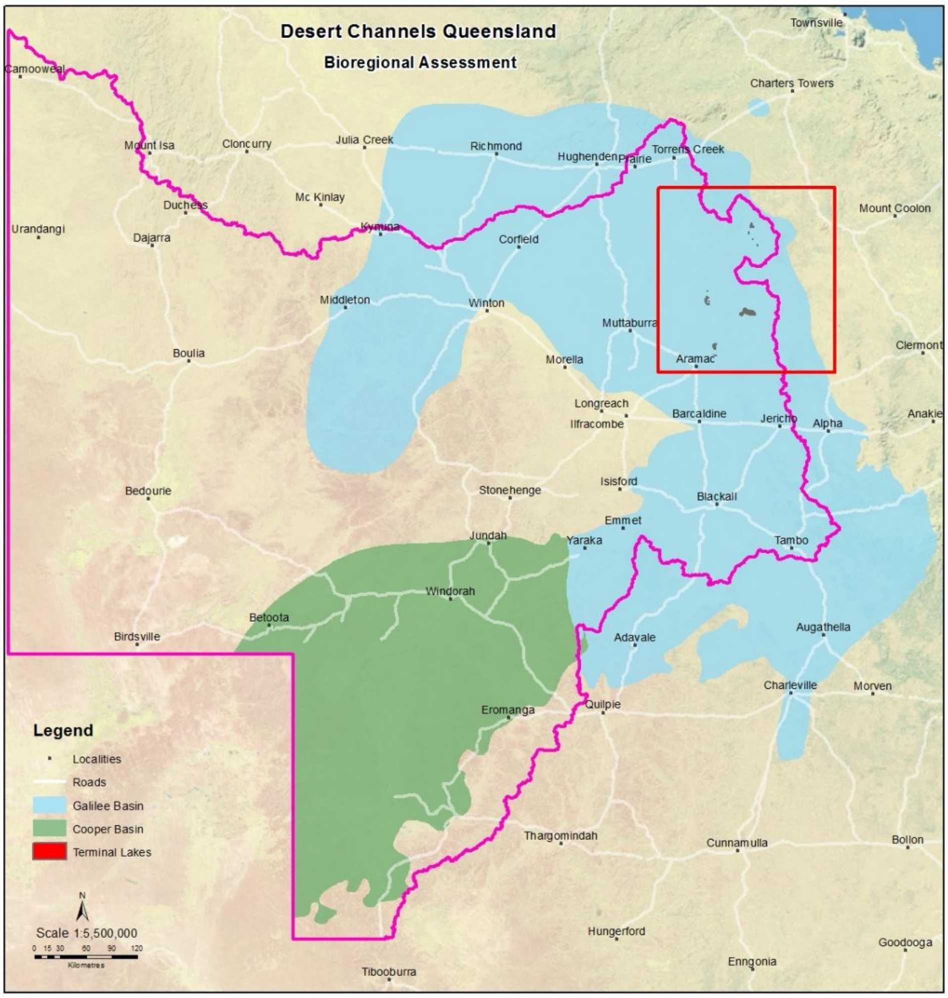


Figure 35 - Localised Terminal Lakes

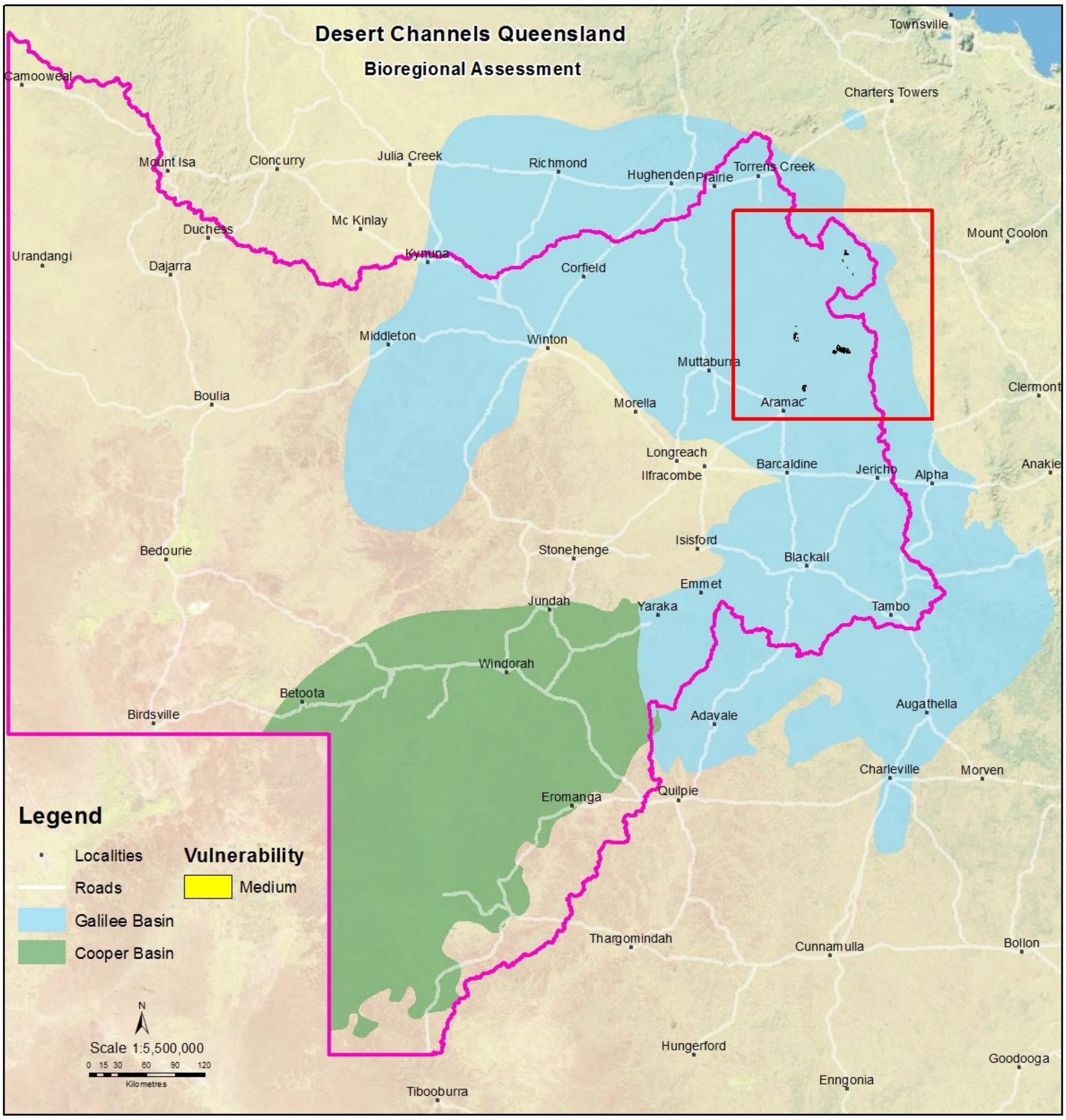


Figure 36 - Localised Terminal Lakes – Vulnerability

These water assets are unique, fragile and easily disturbed. Local terminal lakes, found only within the Desert Uplands part of the region are also in the area of most interest from CSG and coal mining companies.

The unique biota, saline environment and limited rainfall all contribute to a fragile ecosystem. Changes in flow patterns, loss of water quantity and contamination are all direct threats. As the assets are terminal lakes, no additional water sources contribute to the ecology and flushing of water courses or lakes does not occur.

Mitigation of this vulnerability will rely on the quality of well construction, management of any discharges and management of the work site to reduce contaminated runoff.

Knowledge and Information Gaps

This section reviews the knowledge and information gaps identified by the work and any specific data issues encountered, along with an overall assessment of the most vulnerable assets.

