Baseline assessment and proposed monitoring of surface-water dependent receptors for coal seam gas development in the Galilee Subregion of the Lake Eyre Basin.

Final report to the South Australian Department of Environment, Water and Natural Resources by the Queensland Department of Natural Resources and Mines.

Funding for these projects has been provided by the Australian Government through the Bioregional Assessment Programme.

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Summary

The Australian Government is undertaking a programme of Bioregional Assessments (BA) to better understand the potential impacts of coal seam gas and large coal mining developments on water resources and water-related assets. The current project is an Australian Government funded initiative designed to provide water resource information to the Bioregional Assessment Receptor Register for the Galilee subregion of the Lake Eyre Basin Bioregional Assessment (http://www.bioregionalassessments.gov.au).

The Queensland coal-seam gas (CSG) industry is expanding rapidly and, although production is currently limited in spatial extent, exploration is ongoing in a number of major biogeographic subregions. The Galilee Basin in central Queensland is recognised as an emerging CSG province with significant gas reserves. However, key knowledge gaps relating to the production and release of co-produced water currently remain.

In the first report of this series (Sternberg and Cockayne 2014), key environmental pressures associated with a change in surface-water quality or quantity as a result of the release of treated co-produced water into the surface water in the Galilee Basin were reviewed. In addition, the potential impacts of these pressures on surface-water dependent ecological receptors were conceptualised and key knowledge gaps and priority receptors for future baseline assessments in the region were identified.

This report builds on previous work by presenting a baseline assessment of priority receptors in the Galilee basin. To assist in the development of a reference condition, a surface-water dependent monitoring program for coal seam gas development in the Galilee Subregion is then proposed, to begin addressing the key knowledge gaps identified in previous reports.

Baseline assessment and receptor characterisation in the Galilee subregion of the Lake Eyre Basin (LEB) was conducted for fish assemblages, macroinvertebrates, flow regimes, water quality, sedimentation and waterhole dynamics on two occasions over a natural cycle of wetting and drying.

Results suggest that the majority of 'priority receptors' identified by Sternberg and Cockayne (2014) are likely to form a key part of any future monitoring program in the Galilee subregion. Continued monitoring of the natural spatio-temporal patterns in waterhole physicochemical properties, long-term hydrological patterns and invasive species distribution and abundance, is particularly important given their responsiveness to a range of CSG related developmental pressures. In addition, changes in environmental risk and resource availability (time, money and information) can then be incorporated into the surface-water monitoring program in an adaptive capacity.

Ecological condition in dryland river ecosystems is naturally variable in time and space due to the prevailing patterns of wetting and drying and associated 'boom and bust' ecology. Some ecological components fluctuate seasonally (short-term receptors), while other components are representative of cumulative trajectories in ecosystem services (long-term receptors). Effectively capturing this natural variability in short- and long-term ecological condition, and identifying any variation beyond what is considered natural, is the major challenge for any monitoring program in the LEB.

The report also highlights how the proposed monitoring program would complement a range of state and commonwealth policy objectives and external reporting frameworks. Importantly, any monitoring program in the Galilee subregion of the LEB would provide valuable baseline information that could be accessed by a diverse range of stakeholders.

This project was commissioned by the South Australian Department of Environment, Water and Natural Resources through the Commonwealth Department of the Environment as part of the Bioregional Assessment Programme, which at the time of initiating these works the Queensland Government were not yet a signatory to the National Partnership Agreement for Coal Seam Gas and Large Coal Mining.

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1. Introduction

The Queensland coal-seam gas (CSG) industry is expanding rapidly and, although current extraction is spatially limited, exploration is expanding in a number of major biogeographic subregions. The Galilee Basin in central Queensland is recognised as potential CSG province with significant gas reserves. However, key knowledge gaps relating to the production and release of co-produced water currently remain. These are particularly relevant for the naturally ephemeral rivers and streams of the Lake Eyre Basin (LEB) which are highly sensitive to environmental change (Mackay et al. 2012). If gas reserves in the Galilee Basin are developed in future, it will be necessary to gain an understanding of the current condition of this ecosystem, against which, potential development impacts can be compared.

In the first report of this series (Sternberg and Cockayne 2014), the key environmental pressures associated a change in surface-water quality or quantity as a result of the release of treated co-produced water into the surface water in the Galilee Basin were reviewed, the potential impacts of these pressures on surface-water dependent ecological receptors were conceptualised, and the key knowledge gaps and priority receptors for future baseline assessments in the region were identified (Sternberg and Cockayne 2014).

This report builds on previous work by presenting a baseline assessment of priority receptors in the Galilee basin. To assist in the development of a reference condition, a surface-water dependent monitoring program for coal seam gas development in the Galilee Subregion is proposed, to begin addressing key knowledge gaps identified in previous reports.

1.1 Bioregional Assessment Programme

Funding for these projects has been provided from the Bioregional Assessment Programme through the Department of the Environment.

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated on potential water-related impacts of coal seam gas and large coal mining developments. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Lake Eyre Basin Rivers Monitoring (LEBRM) project has been developed to inform the Lake Eyre Basin Bioregional Assessment. LEBRM was delivered across the South Australian, Northern Territory and Queensland regions of the Basin, consistent with priorities for Coal based developments in the Arckaringa, Pedirka, Cooper and Galilee Basins. The LEBRM project was designed as an integrated approach utilising the capability and methodological approach already developed under the current Lake Eyre Basin Rivers Assessment (LEBRA) monitoring program.

1.2 IESC

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC) is a statutory body under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) which provides scientific advice to Australian governments on the water-related impacts of coal seam gas and large coal mining development proposals.

Under the EPBC Act, the IESC has several legislative functions to:

- Provide scientific advice to the Commonwealth Environment Minister and relevant state ministers on the water-related impacts of proposed coal seam gas or large coal mining developments.
- Provide scientific advice to the Commonwealth Environment Minister on:
    - bioregional assessments being undertaken by the Australian Government, and
    - research priorities and projects commissioned by the Commonwealth Environment Minister.
- Publish and disseminate scientific information about the impacts of coal seam gas and large coal mining activities on water resources.

1.3 Coal Seam Gas in the Galilee Basin

Coal-seam gas was first explored in the Galilee Basin in the early 1990s, and while production is yet to be achieved, 84 test wells have so far been constructed (DNRM 2014). Coal-seam gas exploration has mainly targeted the 'Betts Creek beds', however, recent evidence suggests coal seams in the Galilee Basin likely contains low to very low gas saturation levels. There is currently no publicly available regional estimate of the total CSG resource (gas-in-place) for the basin.

Market uncertainties such as the quantity, quality and projected gas production, combined with the lack of existing gas infrastructure, highlight a number of critical knowledge gaps for the Galilee subregion. In addition, the volumes of co-produced water generated through the CSG extraction process typically vary significantly between CSG sites in relation to regional stratigraphy (Commonwealth of Australia 2014). As a result, potential volumes (and impacts) of co-produced water from CSG extraction in the Galilee basin remain largely unknown and thus predictions surrounding potential impacts will be difficult in the absence of a range of plausible scenarios.

Further information can be found in Lewis et al. (2014) - Coal and coal seam gas resource assessment for the Galilee subregion (available at www.bioregionalassessments.gov.au).

1.4 Ecology of the Lake Eyre Basin Drainage

The LEB system shares its headwaters with those of four other major drainage divisions however, the area is characterised by a distinctive and specialised biota, including numerous endemic species. This diversity is driven by natural cycles of 'boom and bust' (Bunn et al. 2006b) which is critical for maintaining biodiversity throughout riverine and floodplain areas of the Galilee (Fig. 1).

For much of the year, riverine environments exist as a series of disconnected waterholes which, for water-dependent biota, represent refugial habitats with often complex food-web dynamics and interspecific interactions (Bunn et al. 2006a). These 'bust' periods are often associated with worsening physico-chemical conditions and increasing heterogeneity, yet still represent important life-history cues for specialised biota (Fig. 1). During the 'boom', rainfall turns dry rivers into vast networks of interconnected floodplain and channel habitats, accommodating high aquatic and terrestrial productivity. Native species are adapted to take advantage of temporarily abundant food resources and increased habitat connectivity, with numerous species completing important life-history and dispersal processes during these high-flow conditions (Balcombe et al. 2007) (Fig. 1). Although these occasional, large-flood events provide the most dramatic cycles in ecosystem condition, for arid environments like the LEB, flooding is a relatively rare and episodic occurrence. From year to year, the frequency and variability of scattered flow events within the channel network maintain ecosystems between the two boom-bust extremes (Cockayne et al. 2015). These smaller and more seasonal channel flow events connect and refill drying waterholes, maintain water quality, improve waterhole persistence, and sustain resident flora and fauna through time (Fig. 1).

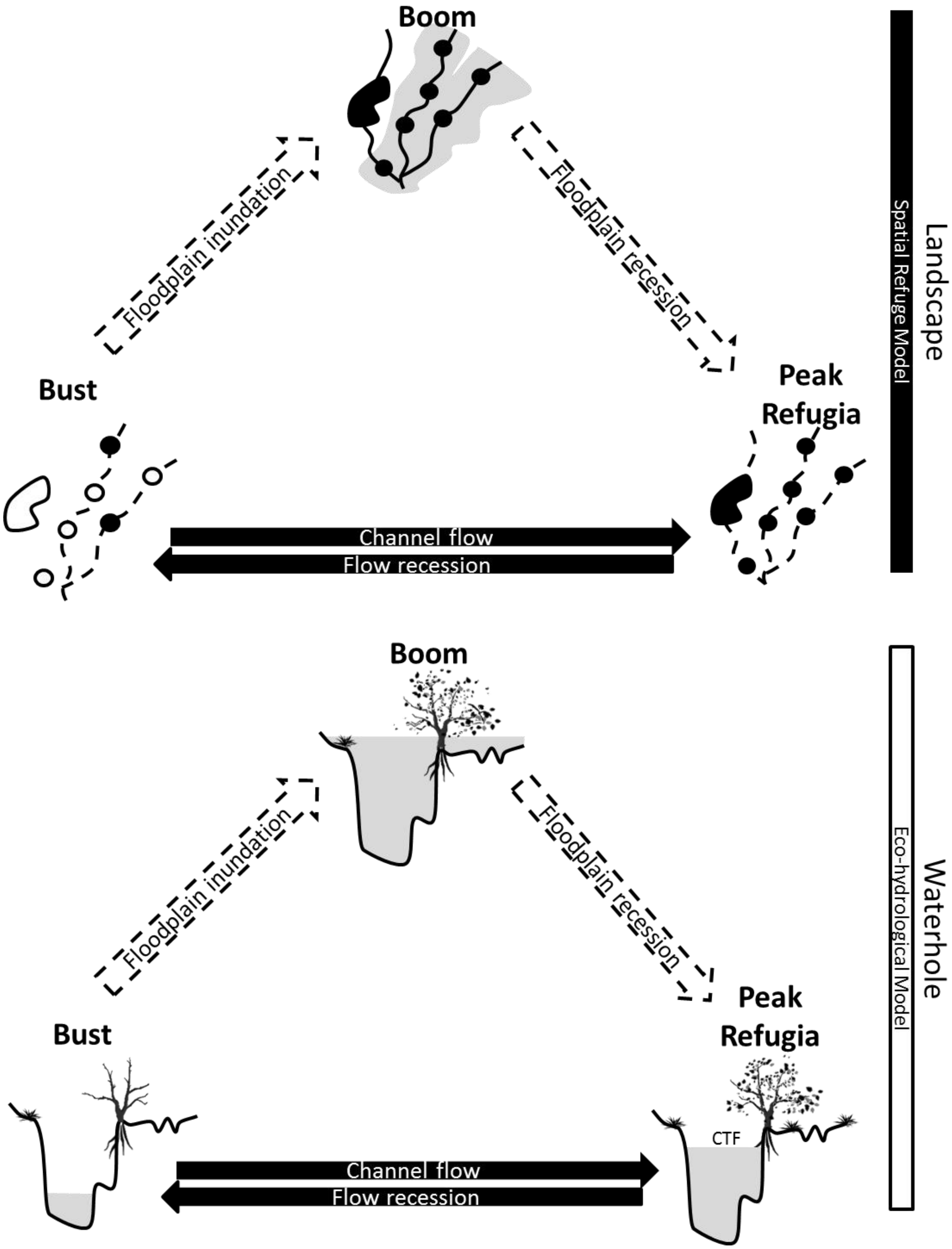


Figure 1: Hydro-ecological associations for LEB riverine ecosystems over a range of flow conditions at the landscape (top) and waterhole (bottom) scale. Darker arrows indicate more frequent and predictable channel flow events, whereas dashed arrows indicate less frequent floodplain inundation events. 'Peak Refugia' refers to an intermediate state following floodplain recession or within-channel flows where ideal physico-chemical conditions and relatively stable resources maximise waterhole persistence and population viability through time. 'CTF' = Cease To Flow.

1.5 PSR Framework

The pressure-stressor-response (PSR) framework is an approach that utilises conceptual models to develop cause and effect linkages between human pressures, physiochemical and biological stressors, and expected ecological response in the context of the extant environmental conditions. Under the PSR approach, the likelihood of known stressors and consequences of the response can be predicted in order to prioritise important biological, ecological or environmental changes for ongoing monitoring purposes. For the purpose of this report, receptor characterisation has been limited to those attributes or entities that are likely to be materially affected by a change in surface-water quality or quantity as a result of the release of treated co-produced water into the surface water, including those surface water-dependent attributes or entities affected by industrial related pressures such as floodplain development and beneficial use schemes.

Two major surface-water pressures; 1) the release of co-produced CSG water into surface waters; and 2) other CSG water and industrial related pressures associated with landscape disturbance, were identified from the primary literature and state agency reports for the development of a CSG industry in the Galilee Basin (Fig. 2). From this four major stressors; 1) alteration to the natural/extant physical and chemical attributes of the receiving environment; 2) alteration to the natural/extant cycles of wetting and drying, and the natural flow regime; 3) inter-basin transfers from external beneficial use schemes; and 4) infrastructure (*e.g.* well pads, roads, rail) associated with the development of a CSG industry, were identified as potentially having a tangible impact on aquatic receptors in the Galilee Basin (Fig. 2).

For further information and more specific conceptual models, see Sternberg and Cockayne (2014).

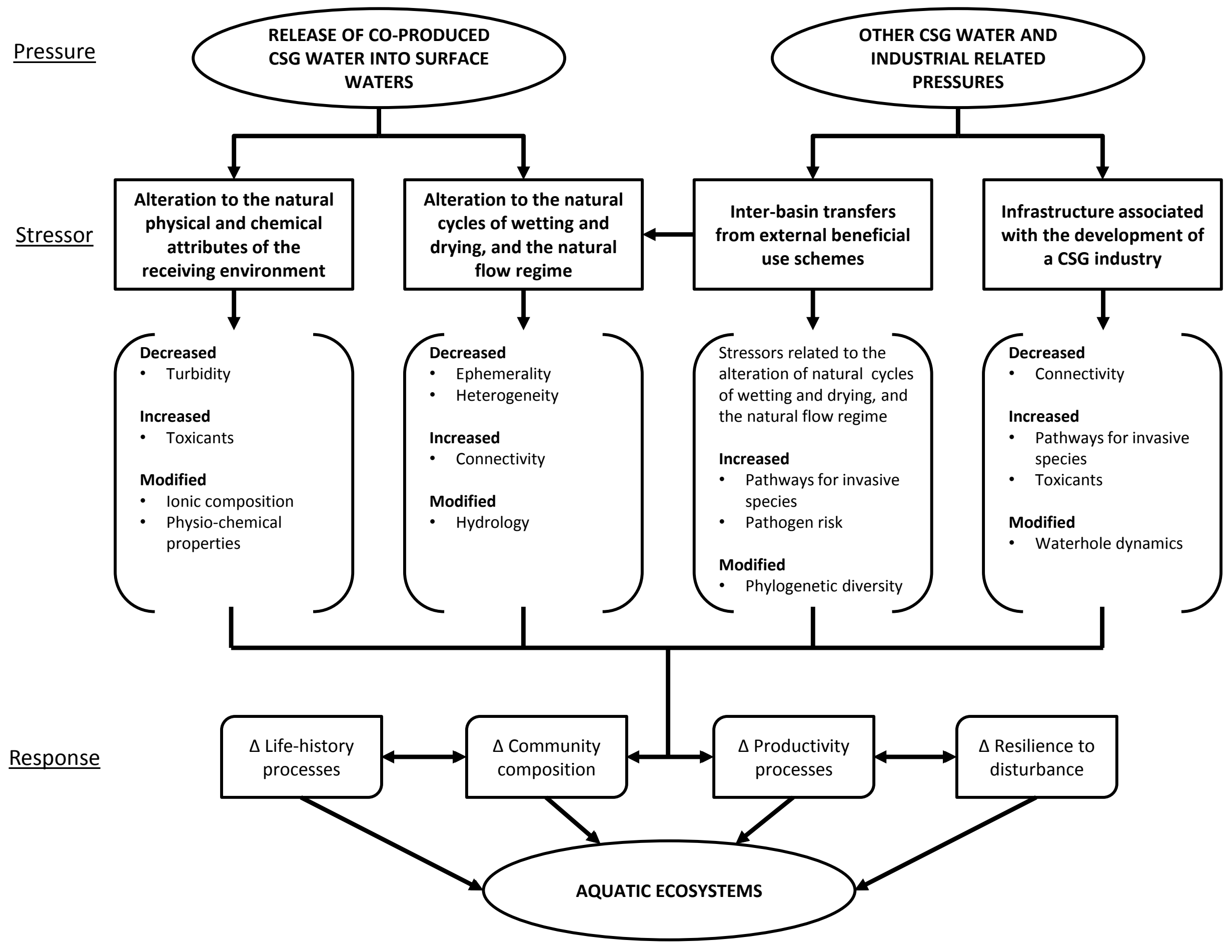


Figure 2: General conceptual model outlining two main surface water-dependent pressures arising from CSG developments and the associated stressor and response linkages to aquatic ecosystems in the Galilee Basin.

Table 1: Summary PSR framework for surface water-dependent receptors associated with the release of co-produced CSG water into surface waters of the Galilee Basin and the resulting stress placed on aquatic ecosystems. Table summarised from Sternberg and Cockayne (2014). Priority receptors were chosen based on the qualitative assessment of specificity to CSG development (irrespective of background variation) and confidence in the knowledge underpinning the conceptual linkages in the PSR framework (see Sternberg and Cockayne 2014).

Pressure	Stressor	Comments	Priority Receptors
Release of co-produced CSG water into surface waters of the Galilee Basin (Lake Eyre Basin)	Alteration to the natural physical and chemical attributes of the receiving environment.	The physiochemical quality of co-produced water is understood at a fundamental level and there is generally a good understanding of the potential water quality variables likely to cause environmental stress (Commonwealth of Australia 2014). However, the actual quality varies widely between wells, with treatment options, such as reverse osmosis (RO), generally producing water with low total suspended solids (TSS), low electrical conductivity (EC) and unbalanced ionic compositions relative to local water quality conditions. *Key Knowledge Gaps:* Natural spatial and temporal water quality patterns and toxicant levels.	- Turbidity. - Physiochemical properties (including EC). - Select macro-invertebrate abundance and distribution.
	Alteration to the natural cycles of wetting and drying and the natural flow regime.	Flow is the major driver of aquatic ecosystem processes for in-stream and off-channel waterholes, floodplains and arid and semi-arid lakes and swamps throughout the LEB. The release of co-produced CSG water to naturally ephemeral streams during low or no-flow periods may cause a temporary decrease in dry spells and low-flow periods, a loss of seasonality, increased flow velocity and flow volume, and increased connectivity throughout the riverine network (Takahashi et al. 2012a; Commonwealth of Australia 2014). These hydrological alterations are likely to cause a complete change in the stream ecology from dry to permanently flowing with the physical and ecological components associated with low-flow attributes likely to be the most severely affected (Commonwealth of Australia 2014). Further, a direct increase in connectivity from the release of CSG water into surface streams is highly likely to favour the proliferation of invasive species - causing obvious secondary and cumulative environmental stressors. *Key Knowledge Gaps:* Distribution and abundance of invasive species; improved knowledge of the ecological values of arid and semi-arid lakes and swamps; long-term flow monitoring data	- Fish assemblage composition. - *Oxyeleotris lineolatus* (Sleepy Cod). - *Cherax quadricarinatus* (Redclaw Crayfish). - Lake Buchanan/Lake Galilee, Lake Dunn. - Flow regime. - Waterhole morphology and persistence modelling. - Diatom community composition.

Pressure	Stressor	Comments	Priority Receptors
Other CSG water and industrial related pressures	Increased infrastructure associated with the development of a CSG industry.	The pressures on surface-water dependent receptors from associated CSG infrastructure intensify with increasing proximity to riverine features (Marshall et al. 2013). Roads, water storage dams, borrow pits and temporary camps can act to disrupt important ecosystem processes throughout the river and floodplain networks of the Galilee Basin. Decreased lateral connectivity between the river network and floodplain environment, modified spatial and temporal waterhole dynamics, and increased toxicants and pathways for invasive species are likely to result from infrastructure associated with the development of a CSG industry. *Key Knowledge Gaps:* Floodplain inundation frequency and waterhole persistence in the Galilee Basin.	- Waterhole spatial profile and sediment characteristics. - Floodplain vegetation. - Background toxicant levels.
	Inter-basin transfers from external beneficial use schemes	The proximity of the Galilee Basin to other major CSG operations in neighbouring coal basins such as the Surat and Bowen, suggests potential for the transfer of co-produced water across catchment boundaries. Along with alteration to the natural cycles of wetting and drying, and the natural flow regime (see above), the transfer of co-produced water into the Galilee Basin is likely to impact the long-term genetic viability of populations of aquatic fauna, increase pathways for the immigration of invasive species, and expose biota to a number of pathogens to which they possess low immunity (Davies et al. 1992; Page et al. 2010). *Key Knowledge Gaps:* Genetic population structure of water-dependent species shared with neighbouring catchments; a basic understanding of the background levels, and spatial and temporal variability in stress or disease in sensitive taxa.	- Flow monitoring. - Stressed or diseased taxa.

2. Surface-water monitoring and baseline assessment in the Galilee subregion of the Lake Eyre Basin

Ecological condition in dryland river ecosystems is naturally variable in time and space due to the prevailing patterns of wetting and drying and associated ‘boom and bust’ ecology (Fig. 1). Some ecological components fluctuate seasonally (short-term receptors), while other components are representative of cumulative trajectories in ecosystem services (long-term receptors).

Surface-water monitoring was conducted biannually in relation to broad seasonal climatic patterns (Fig. 1).

- Autumn; following a period of warmer temperatures, generally wetter conditions, and higher productivity.
- Spring; following cooler temperatures and a typically prolonged period of drying in the surface-waters.

Field surveys consisted of a mixture of high intensity and low intensity sampling sites (Fig. 3). High intensity surveys were conducted in permanent, refugial waterholes on major tributaries within expected high intensity mining areas and included the full range of seasonal and cumulative receptors (see below). Low intensity surveys were conducted at a number of ‘satellite’ sites in low intensity mining areas to increase the spatial coverage of the baseline assessment. Low intensity surveys included a subset of seasonal and cumulative receptors.

Field assessments and surveys were undertaken in spring 2014 and autumn 2015 to ground-truth and verify the existence of key surface-water receptors identified by Sternberg and Cockayne (2014) for CSG development in the Galilee subregion of the LEB. The following sections outline the results of these field surveys, the process for data collection, and the design for a future monitoring program.

Table 2: Overview of the surface-water monitoring program for CSG development in the Galilee subregion of the LEB. Priority receptors for this monitoring program were selected from Table 1 to provide coverage of elements with high specificity to CSG development within logistical, time and monetary constraints.

Design Component	Summary
Baseline assessment	10 years (min); Results of future monitoring should be incorporated into baseline estimates.
Impact monitoring	Indefinite; Adapted to suit changing risk, resources and novel information.
Frequency	Biannually; Autumn (‘good’ condition), Spring (‘poor’ condition).
Site selection	High intensity sites: - Full range of seasonal and cumulative receptors; - Permanent refugial waterholes on major tributaries; - Located in areas of expected high intensity CSG mining.
	Low intensity sites: - Subset of seasonal and cumulative receptors; - Permanent and semi-permanent ‘satellite’ waterholes; - Located in strategic areas that increase spatial coverage.
	Areas of local significance: - Monitored to provide a better understanding of their ecological and social values.
Response Component	Priority receptor groups monitored in this program: - Hydrology (High intensity sites). - Water quality (High and low intensity sites). - Fish assemblages (High intensity sites). - Macroinvertebrates (High intensity sites). - Sedimentation and waterhole dynamics (high and low intensity sites).

Table 3: Survey intensity, site information and GPS coordinates for baseline sampling in the Galilee subregion of the LEB on two occasions in spring 2014 and autumn 2015.

Survey Intensity	Site #	Site Name	Catchment	Latitude	Longitude
High	0032166	Cornish Ck @ Bucksleas	Cooper	-22.47007	144.87446
High	0032168	Edie Ck @ Lake Dunn	Cooper	-22.60187	145.67465
High	0032172	Thomson R @ Camoola	Cooper	-22.98344	144.50465
High	0032174	Torrens Ck @ Fisheries	Cooper	-21.79436	145.26766
High	0032176	Aramack Ck @ Lynch's Hole	Cooper	-23.12643	145.37380
High	0033010	Barcoo R @ Avington Rd	Cooper	-24.30798	145.28880
High	0033021	Barcoo R @ Coolagh	Cooper	-24.03839	144.86748
High	003207a	Thomson R @ Ag College	Cooper	-23.35122	144.32922
High	003208a	Towerhill Ck @ Lammermoor	Cooper	-21.34311	144.64750
High	0021006	Wockingham Ck @ Conn Hole	Diamantina	-22.29639	142.48694
Low	0032165	Bullock Ck @ Dardanelles	Cooper	-21.41522	144.99754
Low	0032170	Rodney Ck @ Yarraman	Cooper	-22.97184	144.79671
Low	0032171	Thomson R @ Broadwater	Cooper	-22.67393	144.56811
Low	0032173	Thomson R @ Jim's Waterhole	Cooper	-23.22476	144.36422
Low	0032175	Towerhill Ck @ Kirby's Waterhole	Cooper	-21.91399	144.67351
Low	003302a	Alice R @ Weir Pool	Cooper	-23.97708	145.21597
Low	0021999	Diamantina R @ Old Cork	Diamantina	-22.91955	141.87949

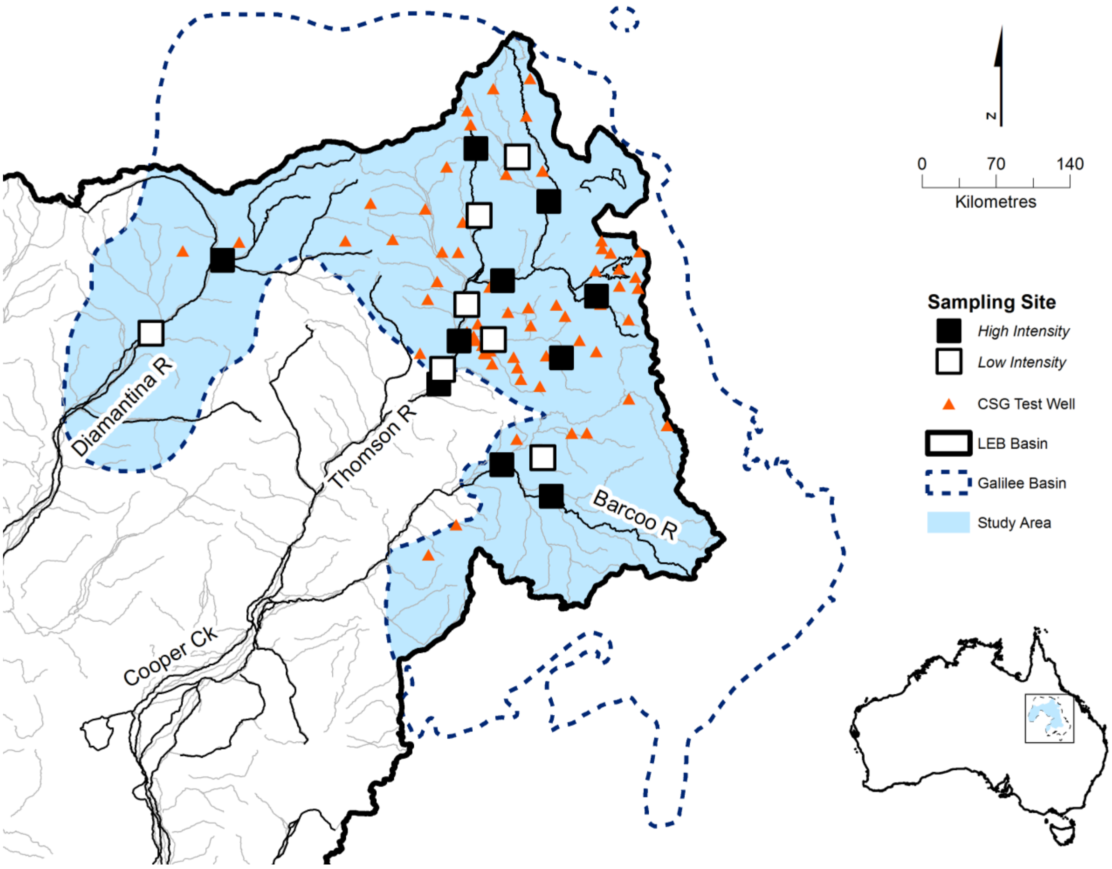


Figure 3: Study area, sampling site location and intensity, and CSG test well locations in the Galilee subregion of the Lake Eyre Basin.

2.1 Hydrology

2.1.1 Values

- Long-term data sets currently exist for some major tributaries.
- Additional benefit to external reporting frameworks and state-wide policy objectives.
- Contributes to social, cultural and aesthetic values of floodplains channels and waterholes.
- Indicates change to natural flow regime and cycles of wetting and drying.
- Indicates spatial and temporal availability of water throughout the basin.
- Indicates patterns of floodplain inundation and waterhole persistence.
- Little ongoing costs once initial investment is made.

2.1.2 Sampling

Two types of surface-water monitoring were conducted for the Galilee subregion of the LEB.

1. Surface-water Network Analysis.

   A network of surface water level recorders were deployed at high intensity sampling sites and areas of local significance throughout the Galilee subregion (Table 3). Temperature and EC data was also captured with water-level recorders and included in water quality monitoring. This hydrological information was used to complement the existing network of state operated flow monitoring stations (Table 4) to better describe the long-term natural flow patterns and seasonal trends in water availability in the monitoring area.

Table 4: Location of state operated water monitoring/gauging stations in close proximity to the Galilee subregion, their collection parameters, and commencement dates.

Site	Gauge #	Water Quality	Latitude	Longitude	Commence
Alice R at Barcaldine	003302A	L, D	23°38'57.5"S	145°12'57.5"E	5/12/1967
Barcoo R at Blackall	003303A	L, D	24°25'36.3"S	145°27'30.0"E	1/05/1969
Barcoo R at Retreat	003301B	L, D	25°11'07.5"S	143°16'52.5"E	3/12/1999
Cornish Ck at Bowen Downs	003204A	L, D	22°26'57.1"S	145°01'27.3"E	11/08/1999
Darr R at Darr	003205A	L, D	23°12'57.5"S	144°04'49.9"E	17/06/1969
Thomson R at Longreach	003202A	L, D, T, E	23°24'35.7"S	144°13'43.3"E	29/05/1969
Mills Ck at Oondooroo	002105A	L, D	22°10'36.59"S	143° 9'49.20"E	22/05/2007

* L = Level (m); D = Discharge (ML/Day); T = Water Temperature (˚C); E = Electrical Conductivity (mS/cm).

2. Spatial Refuge Analysis

   Silcock (2009) identified permanent refuge waterbodies throughout the Galilee subregion and wider LEB using a combination of anecdotal and empirical information. Using this data set, and satellite imagery taken during periods of extended dry conditions, a spatial refuge model can be defined for the monitoring region. Areas of local significance such as floodplain lakes and springs can also be included in this model. Ultimately, this information provides a background context to refuge distribution and function in the region and help define source-sink population dynamics for biological receptors in the monitoring area.

2.1.3 Receptor analysis

Daily water-level readings were offset against local atmospheric pressure and data-logger installation heights prior to analysis and reporting of hydrological data. Data from additional stream monitoring stations were also incorporated into all analysis and reporting. The following table outlines a number of general hydrological receptors, and has been sourced from Thoms *et al.* (2009).

Table 5: Key hydrological variables, links to the long term monitoring of water resources and the relative time-frame of potential response (sourced from Thoms et al. 2009).

Variable	Links to regional water resource monitoring	Response time-frame
Total surface water availability	- Water resource development - Climate change - Land use change	Cumulative Cumulative Cumulative
Frequency of wetting and drying in terminal lakes	- Water resource development - Climate change - Floodplain development - Land use change - Presence of in-channel structures (*e.g.* roads and culverts)	Cumulative Cumulative Cumulative Cumulative Cumulative
Floodplain inundation frequency	- Water resource development - Climate change - Floodplain development - Land use change	Cumulative Cumulative Cumulative Cumulative
Hydrological metrics associated with in-channel flow events	- Water resource development - Climate change - Floodplain development - Land use change - Presence of in-channel structures (*e.g.* roads and culverts)	Cumulative Cumulative Cumulative Cumulative Cumulative
Waterhole persistence	- Water resource development - Climate change	Cumulative Cumulative

2.1.4 Baseline assessment

1. Surface-water Network Analysis

Hydrology and water quality were monitored in 10 high intensity sites in major tributaries (Fig. 3). Using a combination of established gauging stations and installed CTD-Diver dataloggers (Schlumberger, Canada), water level, EC, and temperature readings were collected at -hour intervals, for the period between October 2014 and May 2015. All reaches received a series of 'channel-flow' events between mid-December and mid-January after a prolonged period of drying (Fig. 4, 5, 6). These smaller, in-channel events replenish and temporarily connect drying waterholes (see Fig. 1), ultimately sustaining water dependent biota through time. High flows and floodplain inundation did not occur during the study period.

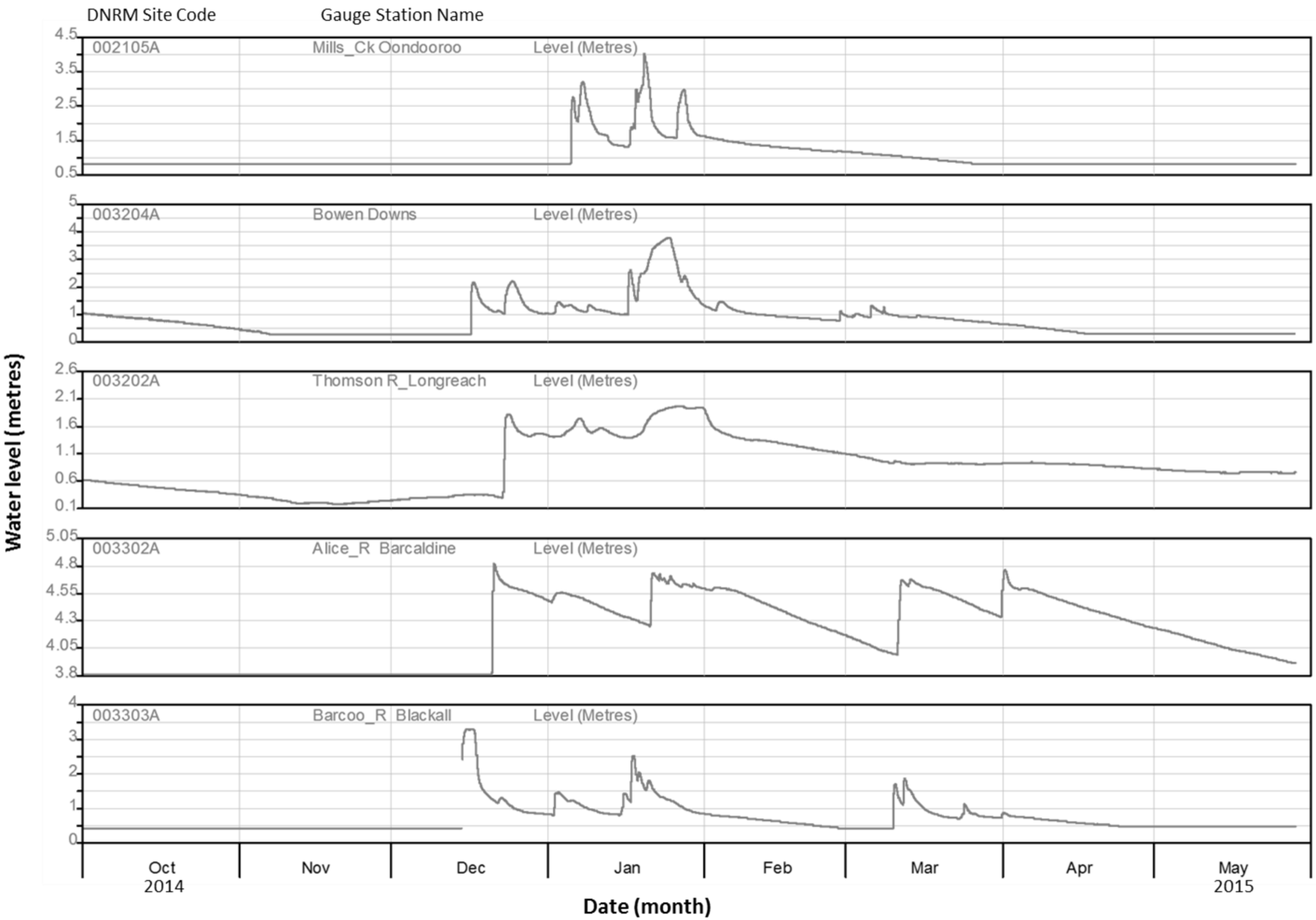


Figure 4: Flow data from 5 fixed DNRM gauging stations in the Galilee subregion of the LEB - i.e. upper Diamantina catchment (002105A), Thomson sub-catchment (003204A, 003202A, 003202A) and Barcoo sub-catchment (003302A, 003303A), between October 2014 and May 2015.

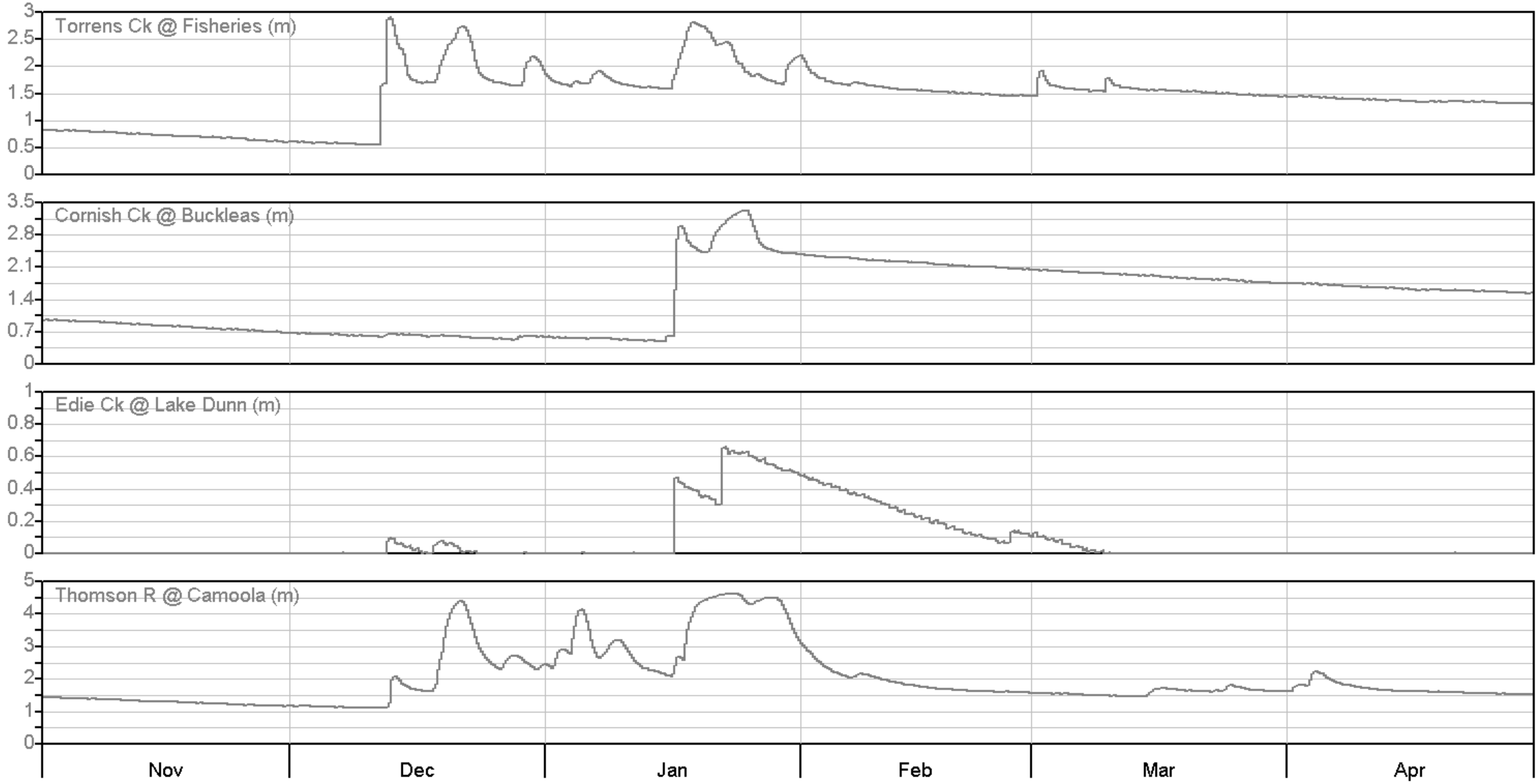


Figure 5: Flow data from 4 CTD divers installed in the Galilee subregion of the LEB between October 2014 and May 2015.