Issues Identified

Analysis of the data has revealed some issues that need to be considered in future work utilising this information. These issues include:

- Accuracy of data, particularly data input in the Formation Names field (see list in Appendix).
- 3494 (41%) have no information on stratigraphy or aquifer – data gap
- Mis-naming of facility type which had to be corrected
- No information on source aquifers of springs – data gap

In addition, the data accessed in this exercise did not include any flow data, consequently no assessment of the state of the aquifers accessed (where known) can be made.

Overall, the current state of many of the other assets (such as springs) cannot be determined as there is no consistent monitoring program in place to record asset condition on a regular basis.

Conclusions

The work has highlighted a number of potentially vulnerable assets across the Desert Channels region. These include:

- Artesian and sub-artesian bores that access aquifers that may be susceptible to development effects. These bores are essential infrastructure for many grazing properties across the region;
- Spring systems (particularly in the eastern part of the region) that also access potentially vulnerable aquifers;
- Terminal lake systems - potentially vulnerable contamination from surface run-off; and
- Various wetlands also potentially at risk from changes in surface flows, surface run-off that leads to weed spread and habitat loss.

The geographic distribution of these significant assets is given in the figures above and is available for further analysis using the derived datasets. All of these assets will require detailed assessment to determine baseline condition in the event of development proceeding.

There is an obvious overlap between the eastern concentration of many of the water assets with stressed source water bodies and the likely target areas for intensive CSG development such as the Koburra Trough. The existing baseline information of these assets and the cumulative impact of the development need to be carefully assessed before production begins.

While CSG development is expected across much of the Galilee Basin and, to a lesser degree, the Cooper Basin, coal mining within the Galilee Basin is not expected to be so extensive. Currently this activity is concentrated on the eastern margins of the Galilee Basin where the coal measures are close to the surface. However, this development is outside of the DCQ region.

Implications for future work

The study has identified that there is considerable information related to water dependent assets within the region, substantially from highly credible sources. However, as expected, there are also many knowledge gaps regarding the Desert Channels region. This suggests that any bioregional assessment of the region to determine the impact of coal seam gas or coal mining development will require additional information and data.

Recommendations

It is recommended that additional investigation is required into:

- Source aquifer determination for springs;
- Filling knowledge gaps for groundwater assets where source aquifer is not known;
- A more intensive study of the eastern zone of the Galilee Basin, from Longreach east, to collate baseline biological information and recommend water body monitoring sites, level and intensity; and
- A cumulative groundwater model for the eastern zone of the Galilee Basin, particularly modelling the highly vulnerable Group A and Group B formations.

Supporting documents

In addition to the GIS resources accessed a literature search was conducted to identify reports, studies, peer reviewed articles not immediately accessible to the project team. The resulting material is given in APPENDIX 3 – Independent Literature Search

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APPENDIX 1 – Vulnerability Rating

Vulnerability Table – DS (DCQ NRM Group)

Asset Type	Loss of Aquifer Pressure	Inter-bed leakage	Change in aquifer Flow pattern	Change in Water Quality	Surface Run-off (contamination)	Reduction in Surface Flow	Weed spread	Loss of habitat	Overall Vulnerability
Group A Groundwater Assets (Lower Sequence)	H	H	M	H	L	L	L	L	H
Group B Groundwater Assets (Upper Sequence)	M	M	M	H	L	L	L	L	H
Group C Groundwater Assets (Shallow Confined/fractured)	M	M	H	H	L	L	L	L	L
Group D Groundwater Assets (Very shallow Unconfined/shallow)	L	L	M	H	H	H	H	H	H
Group E Groundwater Assets (Unknown stratigraphy – Artesian)	M	M	M	M	L	L	L	L	M
Group E Groundwater Assets (Unknown stratigraphy – Sub-artesian)	M	M	M	M	M	M	L	L	M
Spring Assets (Recharge)	H	H	H	H	H	H	H	H	H
Spring Assets (Discharge)	L	L	L	L	M	L	H	L	M
Palustrine surface water Assets	L	L	L	H	H	H	H	M	M
Lacustrine surface water Assets	L	L	L	H	H	H	H	M	H
Riverine surface water Assets	L	L	L	M	M	H	M	H	M
Localised Terminal Lakes surface water Assets	L	L	L	M	M	M	H	M	M
Permanent Rockhole surface water Assets	L	L	H	H	H	H	H	H	H
Semi-permanent Rockhole surface water Assets	L	L	L	L	M	M	M	M	M
Waterholes	L	L	L	L	H	H	H	H	M
Water dependent biological Hot Spots and Reserves	M	M	H	H	M	M	H	H	M