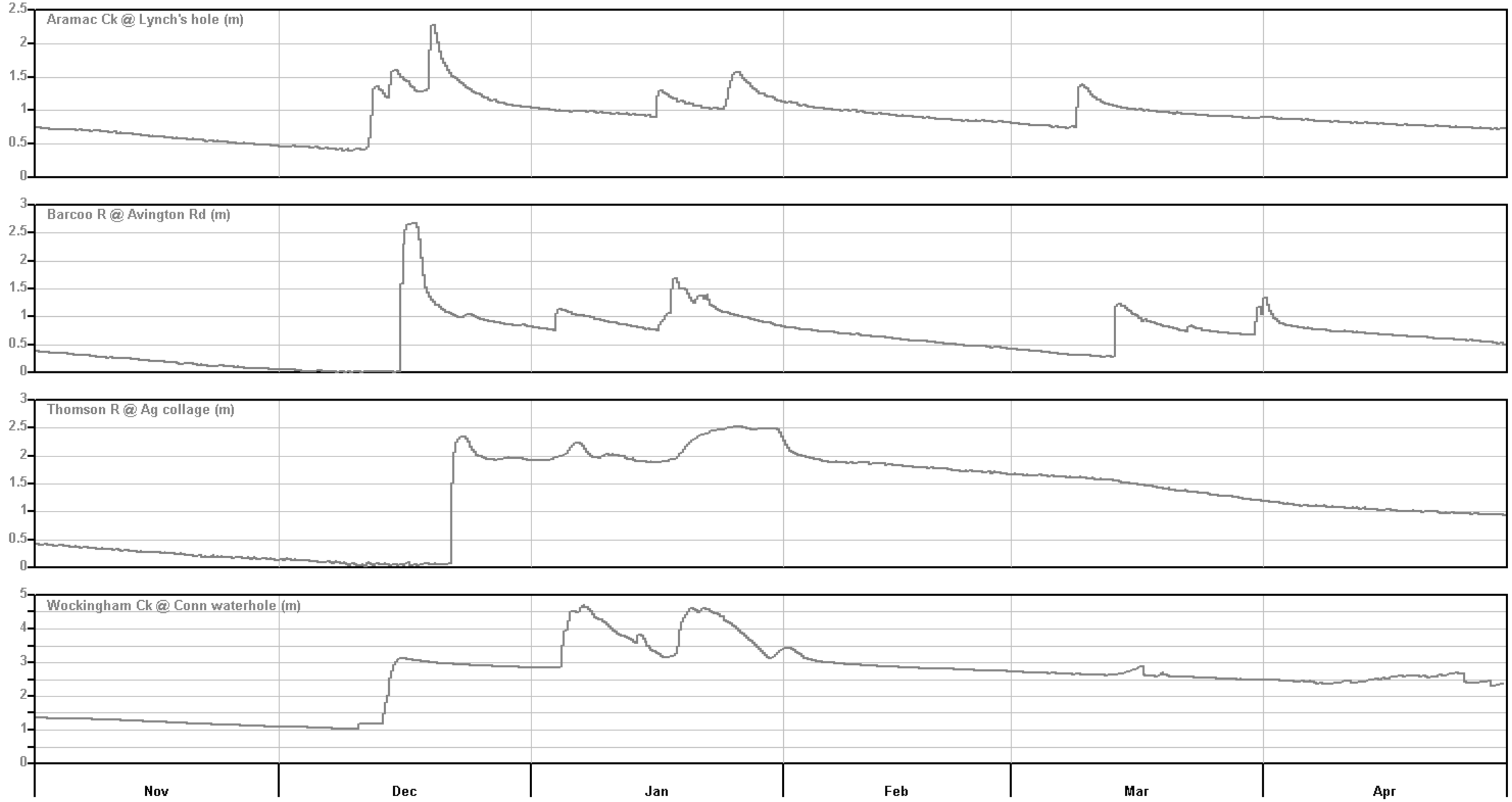


Figure 6: Flow data from 4 CTD divers installed in the Galilee subregion of the LEB between October 2014 and May 2015.

2. Spatial Refuge Analysis

Lake Dunn is a semi-arid, non-floodplain lake situated on the eastern boundary of the LEB catchment. The sandy base has been scoured to a gently sloping depression with maximum depth at CTF less than 2.5 metres (M. Dickson, ‘The Lake’, *pers comm*). The lake is considered an area of local significance, providing cultural, social and aesthetic values to a range of stakeholders. Patterns of wetting and drying, rainfall, and lake morphology were quantified using three sources: 1) Anecdotal evidence. Rainfall records (mm $month^{-1}$) and temporal patterns of ‘full’ and ‘dry’ have been recorded for Lake Dunn by the Dickson family (‘The Lake’) since 1916. 2) Satellite imagery. A combination of aerial, LANDSAT and SPOT imagery was used to digitise the visible bank or water level and create a time series raster catalogue for Lake Dunn water levels over periods of wetting and drying (Fig. 7). This information was used to quantify lake perimeter and surface area summary statistics in years of high and low rainfall (Table 6). And 3) Bathymetry. Waterhole bathymetric mapping was performed during a period of below CTF. This information characterises volume and habitat information for the lake at different stage heights.

Such information could feed into a regional spatial refuge network to provide a better understanding of refuge distribution and function, and help define source-sink population dynamics for biological receptors in the monitoring area.

Table 6: Summary statistics and temporal patterns of wetting and drying for Lake Dunn captured during ‘Wet’ (November - March) and ‘Dry’ (April - October) phases.

Record Length (1916 - 2014)	Occurrence	Periodicity (yrs)	
"Full" Classification	55	1.8	
"Dry" Classification	16	6.1	
Phase	**Mean (± SE)**	**Min**	**Max**
Wet (November - March)			
Perimeter (km)	15.7 (± 1.6)	12.2	20.4
Surface Area (km^2)	58.0 (± 4.4)	44.9	68.4
Rainfall (mm/season)	65 (± 4)	1	194
Dry (April - October)			
Perimeter (km)	9.0 (± 0.8)	8.0	12.0
Surface Area (km^2)	30.4 (± 4.0)	23.5	45.7
Rainfall (mm/season)	65 (± 4)	0	71

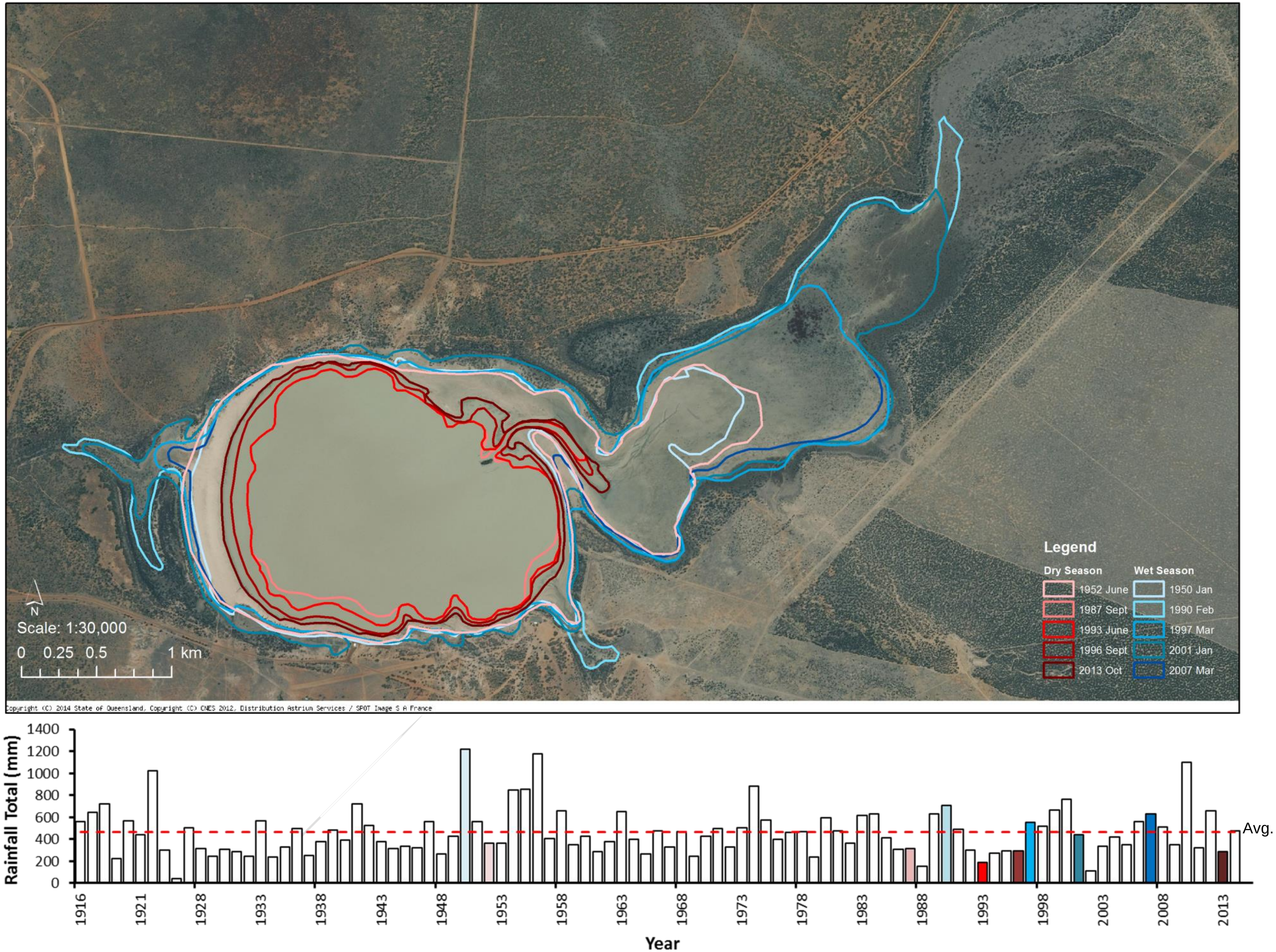


Figure 7: Time series raster catalogue of the temporal patterns of wetting and drying for Lake Dunn captured during wet and dry phases (see Table 6).

2.1.5 *Summary and future monitoring*

Hydrological monitoring of key waterholes in the Galilee subregion of the LEB contributes to the monitoring of healthy aquatic and floodplain ecosystems, supports the maintenance of social, cultural and aesthetic values of aquatic ecosystems, and provides an indicator of anthropogenic disturbance. In addition, hydrologic data may also reveal broader climatic variations and change. Finally, water-level monitoring can be used to describe waterhole persistence and drawdown over time, when bathymetry and evaporation data are also available. It is recommended that flow monitoring be continued and expanded into the future, to provide baseline data from which to quantify the timing, frequency, magnitude, duration, and rates change in the natural flow regime. This information will provide an assessment of total surface-water availability through time, a better understanding of refuge distribution and function throughout the region and long-term assessment of hydrological change due to human disturbance.

2.2 Water quality

2.2.1 *Values*

- Development or review of local water quality guidelines.
- Long-term datasets for specific water quality parameters.
- Highlights changes to the natural physical and chemical conditions.
- Highlights potential contamination from toxicants.
- Potential early indicator of modified productivity potential (*i.e* algal blooms).
- Contributes to social, cultural and aesthetic knowldege of floodplains, channels and waterholes.
- Easy to collect.

2.2.2 *Sampling*

It is proposed that water-quality monitoring be comprised of three complementary approaches:

1. *In-situ* Monitoring.

   Surface and sub-surface sampling at three different points within a waterhole, for both high intensive and low intensive survey sites. Sampling conducted twice per year in conjunction with fish and macroinvertebrate surveys using a hand held multi-probe (Horiba U-50, Japan) to measure temperature, pH, conductivity, dissolved oxygen and turbidity.

2. Water Sample Assessment

   Water samples taken at each of the high and low intensity sampling sites, stored according to standardised methods (*e.g.* AS/NZS 5667.1:1998), and submitted to an accredited testing laboratory. The parameters in Table 7 are to be collected and analysed in conjunction with other sampling.

3. Long-term Monitoring

   Temperature and EC data collected via the daily water-level readings was used to monitor long-term trajectories in physicochemical conditions. This information will aid in the development of improved local water quality guidelines for the region. An array of turbidity probes deployed in strategic waterholes (i.e. at the confluence of two major tributaries, and or in areas of local significance) may also be installed to contribute to the long term collection of water-quality data.

Table 7: Minimum water quality parameters to be tested in a laboratory and collected twice per year in conjunction with other sampling.

Water Quality Parameter		Units
Physico-chemcial		
	Electrical Conductivity @ 25C	ms/cm
	Turbidity	NTU
	Colour - True	HU
	pH	
	Total Alkalinity as CaCO3	mg/L
	Alkalinity Hydroxide as OH	mg/L
	Alkalinity Carbonate as CO3	mg/L
	Alkalinity Bicarbonate as HCO3	mg/L
	Hardness as CaCO3 (calculated)	mg/L
	Hydrogen as H	mg/L
	Total Dissolved Solids (calc)	mg/L
	Total Dissolved Ions	mg/L
	Total Suspended Solids	mg/L
Major Ions		
	Calcium as Ca - soluble	mg/L
	Chloride as Cl	mg/L
	Magnesium as Mg - soluble	mg/L
	Nitrate as NO3	mg/L
	Potassium as K	mg/L
	Sodium as Na	mg/L
	Sulphate as SO4	mg/L
	Aluminium as Al - soluble	mg/L
	Boron as B	mg/L
	Copper as Cu - soluble	mg/L
	Fluoride as F	mg/L
	Iron as Fe - soluble	mg/L
	Manganese as Mn - soluble	mg/L
	Silica as SiO2 - soluble	mg/L
	Zinc as Zn - soluble	mg/L
Nutrients		
	Total Nitrogen	mg/L
	Total Phosphorus as P	mg/L
Productivity		
	Chlorophyll-a	µg/L

2.2.3 Receptor analysis

Water quality has direct links to ecosystem health and the provision of clean, useable water is critical for agricultural, social and cultural stakeholders. The information collected through this monitoring approach should be collated and expressed in terms of descriptive statistics (e.g. range, mean, standard deviation etc.; Table 8) to inform or update local water quality guidelines. Analysis and reporting of water quality data may also be conducted in conjunction fish and macroinvertebrate surveys to determine possible ecological linkages (see Sternberg and Cockayne, 2014).

Microalgae are an important component of aquatic ecosystem productivity and are highly sensitive to a wide range water quality conditions (Sternberg and Cockayne, 2014). Given the paucity of basic assemblage information for the LEB system, algal samples were taken during baseline assessments and 'banked' for later analysis. Spatial and temporal variability in phytoplankton relative abundance and genus richness are presented in Appendix 1. Microalgal sampling is not considered critical to long-term water-quality monitoring in the Galilee subregion, however can be contrasted with these baseline samples following disturbance events.

Table 8: Key water quality variables, ecological links to ecosystem processes (see Sternberg and Cockayne, 2014), and the relative time-frame of potential response.

Variable	Links to ecosystem processes	Response time-frame
Physicochemical parameters (e.g. conductivity, pH, dissolved oxygen, turbidity)	- Alteration to the natural physical and chemical attributes of surface-waters. - Increased light penetration in light limited systems. - Direct impact on freshwater dependent taxa.	Seasonal, cumulative Seasonal Seasonal
Major ions (e.g. Na, Mg, Ca, Cl, SO_4, HCO_3, K)	- Alteration to the natural physical and chemical attributes of surface-waters. - Direct impact on freshwater dependent taxa. - Indicator of potential stress to Ca^{3+} dependent organisms.	Seasonal, cumulative Seasonal Seasonal
Nutrients (e.g. N, P) and Productivity (e.g. Chlorophyll-a)	- Alteration to the natural physical and chemical attributes of surface-waters. - Modified primary productivity dynamics.	Seasonal, cumulative Seasonal, cumulative

2.2.4 Baseline assessment

Currently, no local water quality guidelines exist for the upper Copper catchment, which includes the Thomson and Barcoo River sub catchments. As such, trigger values were sourced from NWQMS (2000) - Australian and New Zealand Guidelines for Fresh and Marine Water Quality. A 95% protection level (*i.e.* level 2 framework for ecosystem condition - slightly to moderately disturbed ecosystems) was selected for the “South central Australia — low rainfall area” aquatic ecosystem guidelines. These guidelines may have only moderate relevance to ecosystems in the north-east Lake Eyre Basin where biota rarely experience the extremes in temperature and electrical conductivity seen in the south-central Australian region.

1. *In-situ* monitoring.

Water quality was measured *in-situ* on two occasions at both high and low intensity sampling sites in spring 2014 and autumn 2015. This information is summarised in Table 9. All *in-situ* water quality information can be found in Appendix 2.

Table 9: *In-situ* water quality monitoring information summarised for 10 high intensity and 8 low intensity sampling sites in the Galilee subregion of the LEB.

Parameter	Units	Mean (± S.E.)	Min	Max	Trigger Value NWQMS (2000)
Temperature	deg C	22.3 (±0.2)	17.0	30.8	n/a
pH		8.26 (0.08)	7.12	10.35	<6.5 or >9.0
DO	mg/L	11.53 (0.28)	5.42	25.20	<5
Electrical Conductivity	µs/cm	254 (13)	89	810	>5000
Turbidity	NTU	328 (22)	3	+1000	>100

2. Water Sample Assessment

Water quality was collected on two occasions at both high and low intensity sampling sites in spring 2014 and autumn 2015. Queensland Health Forensic and Scientific Services (QHFSS) were employed to analyse major ions (Bottle A), unfiltered nutrients (Bottle D) and chlorophyll-a (Bottle F) samples. This information is summarised in Table 10. All water quality sample information can be found in Appendix 3 and 4.

Table 10: Summary of water quality information collected at 10 high intensity and 8 low intensity sampling sites in the Galilee subregion of the LEB.

Water Quality Parameter	Units	Mean (± S.E.)	Min	Max	Trigger Value NWQMS (2000)
Physico-chemcial					
Electrical Conductivity @ 25C	µs/cm	259 (28)	85	749	>5000
Turbidity	NTU	377 (78)	6	1710	>100
Colour - True	HU	32 (5)	4	111	n/a
pH	-	7 (0)	6.79	8.69	<6.5 or >9.0
Total Alkalinity as $CaCO_3$	mg/L	86 (8)	21	196	n/a
Alkalinity Hydroxide as OH	mg/L	0 (0)	0	0.1	n/a
Alkalinity Carbonate as CO_3	mg/L	0.4 (0.1)	0	3.6	n/a
Alkalinity Bicarbonate as HCO_3	mg/L	104 (10)	26	236	n/a
Hardness as $CaCO_3$ (calculated)	mg/L	60 (5)	18	122	n/a
Hydrogen as H	mg/L	0 (0)	0	0	n/a
Total Dissolved Solids (calc)	mg/L	156 (15)	57	434	n/a
Total Dissolved Ions	mg/L	192 (20)	60	553	n/a
Total Suspended Solids	mg/L	126 (23)	7	541	n/a
Major Ions					
Calcium as Ca - soluble	mg/L	15.49 (1.23)	4	28	n/a
Chloride as Cl	mg/L	16.39 (3.45)	2.5	96	n/a
Magnesium as Mg - soluble	mg/L	5.08 (0.47)	1.9	12	n/a
Nitrate as NO_3	mg/L	1.25 (0.19)	0	5.8	>0.7
Potassium as K	mg/L	6.5 (0.83)	1.3	28	n/a
Sodium as Na	mg/L	27.44 (5.22)	5	145	n/a
Sulphate as SO_4	mg/L	15.02 (2.99)	1.1	85	n/a
Aluminium as Al - soluble	mg/L	0.35 (0.18)	0	5.3	>0.055
Boron as B	mg/L	0.12 (0.01)	0.04	0.32	>0.37
Copper as Cu - soluble	mg/L	0 (0)	0	0	>0.0014
Fluoride as F	mg/L	0.24 (0.04)	0.07	1.2	n/a
Iron as Fe - soluble	mg/L	0.23 (0.1)	0	2.6	n/a
Manganese as Mn - soluble	mg/L	0 (0)	0	0.04	>1.9
Silica as SiO_2 - soluble	mg/L	17 (2.04)	1	48	n/a
Zinc as Zn - soluble	mg/L	0.02 (0)	0	0.11	>0.008
Nutrients					
Total Nitrogen	mg/L	1.38 (0.18)	0.42	4.7	>1
Total Phosphorus as P	mg/L	0.28 (0.03)	0.05	0.79	>0.1
Productivity					
Chlorophyll-a	µg/L	19 (4)	3	130	5

3. Long-term monitoring.

Electrical conductivity (mS/cm) and temperature (deg C) were recorded at 3 hourly intervals between November 2014 and April 2015 at 10 high intensity sites in the Galilee subregion of the LEB (Fig. 8, 9, 10, 11). Electrical conductivity was shown to increase steadily as waterhole volume decreased following prolonged drying. This was followed by a sharp decrease in EC as flow entered the system. These patterns were reflected in the temperature readings over the same period. Strong diurnal fluctuations in water temperature were seen in shallow, drying waterholes, followed by a general decrease in temperature and diurnal cycling as flow entered the system. These patterns show the long term trajectory of some water-quality parameters over the natural cycles of wetting and drying in the LEB and are important for capturing both seasonal and cumulative changes due to CSG development, as well as influencing biotic patterns through time.

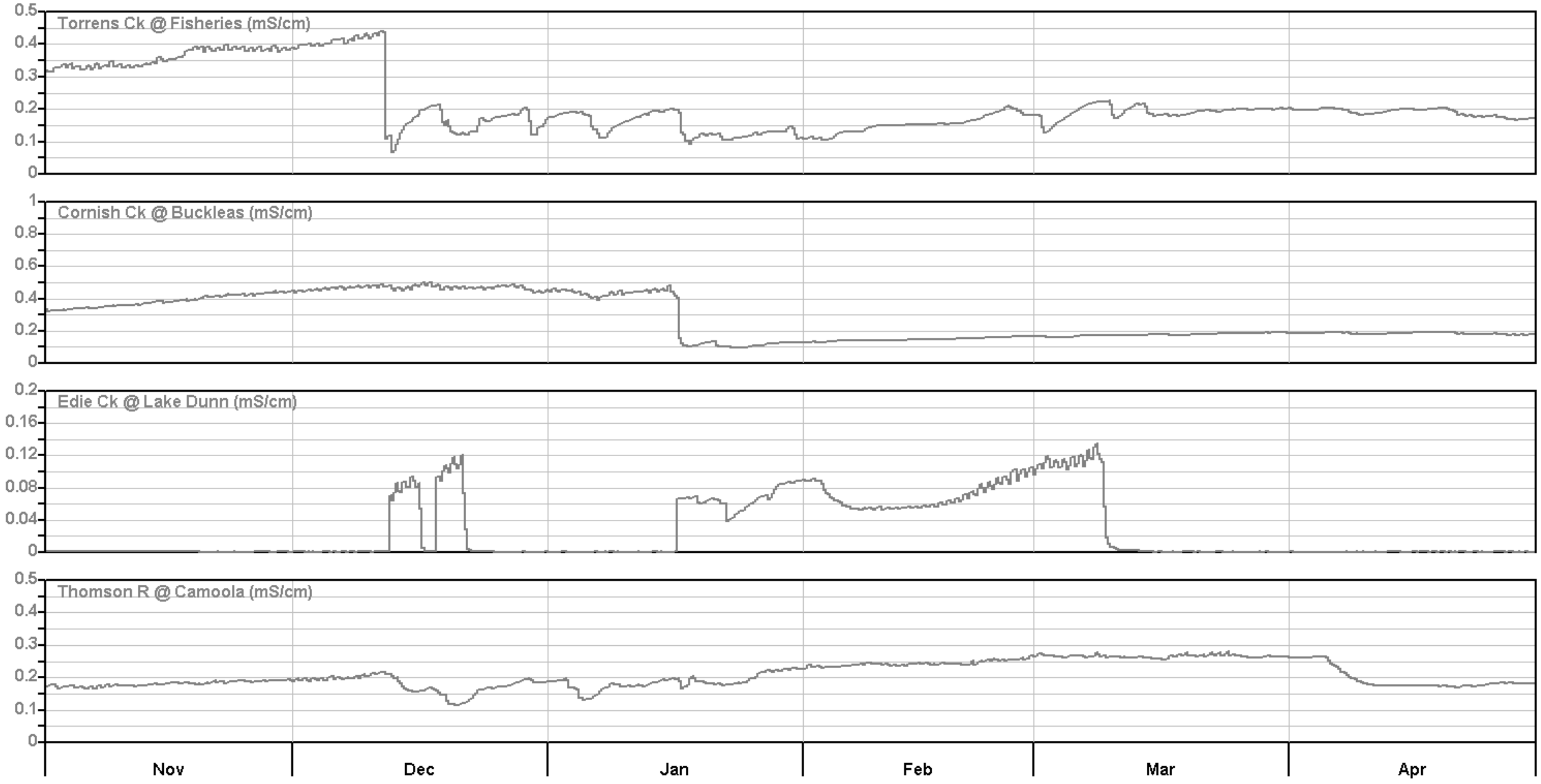


Figure 8: Electrical conductivity (mS/cm), measured in 3 hourly intervals, between November 2014 and April 2015 in 4 high intensity survey sites in the Galilee subregion of the LEB. Missing data indicates the reach was dry.

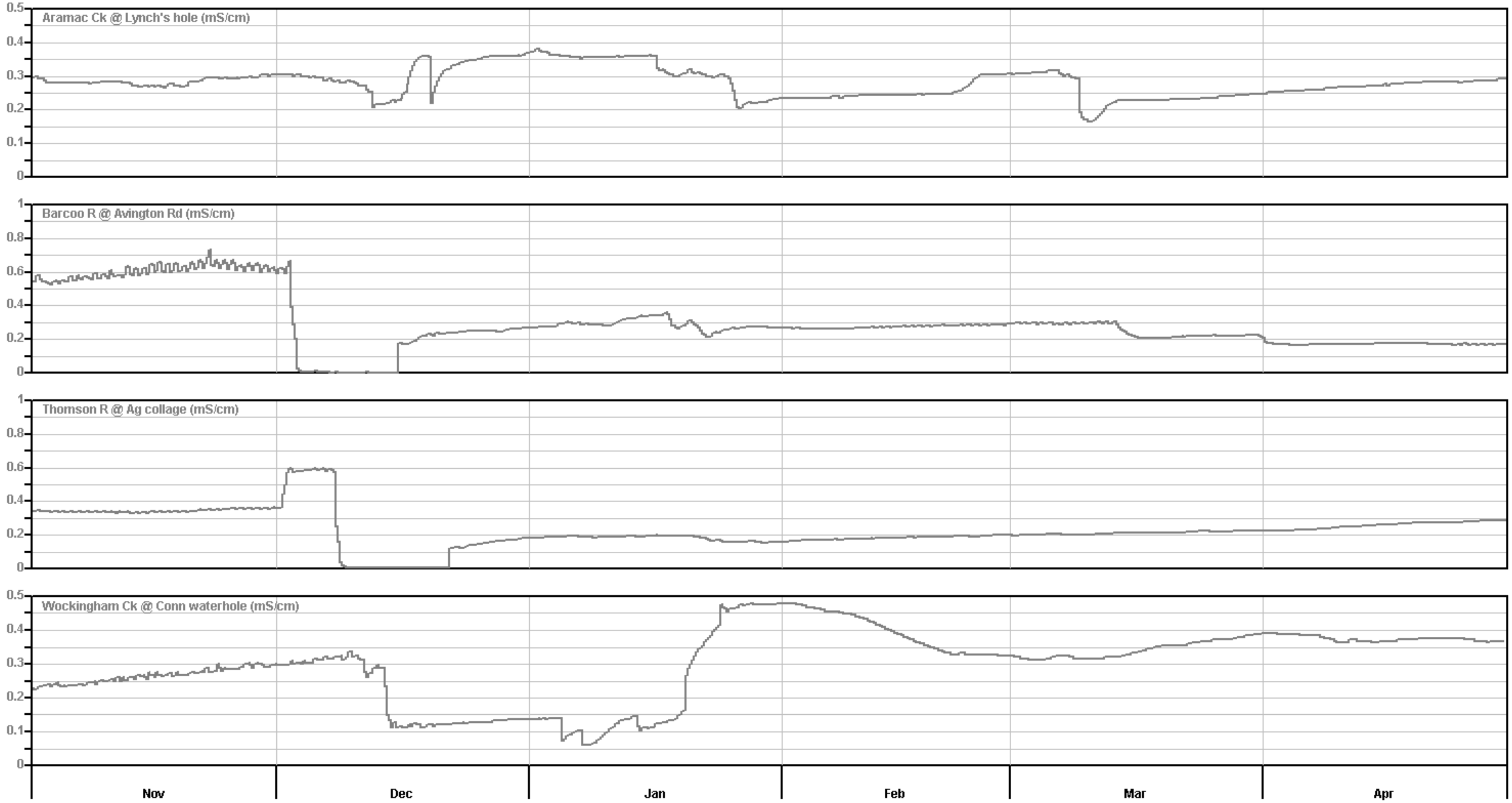


Figure 9: Electrical conductivity (mS/cm), measured in 3 hourly intervals, between November 2014 and April 2015 in 4 high intensity survey sites in the Galilee subregion of the LEB. Missing data indicates the reach was dry.

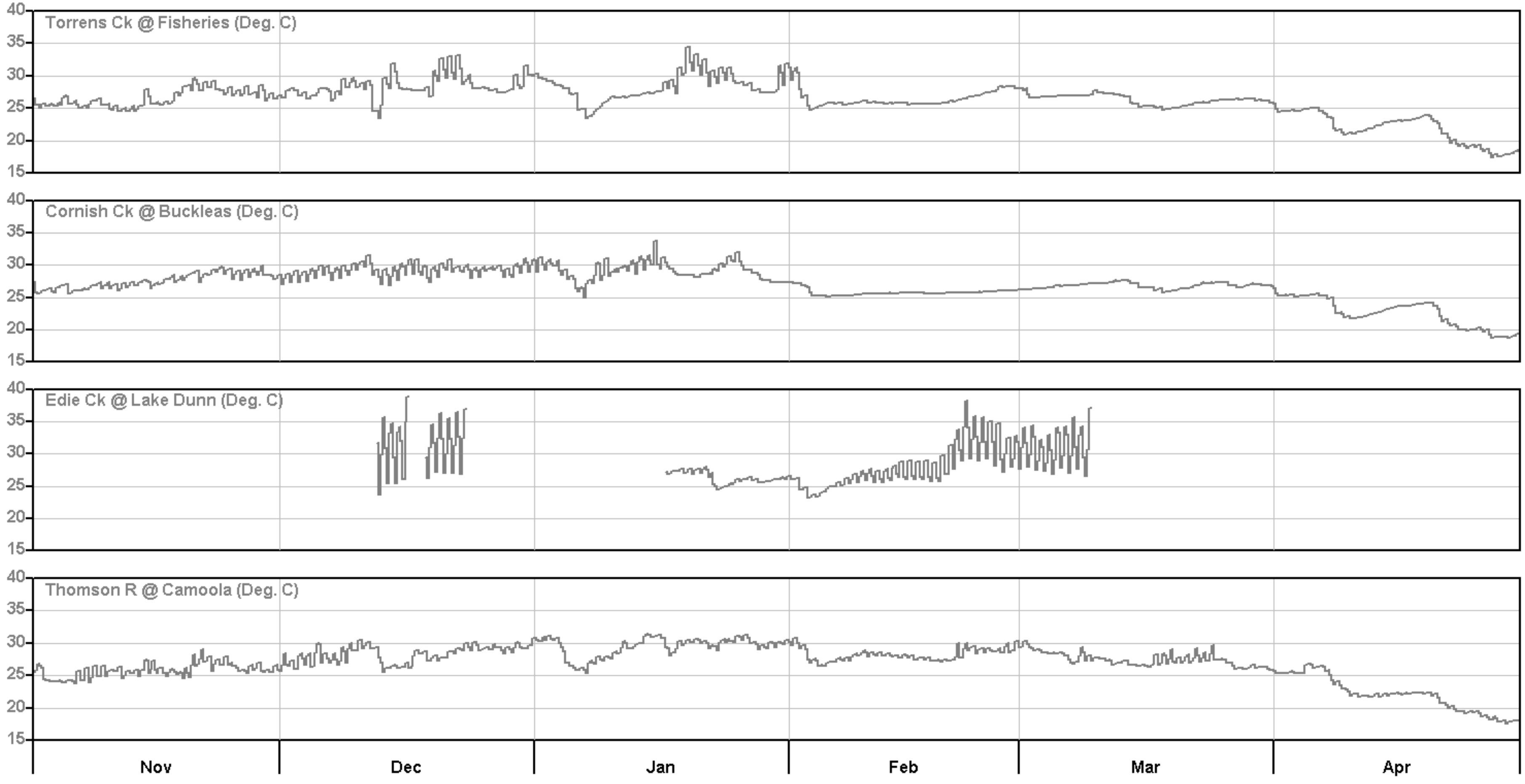


Figure 10: Water temperature (deg C), measured in 3 hourly intervals, between November 2014 and April 2015 in 4 high intensity survey sites in the Galilee subregion of the LEB. Missing data indicates the reach was dry.

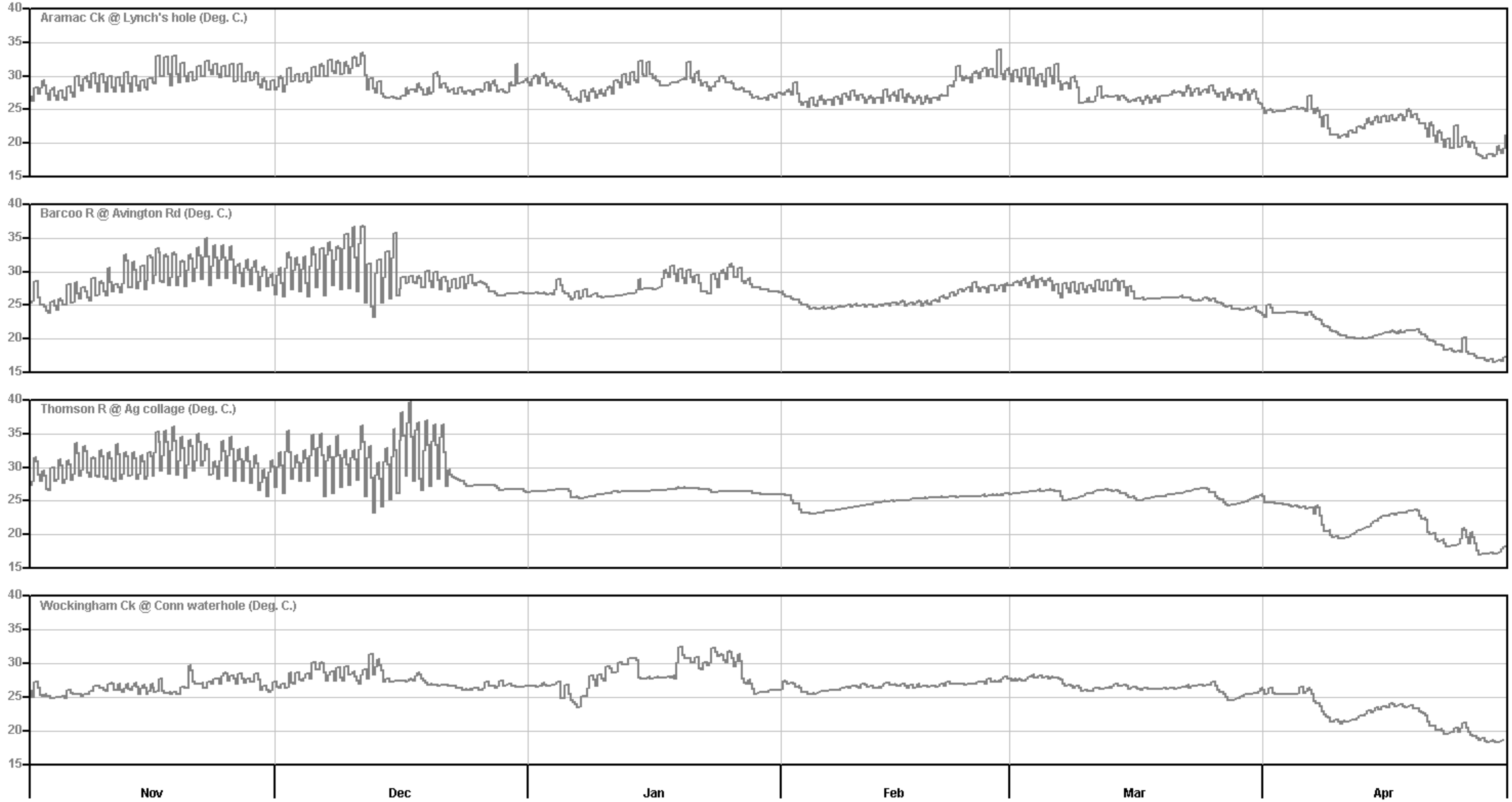


Figure 11: Water temperature (deg C), measured in 3 hourly intervals, between November 2014 and April 2015 in 4 high intensity survey sites in the Galilee subregion of the LEB. Missing data indicates the reach was dry.

2.2.5 Summary and future monitoring

The water-quality information presented in this report represents a snapshot of the regional physicochemical conditions over a natural wetting and drying cycle for the LEB. Although local water-quality guidelines are absent for the Galilee subregion, no alarming values were recorded relative to the NWQMS (2000) guidelines. However, these values are likely to vary considerably in relation to antecedent hydrological conditions, highlighting the importance of long-term baseline assessments and disturbance-event based monitoring to the development of local water-quality guidelines. The three complementary approaches presented in this report, *in-situ* monitoring, water sampling and long-term monitoring, are key components for updating these local water-quality guidelines, better understanding the changes in physicochemical conditions of drying waterholes, and monitoring the potential impacts of CSG development in the Galilee subregion. This information also contributes to assessment of the natural variation in biotic receptors such as fish and macroinvertebrates for the monitoring program.

2.3 Fish assemblages

2.3.1 Values

- Iconic biota that resonate with a wide range of stakeholders;
- Easily captured, identified and measured;
- Indicate seasonal change in short-term ecosystem condition;
- Indicate cumulative change in long-term ecosystem condition;

2.3.2 Sampling

In order to capture fish from a range of size classes, a combination of two double wing (large), and six single wing (small), fyke nets was employed. Large fyke nets were set in both upstream and downstream directions, parallel to flow, in relatively deep open sections of waterhole, while small fykes were set perpendicular to flow along littoral habitat. All nets were set overnight (c. 16hrs) (Sternberg *et al.* 2014). Fish captured during standardised macroinvertebrate seine netting were also included in fish assemblage estimates.

All individuals were identified to species, measured to the nearest millimetre (standard length), and external signs of disease noted.

2.3.3 Receptor analysis

Fish from individual fyke nets were standardised to a common set time prior to analysis, to allow for the calculation of Catch-Per-Unit-Effort (CPUE) estimates.