APPENDIX 2 - Bore Group Definition by Aquifer

The Groundwater Database records the name of the formation or aquifer accessed for each bore. Each bore was assigned a Group value based on the table below.

Group A Groundwater Asset Formation Names

BOXVALE SANDSTONE MEMBER
CLEMATIS SANDSTONE
EVERGREEN FORMATION
HUTTON SANDSTONE
MOOLAYEMBER FORMATION
OLD CORK BEDS
PRECIPICE SANDSTONE

Group B Groundwater Asset Formation names

ALLARU MUDSTONE
BIRKHEAD FORMATION
CADNA-OWIE FORMATION
CAMBRIAN FORM
COREENA MEMBER
DONCASTER MEMBER
GILBERT RIVER FORMATION
GLENDOWER FORMATION
HOORAY SANDSTONE
INJUNE CREEK GROUP
LONGSIGHT SANDSTONE
MARION FM/WALLUFORM
MARION FORMATION
NATIVE COMPANION ALLUVIUM
RANMOOR MEMBER
ROMA
RONLOW BEDS
TOOLEBUC FORMATION
WALLUMBILLA FORMATION
WARANG SANDSTONE
WESTBOURNE FORMATION
WILGUNYA SUBGROUP
WYANDRA SANDSTONE MEMBER
WYANDRA/HOORAY

Group C Groundwater Asset Formation Names

AGE CREEK FORMATION
AGE/CAMO FORM
ARMRAYNALD BEDS
AUSTRAL DOWNS LIMESTONE
BASALT
CAMOOWEAL DOLOSTONE
CHATSWORTH LIMESTONE
CHUDLEIGH BASALT
CURRANT BUSH LIMESTONE
DEVONCOURT LIMESTONE
DOOMADGEE FORMATION
EASTERN CREEK VOLCANICS
ESMERALDA GRANITE