Fish assemblages potentially indicate a wide range of ecosystem processes through standardised estimates of abundance, biomass and richness, size class structure. More complex estimates of trophic and life-history guild abundance and biomass, and multivariate estimates of change in assemblage composition through time, may provide additional estimates of more long-term and complex ecosystem patterns.

Table 11: Key fish assemblage variables, ecological links to ecosystem processes (see Sternberg and Cockayne, 2014), and the relative time-frame of potential response.

Variable	Links to ecosystem processes	Response time-frame
Species richness	- Loss of iconic species. - Modified biodiversity and ecosystem services.	Seasonal Cumulative
Abundance/Biomass	- Failed recruitment and/or high mortality. - Modified long-lived species biomass. - Reduced primary productivity.	Seasonal Cumulative Seasonal, Cumulative
Size structure	- Failed recruitment and population persistence. - Modified effective breeding stock.	Seasonal Cumulative
Detritivore species abundance/biomass	- Reduced primary productivity. - Modified bottom-up trophic pathways.	Seasonal, Cumulative Cumulative
Carnivore species abundance/biomass	- Reduced primary productivity. - Modified top-down trophic pathways.	Seasonal, Cumulative Cumulative
Potadromous species abundance/biomass	- Modified spatial connectivity throughout the river network. - Modified flow dependent spawning cues.	Cumulative Cumulative
Abundance/Distribution of alien species	- Modified flow and habitat conditions. - New introductions and range expansions.	Seasonal Seasonal
Prevalence of disease	- Poor water quality and/or ecosystem condition.	Seasonal
Multivariate assemblage composition	- Uncoupling of natural flow-ecology patterns.	Seasonal, Cumulative

2.3.4 Baseline assessment

Fish assemblages were surveyed at 10 high intensity sampling sites in spring 2014 and autumn 2015. A total of 9456 individuals from 16 species and 12 families (13 native and 3 exotic) were captured during the baseline assessment (Table 12, Table 13).

Fish assemblages across the two sampling periods were dominated by small bodied, species including *Ambassis mulleri, Melanotaenia splendida tatei, Hypseleotris* spp., and the large bodied *Nematelosa erebi*. Large predators such as *Macquaria* sp., *Scortum barcoo* and the introduced *Oxyeleotris lineolatus*, made up a small proportion of the fish assemblages throughout the study area. Temporal variation in the abundance and distribution of all species was pronounced across the sampling periods (Table 12, Table 13), likely reflecting short-term seasonal variation in climate and ecosystem productivity.

With the exception of *Neosiluroides cooperensis* and *S. barcoo*, all species were captured from a range of size classes (Table 12, Table 13). Cohort abundance for two species, *N. erebi* and *Porochilus argenteus*, highlight the variation in fish life-history strategies across the region (Fig. 12). Abundant juvenile (~50mm) and sub-adult (~150mm) *N. erebi* cohorts suggest this species has a generalist spawning strategy, while the absence of juvenile *P. argenteus*, and dominance of adult individuals, suggests a more flow-dependent spawning strategy (Fig. 12). Seasonal changes to these natural size-class structure patterns may indicate failed recruitment or high mortality due to anthropogenic disturbance, while long-term changes may reflect alterations to the natural flow regime and or fish spawning cues.

Non-native fish abundance was generally low over the spring 2014 and autumn 2015 sampling period, accounting for a maximum of 8% of individuals captured (Table 12, Table 13). *Oxyleotris lineolatus* was the most abundant and widespread alien species, present in 50% of the sampling sites (Table 12, Table 13) and accounted for as much as 60% of total site abundance in some sampling locations (data not shown).

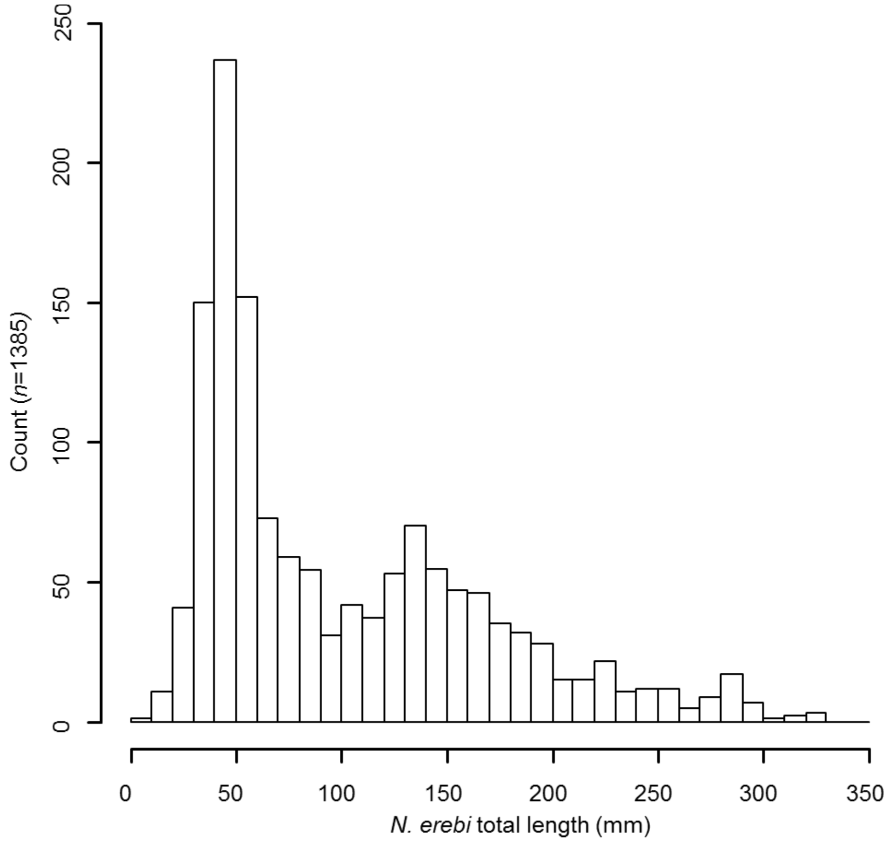
Given the knowledge gaps and survey priorities for baseline assessment (Fig. 6 *in* Sternberg and Cockayne, 2014), a total of 84 introduced *O. lineolatus* were retained for dietary analysis. Baseline assessment of non-native species resource use and trophic breadth in the LEB will help develop our understanding of the direct links with native biota and the predicted response to altered hydrological patterns from potential CSG development. In the Galilee subregion of the LEB, this species was shown to primarily consume fish and crustaceans, with minor inputs from aquatic and terrestrial invertebrates (Fig. 13). Average stomach fullness was 33% suggesting this species may be unable to feed at maximum capacity in turbid environments. Any changes in turbidity associated with the potential release of co-produced CSG water may increase their ability to feed and reproduce in the LEB. Post-larval *O. lineolatus* (c. 10 mm total length) were sampled in the Thomson River at Camoola waterhole in Autumn 2015, following a small flow during a period of waterhole drawdown (*see* "Hydrology" section below). This indicates that *O. lineolatus* may possess a no- or low-flow spawning life-history strategy in the LEB.

Table 12: Summary statistics for native and exotic fish species sampled from 10 sites in the Galilee subregion of the Lake Eyre Basin in spring 2014

Family/Species	Common name	CPUE	% of total CPUE	Size range (mm)	% Site Presence
Native					
Ambassidae					
Ambassis mulleri (Klunzinder, 1880)	Western chanda perch	1148	18%	29 - 68	70%
Atherinidae					
Craterocephalus s. stercusmuscarum "maculatus"	Hardyhead	272	4%	24 - 72	10%
Clupeidae					
Nematalosa erebi (Günther, 1864)	Bony herring	2048	32%	29 - 485	100%
Eleotridae					
Hypseleotris Spp.	Gudgeon	708	11%	16 - 46	90%
Melanotaeniidae					
Melanotaenia splendida tatei (Zietz, 1896)	Desert rainbowfish	1061	16%	5 - 97	90%
Percichthyidae					
Macquaria sp.	Lake Eyre golden perch	105	2%	15 - 460	70%
Plotosidae					
Neosiluroides cooperensis (Allen & Feinberg, 1998)	Cooper Creek catfish	3	0.05%	284 - 406	10%
Neosilurus hyrtlii (Steindachner, 1867)	Hyrtl's tandan	381	6%	10 - 306	100%
Porochilus argenteus (Zeitz, 1896)	Silver tandan	93	1%	77 - 227	70%
Retropinnidae					
Retropinna semoni (Weber, 1895)	Australian smelt	267	4%	15 - 41	30%
Terapontidae					
Bidyanus welchi (McCulloch & Waite, 1917)	Welch's grunter	1	0.02%	212	10%
Leiopotherapon unicolor (Günther, 1864)	Spangled perch	183	3%	42 - 203	70%
Scortum barcoo (McCulloch & Waite, 1917)	Barcoo grunter	4	0.1%	227 - 345	30%
Exotic/Introduced					
Cyprinidae					
Carassius auratus (Linnaeus, 1758)	Goldfish	21	0.3%	33 - 75	10%
Eleotridae					
Oxyeleotris lineolatus (Steindachner, 1867)	Sleepy cod	60	1%	60 - 350	50%
Poeciliidae					
Gambusia holbrooki (Girard, 1859)	Gambusia	80	1%	22 - 36	30%

Table 13: Summary statistics for native and exotic fish species sampled from 10 sites in the Galilee subregion of the Lake Eyre Basin in autumn 2015

Family/Species	Common name	CPUE	% of total CPUE	Size range (mm)	% Site Presence
Native					
Ambassidae					
Ambassis mulleri (Klunzinder, 1880)	Western chanda perch	267	9%	15 - 145	90%
Atherinidae					
Craterocephalus s. stercusmuscarum "maculatus"	Hardyhead	10	0.3%	45 - 45	10%
Clupeidae					
Nematalosa erebi (Günther, 1864)	Bony herring	1011	32%	15 - 325	100%
Eleotridae					
Hypseleotris Spp.	Gudgeon	489	16%	20 - 45	70%
Melanotaeniidae					
Melanotaenia splendida tatei (Zietz, 1896)	Desert rainbowfish	637	20%	15 - 81	90%
Percichthyidae					
Macquaria sp.	Lake Eyre golden perch	60	2%	15 - 495	80%
Plotosidae					
Neosiluroides cooperensis (Allen & Feinberg, 1998)	Cooper Creek catfish	-	-	-	-
Neosilurus hyrtlii (Steindachner, 1867)	Hyrtl's tandan	110	4%	76 - 299	80%
Porochilus argenteus (Zeitz, 1896)	Silver tandan	176	6%	20 - 205	100%
Retropinnidae					
Retropinna semoni (Weber, 1895)	Australian smelt	17	1%	33 - 51	20%
Terapontidae					
Bidyanus welchi (McCulloch & Waite, 1917)	Welch's grunter	2	0.1%	57 - 264	20%
Leiopotherapon unicolor (Günther, 1864)	Spangled perch	78	3%	59 - 200	60%
Scortum barcoo (McCulloch & Waite, 1917)	Barcoo grunter	-	-	-	-
Exotic/Introduced					
Cyprinidae					
Carassius auratus (Linnaeus, 1758)	Goldfish	2	0.1%	180 - 185	10%
Eleotridae					
Oxyeleotris lineolatus (Steindachner, 1867)	Sleepy cod	217	7%	10 - 365	50%
Poeciliidae					
Gambusia holbrooki (Girard, 1859)	Gambusia	40	1%	14 - 42	40%



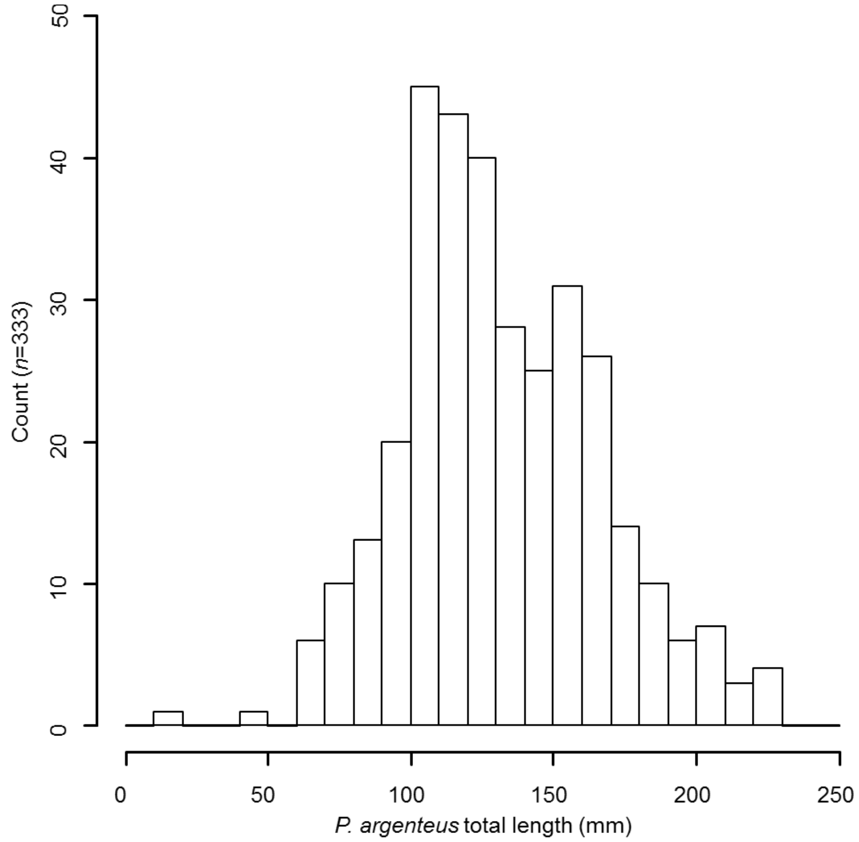


Figure 12: Length-frequency histograms for *N. erebi* (*n*=1385) and *P. argenteus* (*n*=333) from 10 sites in the LEB collected over the spring 2014 and autumn 2015 sampling period.

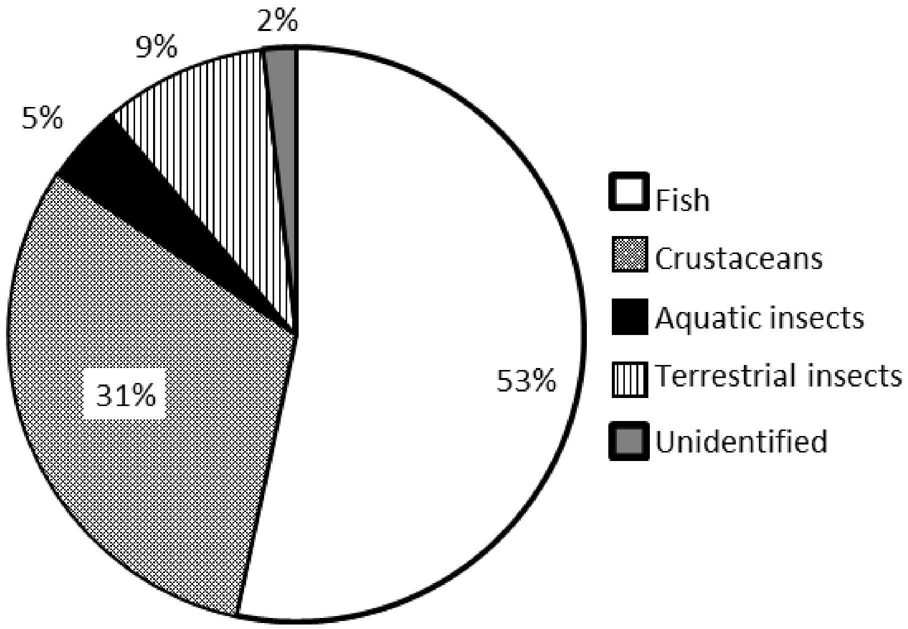


Figure 13: *Oxyeleotris lineolatus* diet variability (*n*=84) in the Galilee subregion of the Lake Eyre Basin. Average stomach fullness = 33%.

Craterocephalus stercusmuscarum stercusmuscarum (Hardyhead) was sampled in both spring 2014 and autumn 2015 from a single location, Aramac Creek at Lynch's Hole (-23.12643 S; 145.37380 E). Phylogenetic analysis performed by the Molecular Ecology Lab, Griffith University, Brisbane, suggest this species belongs to the "maculatus clade" of subspecies *Craterocephalus stercusmuscarum stercusmuscarum* (Fig. 14). The maculatus clade is distributed in coastal Queensland from the Mulgrave River to Deepwater River and also extends inland into Cooper Creek (Unmack and Dowling 2010). The population has previously been referred to as "Aramac Springs hardyhead" and is known from a single spring fed habitat in Pelican Creek, upper Cooper Creek drainage, as well as from a single isolated waterhole in McDonnell Creek (northern Flinders Ranges). These two localities are separated by ~1,000km. This is the first record of this sub-species outside of this range.

Figure 14: *Craterocephalus stercusmuscarum stercusmuscarum* "maculatus" from Aramac Creek, in the upper Cooper catchment.

2.3.5 Summary and future monitoring

Fish assemblages are a key component of ecosystem monitoring as they are easy to capture and identify, are responsive to a range of short- and long term changes in ecosystem function, resonate with a wide range of stakeholders, and have been well studied to date. The diversity and abundance of fish species captured during the baseline assessment was consistent with previous reporting frameworks (Cockayne *et al.* 2012; Cockayne *et al.* 2013; Sternberg *et al.* 2014) for the Galilee subregion of the LEB. As expected, spatial and temporal variation in assemblage composition was pronounced, highlighting the natural variability in refugial waterholes throughout the river network and the importance of long-term monitoring to establish baseline trends in fish community composition over time. Biannual monitoring in expected high pressure areas is therefore recommended. This information is critical to detect potential changes in the natural cycles of wetting and drying and alteration to the natural physical and chemical attributes of the surface water. Future monitoring could be expand to include species reproduction, diet and body condition as part of annual assessments to better quantify cause and effect links between potential CSG development and fish trophic dynamics and flow-spawning cues in the LEB.

2.4 Invertebrates

2.4.1 Values

- Sensitive indicator of physicochemical decline;
- Sensitive indicator of contaminants and toxicants;
- Indicate short-term changes to primary productivity and food web dynamics.

2.4.2 Sampling

A combination of dip and seine netting was used to capture a range of aquatic macroinvertebrates sensitive to changes in electrical conductivity (EC) and Calcium (Ca^{3+}) deficiency. Dip nets were swept at right angles to the bank in multiple habitat types until a minimum of 10m was reached. Seine nets were swept on two occasions through open littoral areas, recording the two-dimensional area for each seine. Macroinvertebrates (*e.g.* Decapod crustaceans, Macrobranchiopods, Bivalves, Gastropods), were counted and identified in the field to genus where possible or voucher specimens retained for laboratory identification.

2.4.3 Receptor analysis

Combined samples from dip and seine nets were standardised to a common length (dip net, 10 m) and common area (seine net, 40 m) prior to analysis. This enabled calculation of Catch-Per-Unit-Effort (CPUE) estimates. *Cherax spp.* and *A. transversa* captured during fyke net sampling for fish were also included in sampling estimates.

Macroinvertebrates can potentially indicate a wide range of ecosystem processes at the primary and secondary trophic level. For example, physiological estimates of Ca^{3+} for individuals may provide an early indication of physico-chemical stress, while changes in abundance and biomass of sensitive taxa can indicate more prolonged contamination or altered productivity dynamics.

Table 14: Key macroinvertebrate variables, ecological links to ecosystem processes (see Sternberg and Cockayne, 2014), and the relative time-frame of potential response

Variable	Links to ecosystem processes	Response time-frame
Abundance/Distribution of alien species	- Modified flow and habitat conditions. - New introductions and range expansions.	Seasonal Seasonal
Abundance/Biomass of sensitive taxa	- Modified physicochemical properties. - Modified primary productivity. - Increase in toxicity and or contamination.	Seasonal Cumulative Cumulative
Multivariate assemblage composition	- Uncoupling of natural flow-ecology patterns. - Modified physicochemical properties. - Modified primary productivity. - Increase in toxicity and or contamination.	Seasonal, Cumulative Cumulative Cumulative Cumulative
Desiccation dependent invertebrate guild	- Loss of natural patterns of wetting and drying.	Cumulative

2.4.4 Baseline assessment

Macroinvertebrate abundance and distribution was estimated on two occasions over spring 2014 and autumn 2015. Combined CPUE and site presence data for the sampling period is presented in Table 15. Targeted sampling for the macroinvertebrate receptors, highlighted in Sternberg and Cockayne (2014), found 12 species from 11 genera including branchiopods, bivalves, gastropods and decapod crustaceans (Table 15). Predictably, the freshwater prawn/shrimp *Macrobrachium* sp., *Caridina* sp. and *Paratya* sp. dominated catches, being present in high abundances in all sites (Table 15). Freshwater snails were also abundant where present, however showed greater spatial variability throughout the catchment (Table 15).

The freshwater mussel, *Velesunio* sp., and the introduced Red claw crayfish, *Cherax quadricarinatus,* were both widespread throughout the Galilee subregion of the LEB (Table 15), however the latter was notably absent from the Diamantina catchment and the semi-arid Lake Dunn (Cooper Catchment), an ecosystem of regional social and ecological significance (Table 16). Spatial and temporal variability in *C. quadricarinatus* distribution and abundance was highlighted in Sternberg and Cockayne (2014) as a priority receptor for monitoring alteration to the natural cycles of wetting and drying the Galilee subregion. Further investigation into diet, reproduction and population structure of this species may yield a better understanding of interactions with other native macroinvertebrates, as well as better confidence in predicting their response to CSG development in the Galilee subregion.

Table 15: Macroinvertebrate CPUE and site distribution for combined high intensity surveys between spring 2014 and autumn 2015 across the Galilee subregion of the LEB. Brackets indicate combined species CPUE estimates.

Genus/Species	Common Name	Abundance (CPUE)	% Site Presence
Invertebrates			
Branchiopoda			
Anostraca sp.	Fairy shrimp	4	10%
Notostraca sp.	Shield shrimp	-	-
Bivalvia			
Velesunio sp.	Freshwater mussel	19	100%
Gastropoda			
Plotiopsis balonnensis	Sculptured snail	[1258]	30%
Physa acuta (exotic)	Tadpole Snail		20%
Notopala alisoni	River Snail		40%
Bullastra affinis	-		10%
Malacostraca			
Macrobrachium sp.	Freshwater prawn	[2777]	100%
Paratya sp.	Freshwater shrimp		
Caridina sp.	Freshwater shrimp		
Cherax destructor	Common Yabby	44	70%
Cherax quadricarinatus (exotic)	Redclaw crayfish	208	80%
Austrothelphusa transversa	Inland freshwater Crab	2	20%
Sponges*			
Spongillidae			
Ephydatia sp.	Freshwater sponge	-	60%
Turtles*			
Cheluidae			
Chelodina sp.	Long-necked turtle	[24]	70%
Emydura macquarii "emmotti"	Cooper creek turtle		

* included here for data presentation purposes only.

Table 16: Spatial and temporal variability in the introduced Red claw crayfish, *Cherax quadricarinatus*, CPUE across spring 2014 and autumn 2015.

Catchment	Site Name	Site #	Spring 2014 (CPUE)	Autumn 2015 (CPUE)
Cooper	Cornish Ck @ Bucksleas	0032166	14	25
Cooper	Barcoo R @ Coolagh	0033021	1	1
Cooper	Edie Ck @ Lake Dunn	0032168	0	0
Cooper	Thomson R @ Camoola	0032172	1	3
Cooper	Torrens Ck @ Fisheries	0032174	8	3
Cooper	Towerhill Ck @ Lammermoor	003208a	55	39
Cooper	Barcoo R @ Avington Rd	0033010	1	3
Cooper	Aramack Ck @ Lynch's Hole	0032176	4	57
Cooper	Thomson R @ Ag College	003207a	1	5
Diamantina	Wockingham Ck @ Conn Hole	0021006	0	0

2.4.5 Summary and future monitoring

Macroinvertebrates were highlighted in Sternberg and Cockayne (2014) as a key component of ecosystem monitoring given their responsiveness to a range of short- and long term changes in EC and calcium deficiency. The diversity and spatial variation in macroinvertebrate families captured in the Galilee subregion was consistent with previous sampling across the wider LEB region (e.g SEAP, MRHI, FARWH, see Sternberg and Cockayne, 2014). Freshwater shrimp/prawns, gastropods, bivalves and the invasive Red claw cray fish were shown to be the most widespread and abundant macroinvertebrates, suggesting these species are likely to be suitable for monitoring a range of CSG stressors in the Galilee subregion. Future monitoring should seek to capture additional physiological information for these species to improve our conceptual understanding of the PSR linkages for CSG development throughout the LEB.

2.5 Sedimentation and Waterhole Bathymetry

2.5.1 Values

- Contributes to knowledge of spatial and temporal availability of water throughout the basin.
- Information is straightforward to collect and analyse.
- Links with other short- and long-term receptors.
- Potential indicator of broader land-use change.
- Regular resampling not essential (*i.e.* every ~5 years).

2.5.2 Sampling

Sedimentation and waterhole bathymetry are both likely to show gradual change over time and therefore represent a long-term indicator of land-use modification. As such repeated sampling is not required, however, should follow any significant natural or anthropogenic disturbance.

Sedimentation:

Sediment was investigated through "probing" the substrate from a boat using sediment coring poles pushed into the sediment at twenty evenly spaced points along the thalweg of each waterhole. Due to time restrictions, when waterholes are greater than two kilometres in length, 100 metre intervals were used to cover a total of 2100 metres of waterhole. Three cross-sections were also taken when time permitted. The depth of water and the depth of sediment were recorded for each of the points, along with any comments on the substrate composition e.g. muddy, sandy and rocky.

Bathymetry:

Waterhole bathymetry consisted of a boat-mounted sonar and linked GPS device to associate waterhole depth and position into a digital elevation model (DEM). A combination of longitudinal and lateral zigzag profiling was employed to ensure maximum coverage of the waterhole area. Circumnavigation of the perimeter was also employed when time permitted.

2.5.3 Receptor analysis

Post-processing of waterhole bathymetry data is relatively time consuming and requires trained staff to complete. Digital elevation models and sedimentation dynamics can be used to estimate waterhole persistence curves, total available water resources, physical habitat diversity, groundwater-surface water interactions and time-series data over different hydrological scenarios.

Table 17: Key morphological receptors, ecological links to ecosystem processes (see Sternberg and Cockayne, 2014), and the relative time-frame of potential response.

Variable	Links to ecosystem processes	Response time-frame
Waterhole persistence	- Water resource development - Climate change - Spatial and temporal availability of aquatic refuges - Changes to groundwater-surface water interactions	Cumulative Cumulative Cumulative Cumulative
Metrics associated with waterhole morphology and habitat diversity	- Indicator of flow and sediment variability - Direct links to aquatic biota.	Cumulative Cumulative
Sedimentation rates	- Indicator of potential land-use change.	Cumulative

2.5.4 Baseline assessment

Sediment probing was conducted in 9 high intensity and 7 low intensity sampling sites in spring 2014. Average, and maximum, sediment depth was highest at Aramack Creek at Lynch's hole. Sheep grazing prior to the 1960's contributed to the high sediment loads seen today (D. Stent-Smith, 'Shandon Vale', *pers comm*). Repeat sediment probing is not required on a biannual basis; however it is appropriate when substantial changes are known to have occurred. Summary statistics from sediment probing are presented in Table 18.

Table 18: Site details and summary statistics for sediment depth (m) conducted in high and low intensity sampling sites in spring 2014.

Catchment	Site name	Site #	Mean (± S.E.)	Min	Max	Dominant substrate
Diamantina	Wockingham Ck @ Conn Hole	0021006	0.34 (±0.05)	0.02	1.35	Silt / Mud
Diamantina	Diamantina R @ Old Cork	0021999	1.04 (±0.14)	0.08	2.35	Silt
Cooper	Bullock Ck @ Dardanelles	0032165	0.54 (±0.06)	0.35	0.82	Sand
Cooper	Cornish Ck @ Bucksleas	0032166	0.66 (±0.11)	0.07	2.37	Silt
Cooper	Rodney Ck @ Yarraman	0032170	0.66 (±0.09)	0.10	1.65	Silt
Cooper	Thomson R @ Broadwater	0032171	0.60 (±0.08)	0.01	1.87	Silt
Cooper	Thomson R @ Camoola	0032172	0.31 (±0.04)	0.02	0.84	Silt
Cooper	Thomson R @ Jim's Waterhole	0032173	0.04 (±0.02)	0.00	0.17	Silt / Gravel
Cooper	Torrens Ck @ Fisheries	0032174	0.22 (±0.02)	0.08	0.42	Silt
Cooper	Towerhill Ck @ Kirby's Waterhole	0032175	0.37 (±0.05)	0.13	0.63	Silt / Sand
Cooper	Aramack Ck @ Lynch's Hole	0032176	1.54 (±0.25)	0.10	3.30	Silt
Cooper	Barcoo R @ Avington Rd	0033010	0.59 (±0.08)	0.01	1.49	Silt
Cooper	Barcoo R @ Coolagh	0033021	0.60 (±0.11)	0.00	1.98	Silt
Cooper	Thomson R @ Ag College	003207a	0.22 (±0.02)	0.12	0.54	Silt
Cooper	Towerhill Ck @ Lammermoor	003208a	0.50 (±0.07)	0.00	1.16	Sand

Bathymetric surveys were undertaken at 10 high intensity and 7 low intensity sampling sites in autumn 2015. The majority of waterholes were below cease-to-flow (CTF) at time of survey. When combined with waterhole depth (CTD-Diver) and/or gauged height data, these surveys can give an indication of the rate of waterhole recession, thus permitting estimates of waterhole persistence. The bathymetric maps also provide an insight into waterhole morphology and the different types of potential fish habitat. Repeat bathymetric mapping is not required on a biannual basis, however, it is appropriate when substantial changes are known to have occurred. Summary statistics are presented below.

Table 19: Summary morphological statistics showing variation in depth, volume, surface area and length for five semi-permanent refugial waterholes in the Lake Eyre Basin.

Site	Max Depth (m)	Volume (ML)	Water Surface Area (m^2)	Benthic Surface Area (m^3)	Length (m)
Barcoo River @ Coolagh	6.5	302	95,277	99,039	2,335
Thomson River @ Camoola	4.5	102	60,309	61,617	1,842
Towerhill Creek @ Lammermoor	4.22	42	39,681	40,848	1,562
Thomson River @ Ag College	2.35	16	17,129	18,243	1,240
Thomson River @ Jim's Hole	1.51	7	12,181	12,213	360

2.5.5 Summary and future monitoring

Spatial and temporal variability in waterhole sedimentation and morphological dynamics are likely to respond to cumulative CSG developmental pressures over prolonged time periods. As such, monitoring this variability is not considered a priority. Major episodic events, both natural and anthropogenic, may potentially cause significant changes to these waterhole dynamics, and should therefore trigger replicate sampling. The value of bathymetric and sediment surveys is in the initial estimate of waterhole characteristics - volume, perimeter, surface area, 3-dimensional area and habitat diversity. When coupled with hydrological monitoring, estimates of water resource volumes, waterhole persistence, groundwater interactions, habitat availability and changes sedimentation rates over time ultimately provide an ecological, social and management context for a wider range of potential CSG receptors in the Galilee subregion.

3. Alignment with Policy Objectives and External Reporting Frameworks

The following table highlights how the proposed monitoring program would complement a range of state and commonwealth policy objectives and external reporting frameworks. This list is not intended to be exhaustive, however, includes a wide range of legislation, policy and guidelines to highlight the cost-effectiveness of the proposed monitoring program and the valuable baseline information that could be accessed by a diverse range of stakeholders.

Table 20: Summary of Commonwealth and state reporting policy objectives and external reporting frameworks, and their applicability to the Lake Eyre Basin Rivers Monitoring program.

Legislation / Policy / Guidelines etc.	Description and links to Lake Eyre Basin Rivers Monitoring program
Commonwealth	
Information Guidelines for Independent Expert Scientific Committee (IESC) advice on coal seam gas and large coal mining development proposals	Guidelines specify the information required to enable the IESC to provide robust scientific advice to government regulators on coal seam gas (CSG) and large coal mining (LCM) development proposals. The LEBRM project was initiated as part of the targeted bioregional assessment for the Galilee subregion; results will enhance the scientific knowledge base which the IESC draws on, and provide explicit advice on the direct impacts of CSG and LCM developments on surface water assets.
Environment Protection and Biodiversity Conservation Act 1999	The overarching purpose of the LEBRM project is to inform the IESC, which is a statutory body under the EPBC Act. Data obtained by the LEBRM project may be shared to assist the management of threatened species and ecological communities as listed under the EPBC Act.
Environmental Offsets Policy October 2012	Provides guidance on the role of offsets in environmental impact assessments; including offsets proposed for mining developments. Data collected during the LEBRM project may represent the best available scientific information and evidence, and can be utilised for assessment of suitable offsets within the Galilee subregion.
Lake Eyre Basin Intergovernmental Agreement Act 2001	The LEB Intergovernmental Agreement is recognised in legislation by the Parliaments of Australia, Queensland, South Australia and the Northern Territory. The purpose of LEB Agreement is to develop and implement policies and strategies concerning water and related natural resources of the Basin to avoid or eliminate, so far as is reasonably practicable, adverse cross-border impacts. One of the activities under the Agreement is the Lake Eyre Basin Rivers Assessment (LEBRA) monitoring programme which was established to collect some of the data needed to assess the condition of the Basin's watercourses and their catchments. The monitoring methods under the proposed BA program should try to align and build on the LEBRA monitoring programme as the LEBRA monitoring methods are well established and consistently applied by the Basin jurisdictions
Australian and New Zealand Guidelines for Fresh and Marine Water Quality: Volume 1 – The Guidelines	Represents a major element of the National Water Quality Management Strategy, and provides biological, water and sediment quality guidelines and trigger values for protecting freshwater aquatic ecosystems. Data collected can be used to develop locally relevant values for the LEB region for inclusion in the Queensland Water Quality Guidelines, and ultimately support the scientific underpinning of the National Water Quality Management Strategy (NWQMS).
State	
The Environmental Protection (Water) Policy 2009	Seeks to achieve objectives from the Environmental Protection Act 1994 - to protect Queensland's waters via an integrated management program while allowing for ecologically sustainable development. Data from the LEBRM project could support development of the Environmental Values for aquatic ecosystems, and Water Quality Planning framework for the 'Desert Channels Queensland' area, which are currently under consideration.

Water Resource (Cooper Creek) Plan 2011 Cooper Creek Resource Operations Plan 2013 Water Resource (Georgina and Diamantina) Plan 2004 Georgina and Diamantina Resource Operations Plan 2006	Relevant subordinate legislation for water resources within the Galilee subregion, to support requirements under the Water Act, 2000 and the National Water Initiative, 2004. Data and research outcomes from the LEBRM project could be used to assess the performance of Water Resource Plan (WRP) and Resource Operations Plan (ROP) strategies in achieving their general and specific ecological outcomes (e.g. maintain the ecological integrity and natural function of in-stream, riparian, wetland and floodplain ecosystems). This is achieved through the Environmental Flows Assessment Program (EFAP). Data could also be incorporated into the review of the WRPs and ROPs; specifically, to determine the risk to surface water assets associated with increased water resource development.
Queensland Integrated Waterways Monitoring Framework 2013	Describes best practice waterways monitoring processes and procedures that improve the quality, efficiency, coordination and integration of monitoring coordinated by Queensland Government and other organisations; and acknowledges the LEBIA as a key policy driver. Monitoring for the LEBRM project would be aligned with the framework structure.
Control of pest fish: An operational strategy for Queensland freshwaters 2011-2016	Describes priority actions to manage the impacts of, and control the spread of pest fish in Queensland's freshwaters. The LEBRM monitoring program is aligned with this strategy, and can directly contribute to the management of pest fish in the LEB by removing all pest fish captured during surveys; and, where appropriate, providing specimens and associated data to external research bodies (e.g. Griffith University).
Regional Planning Interests Act 2014	Act to identify, manage and protect Queensland's areas of regional interest. The Act defines Strategic Environmental Areas (SEA) where protection of ecological integrity is the priority land use, and development is only facilitated where it can be demonstrated that ecological integrity is not jeopardised. Outcomes from the LEBRA project would support the assessment of risk to ecological integrity within the Galilee subregion of the Channel Country SEA.
Guideline: Triggers for environmental impact statements (EIS) under the Environmental Protection Act 1994 for mining and petroleum activities	Explains EIS triggers for mining and petroleum activities. When an EIS is triggered, the regulator may consider existing relevant data, including information from bioregional assessments, to determine the impacts on environmental values from an activity. The LEBRM project could provide general and explicit baseline information to assist in this assessment process, for activities within the LEB area.
Coal Seam Gas Water Management Policy 2012	Details the government's position on the strategic management and use of CSG water to protect the environment, and provides guidelines for operators to manage CSG water under the environmental regulator, according to obligations under the Environmental Protection Act 1994. Data from the LEBRM project could contribute to the assessment of potential impacts on environmental values, which must be considered under Management Options, and as part of greater EIS process.
State of the Environment Queensland	Whole-of-government report that assess the condition of Queensland's environment, identifies trends in environmental values, and reviews and evaluates activities aimed at managing the environment. Data from the LEBRM project can be made available for inclusion – specifically to increase knowledge regarding water quality and fish community condition in the Galilee subregion of the LEB.
Desert Channels Queensland NRM Plan 2016-2020	Provides information regarding strategies and actions to promote natural resource management outcomes in the Desert Channels region from 2016-2020. Data from the LEBRM project would support, and can directly contribute to Management Actions: *4. Improved management of permanent waterholes in the region*; and *23. Updating knowledge of groundwater hydrology and baseline water quality relating to future areas of coal seam gas operations*
Q-Catchments / Stream and Estuary Assessment Program (SEAP) – Freshwater	A scientifically robust monitoring and assessment program that can be universally applied across a variety of ecosystems and scales to monitor the condition of riverine ecosystems, and their risk from human activities. Results from the LEBRM project could be used to refine existing conceptual models and outputs for the 'Lake Eyre and Bulloo' province; while the methodology and outcomes could support the next sampling event in the LEB area.
Aquatic Conservation Assessments (ACA) and Aquatic Biodiversity Assessment and Mapping Method (AquaBAMM)	The AquaBAMM was developed by the Department of Environment and Heritage Protection (EHP) to assess the conservation values of Queensland wetlands. Data from the LEBRM project could be directly used in the ACA process for catchments within the Galilee subregion.

4. Conclusion

Ecological condition in dryland river ecosystems is naturally variable in time and space due to the prevailing patterns of wetting and drying and associated 'boom and bust' ecology (Fig. 1). Some ecological components fluctuate seasonally (short-term receptors), while other components are representative of cumulative trajectories in ecosystem services (long-term receptors). Effectively capturing this natural variability in short- and long-term ecological condition, and identifying any variation beyond what is considered natural, is the major challenge for monitoring programs in the LEB.

In order to effectively capture the range of short-term ecological conditions and long-term ecosystem trajectories, any surface-water monitoring program for the LEB should be underpinned by a minimum of 10 years of baseline data. Given that significant floodplain inundation (i.e 'boom' phase) occurs once every 5-10 years (Cockayne et al. 2015), a 10 year monitoring period should capture at least one 'boom and bust' cycle, as well as numerous smaller scale wetting and drying events. This level of information will help define the 'reference condition', against which future developmental impacts can be compared. Surface-water monitoring should then be continued in this form, until such time that the risks identified in the Pressure-Stressor-Response (PSR) model have been investigated to an acceptable level (*see* Sternberg and Cockayne, 2014). Changing environmental risks, fluctuating time and monetary resources and information derived from previous monitoring, can then be considered to appropriately adapt the surface-water monitoring program in accordance with the residual risk.

Surface-water monitoring should be conducted biannually in relation to broad seasonal climatic patterns (Figure 1) as follows:

Autumn; following a period of warmer temperatures, generally wetter conditions, and higher productivity. This sampling period generally represents a phase of elevated ecosystem health (*i.e.* the upper range of short-term ecosystem condition), and may also capture any changes to long-term receptors as a result of potential widespread flooding.

Spring; following cooler temperatures and a typically prolonged dry period. This sampling period generally represents a phase of decreased ecosystem health (*i.e.* the lower range of short-term ecosystem condition) and would also capture any long-term changes to the cumulative trajectory of ecosystem services associated with a failed 'wet-season'. Event based, time-series water quality monitoring during major natural and/or anthropogenic episodic events would also be a worthwhile activity at each of the established gauging stations.