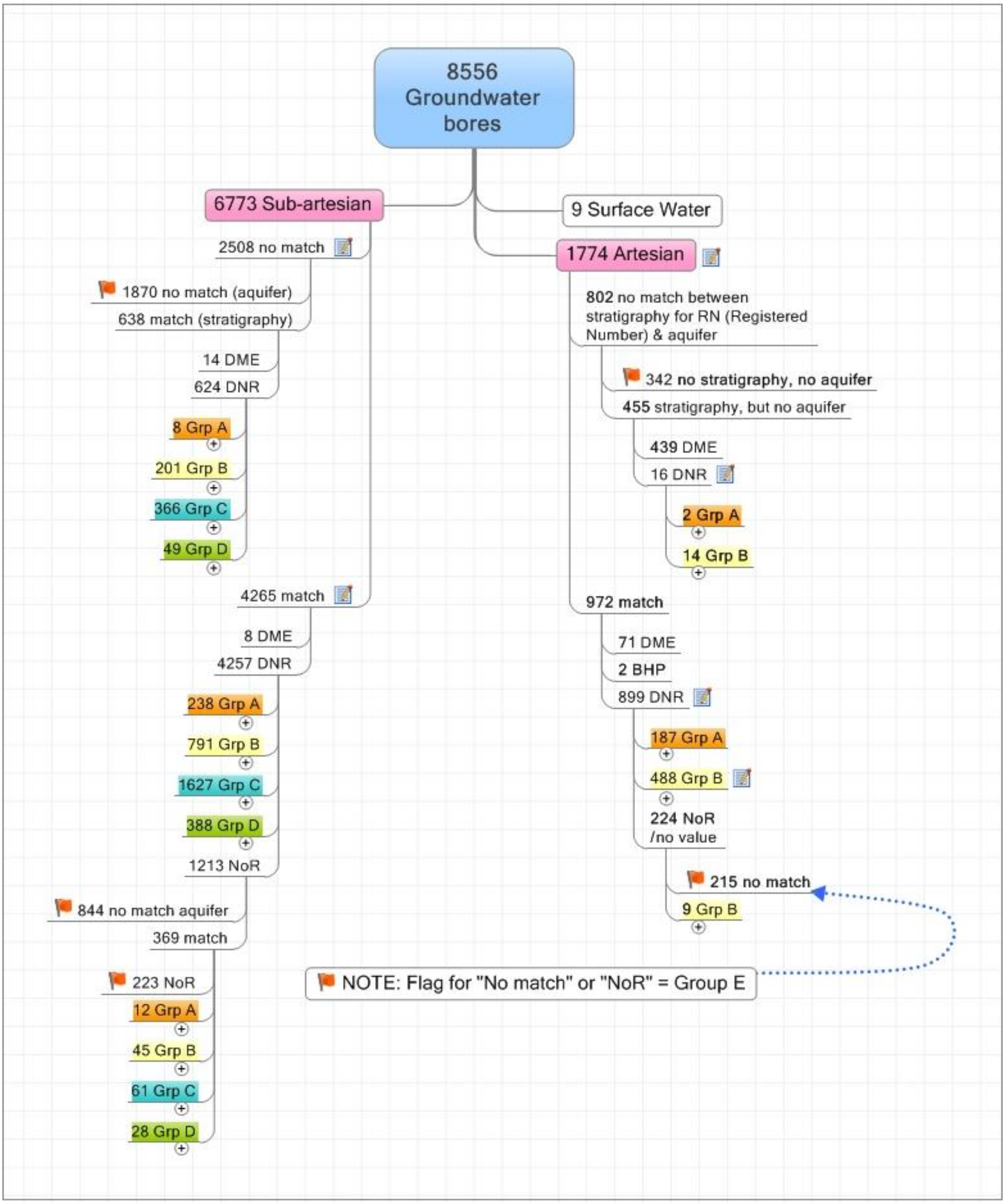
FULLARTON RIVER GROUP
GEORGINA LIMESTONE
GEORGINA LS/SYLFORM
GILDED ROSE BRECCIA
GRANITE
KALKADOON GRANODIORITE
LAWN HILL FORMATION
LEICHHARDT VOLCANICS
LOTH FORMATION
LUNCH CREEK GABBRO
MACKUNDA FORMATION
MAIL CHANGE LIMESTONE
MAKBAT SANDSTONE
MARRABA VOLCANICS
MCNAMARA GROUP
METAMORPHICS - UNDIFF.
MITAKOODI QUARTZITE
MOONDARRA SILTSTONE
MOUNT ANGELAY GRANITE
MOUNT ISA GROUP
MOUNT LES SILTSTONE
MOUNT NORNA QUARTZITE
MULLAMAN BEDS
MYALLY SUBGROUP
NARAKU GRANITE
NICHOLSON GRANITE COMPLEX
NORANSIDE LIMESTONE
NORMANTON FORMATION
OHARA SHALE
PARADISE CREEK FORMATION
PLOUGHED MTN BEDS
POMEGRANATE LIMESTONE
PRECAMBRIAN FORM
ROLLING DOWNS GROUP
ROLLING DOWNS GROUP - UNDIFF.
ROXMERE QUARTZITE
SELWYN RANGE LIMESTONE
SOLDIERS CAP FORMATION
STURGEON BASALT
SURPRISE CREEK FORMATION
SYBELLA
SYBELLA GRANITE
THORNTONIA LIMESTONE
TOOMBA BASALT
V-CREEK LIMESTONE
WALFORD DOLOMITE
WILLIAMS GRANITE
WIMBERU GRANITE
WINTON FORMATION
WONDOOLA BEDS