Surface-water monitoring in the Galilee subregion of the LEB should include high intensity and low intensity surveys. High intensity surveys should be conducted in permanent, refugial waterholes on major tributaries within expected high intensity mining areas and should include the full range of short- and long-term receptors. Low intensity surveys should be conducted at a number of 'satellite' sites in low intensity mining areas in order to increase the spatial coverage of the monitoring program. Low intensity surveys should include a subset of short- and long-term receptors. Baseline surveys and continued monitoring of areas of local significance should also be incorporated into the monitoring program in order to gain a better understanding of their ecological and social values.

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6. References

AS/NZS 5667.1:1998 Water quality – Sampling, Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. Standards Australia.

Balcombe, S.R., Bunn, S.E., Arthington, A.H., Fawcett, J.H., McKenzie-Smith, F.J. and Wright, A. (2007) Fish larvae, growth and biomass relationships in an Australian arid zone river: links between floodplains and waterholes. Freshwater Biology, 52, 2385-2398.

Bunn, S.E., Balcombe, S.R., Davies, P.M., Fellows, C.S. and McKenzie-Smith, F.J. (2006a). *Aquatic productivity and food webs of desert river ecosystems*. *In* Ecology of desert rivers (ed. R. Kingsford), pp. 76-99. Cambridge University Press, Melbourne.

Bunn, S.E., Thoms, M.C., Hamilton, S.K. and Capon, S.J. (2006b) Flow variability in dryland rivers: boom, bust and the bits in between. River Research and Applications, 22, 179-186.

Cockayne, B., Schmarr, D., Duguid, A., and Mathwin, R. (2012) Lake Eyre Basin Rivers Assessment 2012 Monitoring Report, A report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), Canberra, ACT.

Cockayne, B., Schmarr, D., Duguid, A., and Mathwin, R. (2013) Lake Eyre Basin Rivers Assessment 2012 Monitoring Report, A report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), Canberra, ACT.

Cockayne, B.J., Sternberg, D., Schmarr, D.W., Duguid, A.W., and Mathwin, R. (2015). Lake Eyre golden perch (*Macquaria sp.*) spawning and recruitment is enhanced by flow events in the hydrologically variable rivers of Lake Eyre Basin, Australia. *Marine and Freshwater Research*.

Commonwealth of Australia. (2014) Co-produced water - risks to aquatic ecosystems, Background review. Independent Expert Scientific Committee, Department of the Environment, Public Affairs, Canberra.

DNRM. (2014) Coal seam gas well locations - Queensland. Department of Natural Resources and Mines. State of Queensland. Available online: http://www.dnrm.qld.gov.au/mapping-data/queensland-globe. Accessed: 19/08/2014.

Lewis, S., Cassel, R. and Galinec, V. (2014) *Coal and coal seam gas resource assessment for the Galilee subregion*. Product 1.2 for the Galilee subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Mackay, S., Marsh. N., Sheldon, F. and Kennard, M. (2012) *Low-flow hydrological classification of Australia*, National Water Commission, Canberra.

NWQMS (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Paper No. 4, Volume 1: The Guidelines (Chapters 1-7). Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand. October 2000.

Silcock, J. (2009) Identification of Permanent Refuge Waterbodies in the Cooper Creek and Georgina-Diamantina River Catchments for Queensland and South Australia. South Australian Arid Lands Natural Resources Management Board, Port Augusta.

Sternberg, D. and Cockayne, B. (2014) *Surface water-dependent receptors associated with CSG development in the Galilee Subregion of the Lake Eyre Basin*. Queensland Department of Natural Resources and Mines, Mackay.

Sternberg, D., Cockayne, B., Schmarr, D., Duguid, A. and Mathwin, R. (2014) *Lake Eyre Basin Rivers Assessment (LEBRA) 2013 Monitoring Report,* A report to the Department of the Environment (DotE), Canberra, ACT.

Thoms, M., Capon, S., Price, R. and Watkins, D. (2009) Lake Eyre Basin Rivers Assessment Implementation Plan Project- Milestone 2 Report: Proposed LEB Rivers Assessment Methodology. Kir-ganai Research.

Unmack P.J. and Dowling T.E. (2010). Biogeography of the genus *Craterocephalus* (Teleostei: Atherinidae) in Australia. *Molecular Phylogenetics and Evolution* 55, 968- 984.

7. Appendices

Appendix 1: Spatial and temporal variability in phytoplankton relative abundance and genus richness (square brackets) throughout the Galilee subregion of the LEB.

	Bacillariophyta (Diatoms)	Chlorophyta (Green Algae)	Chrysophyta (Golden-Brown Algae)	Cryptophyta (Cryptomonads)	Cyanophyta (Cyanobacteria)	Dinophyta (Dinoflagellates)	Euglenophyta (Euglenoids)	Raphidophyta (Raphidophytes)	Unidentified flagellate	Unidentified single algae	Total Algae (cells/mL)
Spring 2014											
Alice R @ Weir Pool	4 [2]	84 [1]		1 [1]	11 [2]						52116
Aramak Ck @ Lynch's Hole	1 [4]	44 [1]	1 [1]	12 [2]			17 [4]			17	7771
Barcoo R @ Avington Rd	5 [1]	35 [6]	18 [1]	18 [3]	3 [1]		1 [2]			1	3639
Barcoo R @ Coolagh	1 [1]	19 [5]	1 [1]	72 [3]			3 [1]			3	2681
Bullock R @ Dardanelle	1 [5]	11 [7]			83 [5]		2 [2]			2	67912
Cornish Ck @Bucksleas	5 [4]	35 [13]			56 [6]		2 [3]			2	113680
Diamantina @ Old Cork		33 [1]					33 [1]			33	41
Edie Ck @ Lake Dunn	86 [4]	5 [6]	1 [1]	1 [2]	7 [2]						19456
Lammermoor @Towerhill Ck	2 [4]	5 [12]		1 [2]	9 [7]		1 [2]			1	161663
Rodney Creek @ Yarraman	2 [4]	2 [12]		5 [2]	71 [12]	2 [1]					21547
Thomson R @ Ag College	1 [2]	1 [4]			97 [2]		1 [1]			1	48510
Thomson R @ Camoda			57 [1]	2 [2]			11 [3]			11	626
Thomson R @ Jims Hole	11 [5]	3 [17]		3 [2]	44 [4]		6 [3]			6	56353
Thomson R @Broadwater				33 [2]			33 [1]			33	93
Torrens Ck @ Fisheries	1 [1]	9 [3]		2 [1]			44 [4]			44	4609
Towerhill Ck @ Kirbys		6 [2]					45 [1]			45	344
Wockingham Ck @ Conn Hole	35 [1]	2 [1]		45 [2]							403
Autumn 2015											
Alice R @ Weir Pool	8 [1]			15 [1]			69 [1]			8	503
Aramack Ck @ Lynch's Hole				99 [2]			1 [2]				14936
Barcoo R @ Avington Rd	1 [1]	3 [1]	2 [1]	21 [3]			29 [2]	45 [1]			7409
Barcoo R @ Coolagh	2 [1]	9 [2]	11 [1]	64 [3]			14 [2]				889
Bullock Ck @ Dardanelles				53 [2]			41 [1]	6 [1]			644
Cornish Ck @ Bucksleas	1 [2]	21 [12]			76 [9]		2 [2]				76079
Diamantina R @ Old Cork				2 [2]			3 [2]		95		7404
Edie Ck @ Lake Dunn	3 [2]	9 [8]		7 [1]					1		2111
Rodney Ck @ Yarraman	15 [6]	5 [17]		1 [2]	17 [2]		16 [4]				83032
Thomson R @ Ag College	4 [3]	77 [9]		14 [2]			5 [1]				2335
Thomson R @ Camoola	17 [1]			67 [1]			17 [1]				123
Thomson R @ Jim's Waterhole	44 [5]	15 [9]		1 [2]	38 [5]		2 [2]				24325
Torrens Ck @ Fisheries				83 [3]			17 [1]				484
Towerhill Ck @ Kirby's	8 [5]	24 [15]	1 [2]		65 [9]		1 [2]				58224
Towerhill Ck @ Lammermoor	7 [5]	5 [9]			88 [4]	1 [1]					78744
Wockingham Ck @ Conn Hole	13 [2]	17 [1]	4 [1]	39 [2]			26 [2]				468

Appendix 2: Raw *in-situ* water quality parameters for the Galilee subregion of the LEB take between spring 2014 and autumn 2015 at 18 semi-permanent waterholes at various depth ranges. Note, pH probe malfunctioned in autumn 2015.

TRIP	SITE #	Water Column Position	Date	Time	Lattitude	Longitude	Depth [m]	Temp [deg C]	pH	DO [mg/L]	EC [mS/cm]	Turbidity [NTU]
1	0032166	Upper	18/10/2014	16:25	-22.46865	144.87628	0.2	26.22	8.92	12.66	0.265	148
1	0032166	Lower	18/10/2014	16:25	-22.46865	144.87628		22.57	8.34	10.68	0.262	201
1	0032166	Upper	18/10/2014	17:10	-22.46888	144.87590	0.2	22.06	8.83	11.48	0.269	92.4
1	0032166	Lower	18/10/2014	17:10	-22.46888	144.87590		23.47	8.36	9.43	0.267	195
1	0032166	Upper	18/10/2014	17:20	-22.46924	144.87537	0.2	26.78	8.66	10.25	0.270	120
1	0032166	Lower	18/10/2014	17:20	-22.46924	144.87537		20.24	8.45	10.08	0.269	2.72
1	0033021	Upper	22/10/2014	14:30	-24.03798	144.86644	0.2	27.8	8.38	11.3	0.206	236
1	0033021	Lower	22/10/2014	14:30	-24.03798	144.86644		25.2	8.11	9.85	0.206	245
1	0033021	Upper	22/10/2014	14:50	-24.04107	144.87231	0.2	24.32	8.36	11.19	0.205	228
1	0033021	Lower	22/10/2014	14:50	-24.04107	144.87231		23.16	7.96	9.31	0.202	228
1	0033021	Upper	22/10/2014	16:05	-24.03638	144.85805	0.2	29.8	8.5	10.46	0.208	231
1	0033021	Lower	22/10/2014	16:05	-24.03638	144.85805		26.64	8.23	9.75	0.208	248
1	0032168	Upper	19/10/2014	14:50	-22.60258	145.67149	0.2	24.34	8.79	11.96	0.261	132
1	0032168	Upper	19/10/2014	15:00	-22.60262	145.67255	0.2	24.15	8.77	11.25	0.262	121
1	0032168	Upper	19/10/2014	15:10	-22.60239	145.67052	0.2	24.13	8.76	11.12	0.262	119
1	0032168	Lower	19/10/2014	15:10	-22.60239	145.67052	0.8	24.08	8.71	10.64	0.262	124
1	0032172	Upper	23/10/2014	15:00	-22.98587	144.50650	0.2	23.7	8.01	11.09	0.142	743
1	0032172	Lower	23/10/2014	15:00	-22.98587	144.50650		22.26	7.8	9.95	0.142	753
1	0032172	Upper	23/10/2014	15:20	-22.99068	144.50833	0.2	26.38	7.82	10.49	0.143	744
1	0032172	Lower	23/10/2014	15:20	-22.99068	144.50833		25.44	7.78	10.59	0.142	744
1	0032172	Upper	23/10/2014	16:20	-22.97956	144.50053	0.2	27.15	7.81	12.01	0.142	743
1	0032172	Lower	23/10/2014	16:20	-22.97956	144.50053		26.66	7.63	12.12	0.142	748

TRIP	SITE #	Water Column Position	Date	Time	Lattitude	Longitude	Depth [m]	Temp [deg C]	pH	DO [mg/L]	EC [mS/cm]	Turbidity [NTU]
1	0032174	Upper	17/10/2014	14:25	-21.79456	145.26741	0.2	28.2	8.23		0.310	705
1	0032174	Lower	17/10/2014	14:25	-21.79456	145.26741		23.6	7.54		0.282	825
1	0032174	Upper	17/10/2014	14:35	-21.79518	145.26726	0.2	27.14	8.46	5.85	0.272	642
1	0032174	Lower	17/10/2014	14:35	-21.79518	145.26726		22.75	7.89	5.76	0.260	787
1	0032174	Upper	17/10/2014	14:45	-21.79572	145.26721	0.2	24.39	7.82	5.42	0.267	643
1	0032174	Lower	17/10/2014	14:45	-21.79572	145.26721		22.62	7.36	5.71	0.264	910
1	003208a	Upper	16/10/2014	17:45	-21.34230	144.64799	0.2	24.6	8.56		0.229	170
1	003208a	Upper	16/10/2014	17:50	-21.34198	144.64809	0.2	24.2	8.5		0.223	109
1	003208a	Lower	16/10/2014	17:50	-21.34198	144.64809		23	8.29		0.223	229
1	003208a	Upper	16/10/2014	18:05	-21.34296	144.64757	0.2	24.9	8.53		0.219	31
1	003208a	Lower	16/10/2014	18:05	-21.34296	144.64757		20.9	8.03		0.217	77
1	0021006	Upper	15/10/2014	11:45	-22.29501	142.48859	0.4	25	7.81	13.8	0.193	585
1	0021006	Lower	15/10/2014	11:45	-22.29501	142.48859	1.2	20.9	7.59	12	0.192	615
1	0021006	Upper	15/10/2014	11:55	-22.297267	142.4852	0.45	24.2	7.63	13.4	0.190	582
1	0021006	Lower	15/10/2014	11:55	-22.297267	142.4852	1.5	21.9	7.7	11.56	0.190	597
1	0021006	Upper	15/10/2014	12:05	-22.297983	142.482883	0.35	23.1	7.61	11.78	0.191	580
1	0021006	Lower	15/10/2014	12:05	-22.297983	142.482883	1.65	21.9	7.49	10.56	0.190	590
1	0033010	Upper	21/10/2014	14:10	-24.30784	145.2903	0.2	23.79	8.4	12.3	0.499	62.8
1	0033010	Lower	21/10/2014	14:10	-24.30784	145.2903		21.34	8.08	12.38	0.494	62.8
1	0033010	Upper	21/10/2014	14:20	-24.30744	145.29179	0.2	21.81	8.11	8.12	0.506	68.7
1	0033010	Lower	21/10/2014	14:20	-24.30744	145.29179		21.61	8.08	7.51	0.504	70.6
1	0033010	Upper	21/10/2014	14:50	-24.30745	145.28735	0.2	27.47	8.55	10.99	0.511	63
1	0033010	Lower	21/10/2014	14:50	-24.30745	145.28735		24.53	8.8	12.15	0.512	83.6
1	0032176	Upper	20/10/2014	15:55	-23.12234	145.375	0.2	26.6	8.68		0.255	29
1	0032176	Lower	20/10/2014	15:55	-23.12234	145.375		23.2	7.93		0.252	37
1	0032176	Upper	20/10/2014	16:15	-23.12661	145.37383	0.2	26.8	8.82		0.252	46
1	0032176	Lower	20/10/2014	16:15	-23.12661	145.37383		23.8	7.92		0.253	79

TRIP	SITE #	Water Column Position	Date	Time	Lattitude	Longitude	Depth [m]	Temp [deg C]	pH	DO [mg/L]	EC [mS/cm]	Turbidity [NTU]
1	0032176	Upper	20/10/2014	16:45	-23.12932	145.37143	0.2	28.4	9.2		0.249	49
1	0032176	Lower	20/10/2014	16:45	-23.12932	145.37143		26.3	8.28		0.254	46
1	0032173	Upper	24/10/2014	9:55	-22.22441	144.36414	0.2	24.56	9.8	11.24	0.389	167
1	0032175	Upper	18/10/2014	11:00	-21.91262	144.67363	0.2	20.7	7.92		0.141	461
1	0032175	Upper	18/10/2014	11:20	-21.91175	144.67174	0.2	23.2	7.64		0.142	452
1	0032175	Lower	18/10/2014	11:20	-21.91175	144.67174		19.8	7.13		0.142	496
1	0032175	Upper	18/10/2014	11:35	-21.9117	144.67073	0.2	22.2	7.59		0.146	458
1	0032170	Upper	20/10/2014	11:30	-22.9717	144.79669	0.2	25.2	9.6		0.292	39
1	0032170	Lower	20/10/2014	11:30	-22.9717	144.79669		22.3	9.4		0.286	74
1	0032170	Upper	20/10/2014	11:55	-22.9761	144.79472	0.2	25.2	9.59		0.289	65
1	003207a	Upper	24/10/2014	13:15	-23.35097	144.32956	0.2	30.19	10.35	11.78	0.320	99.5
1	003207a	Upper	24/10/2014	13:40	-23.35098	144.32961	0.2	30.78	9.98	13.38	0.339	173
1	003207a	Upper	24/10/2014	14:10	-23.34965	144.3306	0.2	28.79	9.81	11.82	0.333	123
1	003207a	Lower	24/10/2014	14:10	-23.34965	144.3306		27.8	9.78	12.4	0.336	222
1	003207a	Upper	1/10/2014	9:35			0.2	22.81	9.23	13.5	0.285	47
1	0032171	Upper	19/10/2014	9:40	-22.67905	144.56958	0.2	22.4	7.7		0.110	864
1	0032171	Lower	19/10/2014	9:40	-22.67905	144.56958		21.5	7.12		0.109	885
1	0032171	Upper	19/10/2014	10:10	-22.67117	144.56987	0.2	21.8	7.73		0.108	912
1	0032171	Lower	19/10/2014	10:10	-22.67117	144.56987		21.3	7.33		0.108	922
1	0032171	Upper	19/10/2014	10:40	-22.66253	144.56937	0.2	22.6	7.65		0.118	912
1	0032171	Lower	19/10/2014	10:40	-22.66253	144.56937		21.6	7.47		0.117	925
1	0032165	Upper	17/10/2014	9:30	-21.41985	144.9986	0.2	19.1	8.27		0.378	185
1	0032165	Upper	17/10/2014	9:35	-21.42013	144.99825	0.2	19.5	8.22		0.386	150
1	0032165	Upper	17/10/2014	9:40	-21.42028	144.99823	0.2	21	8.09		0.385	145
1	0021999	Upper	15/10/2014	13:15	-22.91839	141.88362	0.2	25.4	7.29		0.114	434
1	0021999	Lower	15/10/2014	13:15	-22.91839	141.88362		22.6	7.12		0.112	443
1	0021999	Upper	15/10/2014	14:00	-22.92283	141.87415	0.2	26.9	7.76		0.111	397

TRIP	SITE #	Water Column Position	Date	Time	Lattitude	Longitude	Depth [m]	Temp [deg C]	pH	DO [mg/L]	EC [mS/cm]	Turbidity [NTU]
1	0021999	Lower	15/10/2014	14:00	-22.92283	141.87415		23	7.5		0.108	399
1	0021999	Upper	15/10/2014	15:16	-22.93596	141.85764	0.2	24.1	7.54		0.106	422
1	0021999	Lower	15/10/2014	15:16	-22.93596	141.85764		22.4	7.43		0.106	417
1	003302a	Upper	21/10/2014	11:50	-23.64936	145.21645	0.2	24.13	8.2	10.34	0.278	63.4
1	003302a	Lower	21/10/2014	11:50	-23.64936	145.21645		23.59	8.18	9.72	0.278	59
1	003302a	Upper	21/10/2014	12:00	-23.65005	145.21648	0.2	26.95	8.72	8.25	0.616	24.2
1	003302a	Lower	21/10/2014	12:00	-23.65005	145.21648		25.73	8.72	8.25	0.616	41.7
1	003302a	Upper	21/10/2014	12:05	-23.64991	145.21643	0.2	24.52	8.7	11.08	0.288	17.4
2	0032166	Upper	3/05/2015	16:30	-22.468444	144.876333	0.2	26.05		17.41	0.187	72
2	0032166	Lower	3/05/2015	16:30	-22.468444	144.876333	0.4	21.1		13.1	0.187	90
2	0032166	Upper	3/05/2015	16:40	-22.46914	144.87531	0.2	24.15		13.65	0.188	72
2	0032166	Lower	3/05/2015	16:40	-22.46914	144.87531	0.6	21.6		11.2	0.187	140
2	0032166	Upper	3/05/2015	16:45	-22.47014	144.87433	0.2	22.45		11.79	0.186	92
2	0032166	Lower	3/05/2015	16:45	-22.47014	144.87433	0.5	19.93		8.98	0.187	144
2	0033021	Upper	7/05/2015	14:30	-24.041806	144.856417	0.2	19.41		10.2	0.207	402
2	0033021	Lower	7/05/2015	14:30	-24.041806	144.856417	1	18.98		8.9	0.205	404
2	0033021	Upper	7/05/2015	14:50	-24.35125	144.86358	0.2	19.8		8.06	0.206	405
2	0033021	Lower	7/05/2015	14:50	-24.35125	144.86358	1	19.07		7.26	0.206	410
2	0033021	Upper	7/05/2015	15:00	-24.03644	144.85856	0.2	21.34		7.58	0.205	408
2	0033021	Lower	7/05/2015	15:00	-24.03644	144.85856	1	19.22		6.23	0.205	426
2	0032168	Upper	5/05/2015	9:05	-22.59314	145.67228	0.2	19.4		18.26	0.771	393
2	0032168	Lower	5/05/2015	9:05	-22.59314	145.67228	0.4	19.02		15.1	0.777	598
2	0032168	Upper	5/05/2015	9:40	-22.59286	145.68100	0.2	19.71		15.1	0.776	359
2	0032168	Lower	5/05/2015	9:40	-22.59286	145.68100	0.4	18.65		13.02	0.776	450
2	0032168	Upper	5/05/2015	10:00	-22.59761	145.67850	0.2	19.83		11.25	0.771	338
2	0032168	Lower	5/05/2015	10:00	-22.59761	145.67850	0.4	19.79		11.29	0.771	366
2	0032172	Upper	8/05/2015	17:10	-22.98344	144.50465	0.2	18.54		13.8	0.115	1000+

TRIP	SITE #	Water Column Position	Date	Time	Lattitude	Longitude	Depth [m]	Temp [deg C]	pH	DO [mg/L]	EC [mS/cm]	Turbidity [NTU]
2	0032172	Lower	8/05/2015	17:10	-22.98344	144.50465		18.49		14.07	0.115	885
2	0032172	Upper	8/05/2015	17:20	-22.98290	144.50427	0.2	18.88		10.7	0.115	1000+
2	0032172	Lower	8/05/2015	17:20	-22.98290	144.50427		18.8		10.6	0.116	1000+
2	0032172	Upper	8/05/2015	17:25	-22.98018	144.50116	0.2	19.24		10.37	0.115	1000+
2	0032172	Lower	8/05/2015	17:25	-22.98018	144.50116		19.23		9.15	0.115	1000+
2	0032174	Upper	2/05/2015	16:30	-21.79583	145.26722	0.2	19.53		13.21	0.100	831
2	0032174	Lower	2/05/2015	16:30	-21.79583	145.26722		19.08		11.25	0.101	831
2	0032174	Upper	2/05/2015	16:35	-21.79500	145.26722	0.2	20.69		9.91	0.101	848
2	0032174	Lower	2/05/2015	16:35	-21.79500	145.26722	0.8	19.06		9.02	0.101	890
2	0032174	Upper	2/05/2015	16:45	-21.79389	145.26778	0.2	24.74		9.9	0.102	850
2	0032174	Lower	2/05/2015	16:45	-21.79389	145.26778	0.4	23.35		9.45	0.102	853
2	003208a	Upper	2/05/2015	8:00	-21.33920	144.64891	0.2	20.09		12.68	0.177	115
2	003208a	Lower	2/05/2015	8:00	-21.33920	144.64891	1.3	19.84		12.82	0.177	115
2	003208a	Upper	2/05/2015	8:15	-21.34132	144.64838	0.2	20.38		11.75	0.174	113
2	003208a	Lower	2/05/2015	8:15	-21.34132	144.64838	0.8	20.26		11.5	0.173	113
2	003208a	Upper	2/05/2015	8:25	-21.34303	144.64737	0.2	19.77		10.78	0.173	113
2	003208a	Lower	2/05/2015	8:25	-21.34303	144.64737	1.3	19.49		10.75	0.174	113
2	0021006	Upper	30/04/2015	14:55	-22.298172	144.473502	0.2	23.06		13.08	0.290	188
2	0021006	Lower	30/04/2015	14:55	-22.298172	144.473502	0.8	19.69		13.26	0.296	193
2	0021006	Upper	30/04/2015	15:10	-22.298056	142.473611	0.2	22.17		13.2	0.289	188
2	0021006	Lower	30/04/2015	15:10	-22.298056	142.473611	1.1	18.62		13.7	0.293	190
2	0021006	Upper	30/04/2015	15:20	-22.295953	142.487306	0.2	22.34		13.4	0.290	188
2	0021006	Lower	30/04/2015	15:20	-22.295953	142.487306	1.1	19.4		13.35	0.287	187
2	0033010	Upper	6/05/2015	16:15	-24.307528	145.291417	0.2	18.4		11.4	0.133	341
2	0033010	Lower	6/05/2015	16:15	-24.307528	145.291417	1.25	17.85		10.5	0.133	345
2	0033010	Upper	6/05/2015	16:25	-24.307531	145.287472	0.2	18.85		8.72	0.133	378
2	0033010	Lower	6/05/2015	16:25	-24.307531	145.287472	0.75	17.61		6.72	0.132	457

TRIP	SITE #	Water Column Position	Date	Time	Lattitude	Longitude	Depth [m]	Temp [deg C]	pH	DO [mg/L]	EC [mS/cm]	Turbidity [NTU]
2	0033010	Upper	6/05/2015	16:30	-24.307944	145.288833	0.2	17.77		7.92	0.130	377
2	0033010	Lower	6/05/2015	16:30	-24.307944	145.288833	0.75	17.03		6.05	0.130	365
2	0032176	Upper	5/05/2015	15:30	-23.124944	145.374556	0.2	25.82		12	0.282	450
2	0032176	Lower	5/05/2015	15:30	-23.124944	145.374556	1	20.62		12.2	0.282	484
2	0032176	Upper	5/05/2015	15:50	-23.130417	145.370417	0.2	21.6		11.32	0.281	396
2	0032176	Lower	5/05/2015	15:50	-23.130417	145.370417	1	20.6		8.62	0.281	590
2	0032176	Upper	5/05/2015	15:55	-23.129167	145.371611	0.2	20.67		9.8	0.283	388
2	0032176	Lower	5/05/2015	15:55	-23.129167	145.371611	0.75	19.06		8.29	0.284	428
2	0032173	Upper	9/05/2015	11:30	-23.225731	144.364238	0.2	18.35		14.93	0.307	76
2	0032173	Upper	9/05/2015	11:40	-23.223575	144.363979	0.2	18.08		14.21	0.305	189
2	0032175	Upper	3/05/2015	11:45	-21.912361	144.673417	0.2	19.73		17.54	0.303	82.6
2	0032175	Lower	3/05/2015	11:45	-21.912361	144.673417	0.5	19.59		14.4	0.301	126
2	0032175	Upper	3/05/2015	11:50	-21.911833	144.671972	0.2	20.2		11.41	0.303	90
2	0032175	Lower	3/05/2015	11:50	-21.911833	144.671972	0.5	19.29		11.18	0.305	93
2	0032175	Upper	3/05/2015	12:00	-21.91175	144.671556	0.2	19.92		10.38	0.305	71
2	0032175	Lower	3/05/2015	12:00	-21.91175	144.671556	0.45	19.86		10.56	0.305	112
2	0032170	Upper	4/05/2015	15:05	-22.971916	144.79664	0.2	24.38		24.8	0.810	810
2	0032165	Upper	2/05/2015	12:50	-21.419567	144.998033	0.2	22.99		16.6	0.106	1000+
2	0032165	Upper	2/05/2015	13:00	-21.420217	144.998083	0.2	21.8		13.8	0.134	1000+
2	0032165	Upper	2/05/2015	13:10	-21.421267	144.998367	0.2	19.15		15.9	0.130	1000+
2	0021999	Upper	1/05/2015	12:25	-22.929833	141.863583	0.2	20.8		12.1	0.194	126
2	0021999	Lower	1/05/2015	12:25	-22.929833	141.863583	1.3	18.64		12.13	0.196	127
2	0021999	Upper	1/05/2015	12:50	-22.9235	141.872722	0.2	20.4		12.4	0.196	127
2	0021999	Lower	1/05/2015	12:50	-22.9235	141.872722	1.2	19.35		11.99	0.197	128
2	0021999	Upper	1/05/2015	13:00	-22.919194	141.881	0.2	22.2		10.93	0.199	129
2	0021999	Lower	1/05/2015	13:00	-22.919194	141.881	1.2	21.25		10.7	0.199	129
2	003302a	Upper	6/05/2015	10:40	-23.628194	145.238861	0.2	18.36		11.38	0.112	93

TRIP	SITE #	Water Column Position	Date	Time	Lattitude	Longitude	Depth [m]	Temp [deg C]	pH	DO [mg/L]	EC [mS/cm]	Turbidity [NTU]
2	003302a	Lower	6/05/2015	10:40	-23.628194	145.238861		18.15		10.4	0.112	93
2	003302a	Upper	6/05/2015	12:20	-23.634	145.22525	0.2	19.7		12.1	0.094	150
2	003302a	Lower	6/05/2015	12:20	-23.634	145.22525		18.59		10.6	0.095	151
2	003302a	Upper	6/05/2015	12:45	-23.646278	145.214833	0.2	18.26		12.05	0.089	157
2	003302a	Lower	6/05/2015	12:45	-23.646278	145.214833		17.77		11.62	0.089	155

Appendix 3: Raw water sample parameters for the Galilee subregion of the LEB taken in spring 2014 at 17 semi-permanent waterholes.

Catchment		Diamantina		Cooper														
Site Name		Wockingham Ck @ Conn Hole	Diamantina R @ Old Cork	BullockCk @ Dardanelles	Cornish Ck @ Buckslea	Edie Ck @ Lake Dunn	Rodney Ck @ Yarraman	Thomson R @ Broadwater	Thomson R @ Camoola	Thomson R @ Jim's Hole	Torrens Ck @ Fisheries	Towerhill Ck @ Kirby's Hole	Barcoo R @ Avington Rd	Barcoo R @ Coolagh	Thomson R @ Ag College	Towerhill Ck @ Lammermoor	Alice R @ Barcaldine	Aramac Ck @ Lynch's Hole
Site Code		0021006	0021999	0032165	0032166	0032168	0032170	0032171	0032172	0032173	0032174	0032175	0033010	0033021	003207A	003208A	003302A	0032164
Water Quality Parameter	**Units**																	
Physico-chemcial																		
Electrical Conductivity @ 25C	ms/cm	201	111	374	278	272	275	115	151	407	273	140	512	213	327	222	286	-
Turbidity	NTU	523	479	65	51	235	25	969	950	40	641	526	80	202	37	16	6	-
Colour - True	HU	4	10	12	20	75	10	40	47	11	75	61	20	22	13	7	33	-
pH		7.47	7.10	7.39	7.30	7.29	7.51	6.82	6.88	7.42	6.79	6.98	7.54	7.40	7.75	7.38	7.32	-
Total Alkalinity as CaCO3	mg/L	82	38	132	103	80	82	25	29	153	71	47	176	85	123	96	96	-
Alkalinity Hydroxide as OH	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Alkalinity Carbonate as CO3	mg/L	0.2	0	0.2	0.2	0.1	0.2	0	0	0.3	0	0	0.4	0.1	0.5	0.2	0.1	-
Alkalinity Bicarbonate as HCO3	mg/L	100	46	161	125	97	100	30	36	186	87	57	214	103	149	116	117	-
Hardness as CaCO3 [calculated]	mg/L	50	31	122	81	46	51	23	30	70	56	39	58	72	70	83	82	-
Hydrogen as H	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Total Dissolved Solids [calc]	mg/L	122	80	197	149	195	152	80	129	226	168	95	284	134	178	118	170	-
Total Dissolved Ions	mg/L	156	88	270	205	197	202	82	105	318	189	108	386	170	248	168	208	-
Total Suspended Solids	mg/L	370	116	66	35	58	21	261	127	45	290	118	47	84	33	10	7	-
Major Ions																		
Calcium as Ca - soluble	mg/L	16	9	28	19	11	11	6	8	17	14	10	16	20	18	22	20	-
Chloride as Cl	mg/L	5	6	26	14	28	9	8	13	27	33	11	42	6	18	6	26	-
Magnesium as Mg - soluble	mg/L	3	2	12	8	5	6	2	3	7	6	4	5	5	6	7	8	-
Nitrate as NO3	mg/L	0	1	2	1	1	1	1	2	3	2	1	1	2	1	1	1	-
Potassium as K	mg/L	4	1	11	8	10	6	2	3	9	12	3	6	5	7	5	10	-
Sodium as Na	mg/L	22	11	22	22	32	36	15	17	59	29	14	90	15	40	10	22	-
Sulphate as SO4	mg/L	7.20	10.50	6.40	6.00	12.20	33.00	16.80	24.00	10.20	7.90	9.00	12.00	12.50	9.10	1.10	3.70	-
Aluminium as Al - soluble	mg/L	0	0	0	0	0.37	0	0.37	0.39	0	0.15	0.52	0	0	0	0	0	-
Boron as B	mg/L	0.14	0.15	0.12	0.11	0.20	0.15	0.18	0.14	0.19	0.24	0.16	0.15	0.20	0.13	0.07	0.12	-
Copper as Cu - soluble	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Fluoride as F	mg/L	0.22	0.15	0.29	0.21	0.20	0.38	0.22	0.21	0.56	0.23	0.16	0.33	0.20	0.38	0.20	0.09	-
Iron as Fe - soluble	mg/L	0	0.03	0	0	0.17	0.01	0.24	0.24	0	0.30	0.38	0.02	0.01	0	0	0	-
Manganese as Mn - soluble	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Silica as SiO2 - soluble	mg/L	16	15	9	8	48	1	13	42	2	23	16	7	17	6	9	22	-
Zinc as Zn - soluble	mg/L	0.06	0.01	0.01	0.02	0.03	0.02	0	0.01	0.02	0.08	0.02	0.11	0.05	0	0.01	0.02	-
Nutrients																		
Total Nitrogen	mg/L	0.81	0.73	1.10	1.10	1.20	0.93	1.20	1.30	2.00	4.10	0.91	0.79	1.10	1.20	0.93	0.85	-
Total Phosphorus as P	mg/L	0.34	0.23	0.13	0.14	0.27	0.09	0.35	0.40	0.22	0.79	0.20	0.23	0.30	0.17	0.07	0.06	-
Productivity																		
Chlorophyll-a	µg/L	13	8	15	17	18	9	36	10	23	130	12	18	9	12	11	11	-

Appendix 4: Raw water sample parameters for the Galilee subregion of the LEB taken in autumn 2015 at 17 semi-permanent waterholes.

Catchment		Diamantina		Cooper														
Site Name		Wockingham Ck @ Conn Hole	Diamantina R @ Old Cork	BullockCk @ Dardanelles	Cornish Ck @ Bucksleа	Edie Ck @ Lake Dunn	Rodney Ck @ Yarraman	Thomson R @ Broadwater	Thomson R @ Camoola	Thomson R @ Jim's Hole	Torrens Ck @ Fisheries	Towerhill Ck @ Kirby's Hole	Barcoo R @ Avington Rd	Barcoo R @ Coolagh	Thomson R @ Ag College	Towerhill Ck @ Lammermoor	Alice R @ Barcaldine	Aramac Ck @ Lynch's Hole
Site Code		0021006	0021999	0032165	0032166	0032168	0032170	0032171	0032172	0032173	0032174	0032175	0033010	0033021	003207A	003208A	003302A	0032164
Water Quality Parameter	**Units**																	
Physico-chemcial																		
Electrical Conductivity @ 25C	ms/cm	274	192	129	181	712	749	-	109	292	99	292	126	193	258	169	85	263
Turbidity	NTU	144	590	1710	71	381	242	-	1200	60	1420	44	392	325	110	20	222	282
Colour - True	HU	11	13	111	29	18	33	-	26	17	109	17	32	31	21	16	74	15
pH		8.12	7.65	7.34	7.56	8.32	7.94	-	7.41	8.69	6.89	7.8	7.16	7.49	7.95	7.66	7.05	7.52
Total Alkalinity as CaCO3	mg/L	113	73	47	72	163	196	-	34	121	21	125	51	61	100	69	28	70
Alkalinity Hydroxide as OH	mg/L	0	0	0	0	0	0	-	0	0.1	0	0	0	0	0	0	0	0
Alkalinity Carbonate as CO3	mg/L	0.9	0.2	0.1	0.2	2.5	1.1	-	0.1	3.6	0	0.5	0	0.1	0.5	0.2	0	0.2
Alkalinity Bicarbonate as HCO3	mg/L	136	89	57	88	194	236	-	41	140	26	151	62	74	121	84	34	85
Hardness as CaCO3 [calculated]	mg/L	63	45	37	54	118	46	-	24	85	18	108	39	52	79	59	23	90
Hydrogen as H	mg/L	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0
Total Dissolved Solids [calc]	mg/L	166	123	95	108	429	434	-	70	165	90	167	78	120	155	101	57	162
Total Dissolved Ions	mg/L	218	147	94	135	487	553	-	77	227	64	225	98	145	201	126	60	192
Total Suspended Solids	mg/L	67	166	178	23	392	276	-	541	46	118	39	105	115	80	11	41	147
Major Ions																		
Calcium as Ca - soluble	mg/L	20	13	8.7	12	28	12	-	6.4	25	4	28	11	15	21	15	6.1	26
Chloride as Cl	mg/L	7.5	5.6	7.1	7.3	96	61	-	4.8	9.4	5.9	12	2.5	5.1	9.1	6	3.6	3.9
Magnesium as Mg - soluble	mg/L	3.2	3.2	3.6	5.6	12	4	-	2	5.6	2	9.1	2.9	3.5	6.3	4.9	1.9	5.8
Nitrate as NO3	mg/L	<0.5	2.8	1.3	<0.5	<0.5	<0.5	-	2	<0.5	5.8	<0.5	1.1	1.6	<0.5	<0.5	0.6	2.1
Potassium as K	mg/L	4.2	4.6	4.2	6.8	28	7.8	-	3.2	5.9	4.5	5.9	4.6	5.1	5.9	4.1	4.5	6.6
Sodium as Na	mg/L	32	19	8	11	85	145	-	9	25	8	14	6	15	20	8	5	12
Sulphate as SO4	mg/L	14.2	10	4	3.6	41	85	-	7.8	12.3	7.7	4.5	8.2	26	17.1	3.5	4	50
Aluminium as Al - soluble	mg/L	<0.05	<0.05	2.2	<0.05	<0.05	<0.05	-	0.32	<0.05	5.3	<0.05	0.13	<0.05	<0.05	<0.05	1.6	<0.05
Boron as B	mg/L	0.07	0.05	0.06	0.07	0.25	0.32	-	0.04	0.1	0.05	0.05	0.05	0.06	0.08	0.05	0.05	0.07
Copper as Cu - soluble	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	-	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Fluoride as F	mg/L	0.22	0.14	0.12	0.13	0.35	1.2	-	0.1	0.29	0.1	0.11	0.1	0.16	0.17	0.1	0.07	0.15
Iron as Fe - soluble	mg/L	<0.01	0.03	1.8	0.02	<0.01	0.01	-	0.19	<0.01	2.6	0.01	0.16	0.03	<0.01	0.03	0.99	<0.01
Manganese as Mn - soluble	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	-	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silica as SiO2 - soluble	mg/L	17	21	29	18	41	2	-	14	9	38	18	11	12	15	17	14	14
Zinc as Zn - soluble	mg/L	0.02	0.01	0.02	0.01	<0.01	0.02	-	0.01	<0.01	0.03	<0.01	0.02	0.01	<0.01	0.02	0.04	0.02
Nutrients																		
Total Nitrogen	mg/L	0.43	1.7	2.3	1.1	1.3	4.7	-	1.5	0.84	3.7	0.78	1.2	1.1	0.7	0.42	0.96	1.3
Total Phosphorus as P	mg/L	0.19	0.39	0.69	0.15	0.32	0.48	-	0.57	0.16	0.69	0.087	0.4	0.29	0.12	0.048	0.21	0.17
Productivity																		
Chlorophyll-a	µg/L	5	9	<1	22	6	61	-	3	6	7	12	52	<1	7	6	9	38