Group D Groundwater Asset Formation Names

ALLUVIUM
ALLUVIUM/CORELLFORM
ALLUVIUM/MARIONFORM

ALLUVIUM/NARAKUFORM
ALLUVIUM/SOLDIEFORM
ARGYLLA FM/KALKFORM
ARGYLLA FORMATION
AUCKLAND CREEK ALLUVIUM
BEETLE CREEK FORMATION
BLACKWATER GROUP
BLAZAN SH/THORNFORM
BLAZAN SHALE
BREAKAWAY SHALE
CAINOZOIC
CAPE RIVER ALLUVIUM
CARLO SANDSTONE
CARMILA BEDS
CLAY
CLONCURRY RIVER ALLUVIUM
COOLIBAH FORMATION
CORELLA FORMATION
DUNDA BEDS
EULO QUEEN GROUP
FLINDERS RIVER ALLUVIUM
FLORAVILLE FORMATION
GOLA BEDS
GUNPOWDER CREEK FORMATION
HASLINGDEN GROUP
INCA FORMATION
JUDENAN BEDS
KALKADOON GRANODIORITE
KELLY CREEK FORMATION
KURIDALA FORMATION
LADY LORETTA FORMATION
LEICHHARDT RIVER ALLUVIUM
LIMESTONE
MINGERA BEDS
MOUNT BIRNIE BEDS
MOUNT GUIDE QUARTZITE
MUNGEREBAR LIMESTONE
NINMAROO FORMATION
QUATERNARY
QUATERNARY - UNDEFINED
QUATERNARY ALLUALUV
QUATERNARY ALLUVIUM
QUATERNARY COLLUVIUM
QUATERNARY DUNE SANDS
QUATERNARY SAND
QUATERNARY SANDS & GRAVEL
QUATERNARY SEDIMENTS
REWAN GROUP
SAND
SANDGRAVEL
SANDSTONE
SHALE
SPLIT ROCK SANDSTONE
STAVELEY FORMATION
STAVELY FORMATION
STEAMBOAT SANDSTONE

SWIFT FM/NINMARFORM
TERTIARY
TERTIARY FORM
TERTIARY - UNDEFINED
TERTIARY SEDIMEFORM
TERTIARY SEDIMENTS
WERITE BEDS
WYAABA BEDS



APPENDIX 3 – Independent Literature Search

The following references were obtained by an independent researcher to identify peer reviewed articles and other reports and references not immediately accessible to Desert Channels. The search results are presented below for the sake of completeness, however not all articles have been obtained.

The articles are grouped by primary search words.

Artesian and sub artesian (sometimes mixed in same paper)

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- http://www.water.gov.au/RiverandWetLandHealth/Assessmentofriverandwetlandhealth/index.aspx?Menu=Level1_5_2
- http://www.lakeeyrebasin.org.au/archive/pages/page25.html
- http://www.water.nsw.gov.au/Water-management/Basins-and-catchments/North-western-NSW-catchments/North-western-NSW-catchments/default.aspx
- water data: http://www.water.nsw.gov.au/Water-management/Basins-and-catchments/Great-Artesian-Basin/Great-Artesian-Basin/default.aspx
- List of threatened species in NT_www.nretas.nt.gov.au/plants-and-animals/animals/home/specieslist
- List of native birds in region_www.nretas.nt.gov.au/plants-and-animals/animals/native/birds
- List of native mammals in region_www.nretas.nt.gov.au/plants-and-animals/animals/native/mammals
- List of native reptiles in region_www.nretas.nt.gov.au/plants-and-animals/animals/native/reptiles
- List of native frogs in region_www.nretas.nt.gov.au/plants-and-animals/animals/native/frogs
- National Water Commission QLD Report Card 2012_key findings incl coal seam gas risk_www.nwc.gov.au/reform/assessing/continuing/report-card/queensland/key-findings
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