Surface water-dependent receptors associated with CSG development in the Galilee Subregion of the Lake Eyre Basin

A 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.

This publication has been compiled by Technical Support staff of Water Services, Department of Natural Resources and Mines, Mackay.

Suggested Citation: 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.

© State of Queensland, 2014.

The Queensland Government supports and encourages the dissemination and exchange of its information.

This work is licensed under the Creative Commons Attribution 4.0 International License.

To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

You must keep intact the copyright notice and attribute the State of Queensland as the source of the publication.

Note: Some content in this publication may have different licence terms as indicated.

The information contained herein is subject to change without notice. The Queensland Government shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.

Funding for these projects has been provided by the Australian Government through the Department of the Environment. For more information on bioregional assessments, visit http://www.bioregionalassessments.gov.au.

Contents

List of Tables

List of Figures

Summary

The Australian Government is undertaking a programme of Bioregional Assessments (BA) in order 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 scientific 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 Galilee Basin in central Queensland is recognised as an emerging coal-seam gas (CSG) province, however, key knowledge gaps relating to the production and release of co-produced water (water generated through the extraction of coal seam gas and the dewatering of coal mines) currently remain. These are particularly relevant for the naturally ephemeral rivers and streams of the Lake Eyre Basin (LEB) which are considered to be among the most environmentally sensitive to change (Mackay et al. 2012).

The purpose of this report is to identify and prioritise the key surface water-dependent receptors (i.e. attributes or entities directly affected by the release of co-produced water and industrial related pressures) materially affected by the development of a coal-seam gas industry in the portion of the LEB that falls within the Galilee subregion. Conceptual models, and a pressure-stressor-response (PSR) framework were used to develop cause and effect linkages for four major surface-water dependent stressors: 1) alteration to the natural physical and chemical attributes of the receiving environment as a result of the release of co-produced water; 2) alteration to the natural cycles of wetting and drying, and the natural flow regime as a result of the release of co-produced water; 3) construction of infrastructure associated with the development of a coal-seam gas industry; and 4) inter-basin transfers from external beneficial use schemes.

A review of the published literature presents a range of ecosystem responses and possible species, guilds, communities and processes with the potential to act as surface-water receptors for CSG development.

Key knowledge gaps identified by the PSR framework are:

- The need to develop a baseline understanding of the natural spatial and temporal water quality patterns.
- The development of a baseline understanding of the distribution and abundance of invasive species, improved knowledge of the ecological values of arid and semi-arid lakes and swamps, and the provision of long-term flow monitoring data.
- The development of a baseline understanding of floodplain inundation frequency and waterhole persistence in the region.
- The development of a baseline understanding of the genetic population structure of water-dependent species shared with neighbouring catchments and a basic understanding of the background levels, and spatial and temporal variability of disease in sensitive taxa.

It is intended that the PSR framework outlined in this report 1) provides an initial baseline assessment of priority receptors; and 2) provides a basis for the design of a monitoring program of appropriate frequency, duration, spatial coverage, and sampling size to capture the potential effects of future CSG developments in the study area.

1. Introduction

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. These are particularly relevant for the naturally ephemeral rivers and streams of the LEB which are considered to be among the most environmentally sensitive to change (Mackay et al. 2012). If gas reserves in the Galilee Basin are developed in future, it will be necessary to gain a baseline understanding of extant ecosystem conditions (i.e reference condition), against which, potential development impacts can be compared. A fundamental step in developing this reference condition is to first review, conceptualise and prioritise the specific ecosystem pressures and potential ecosystems responses associated with development of a CSG industry prior to baseline ecosystem assessment.

1.1 Bioregional Assessment Programme

Funding for these projects has been provided by the Australian Government 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.

For more information on bioregional assessments, visit www.bioregionalassessments.gov.au

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 Purpose and Scope

This report does not aim to provide an exhaustive review of the current extent of knowledge on the ecology, hydrology, geology and hydrogeology of the Lake Eyre Basin (LEB) bioregion, nor does it aim to summarise the known coal and coal seam gas resources, and developments both now and (potentially) in the future. The purpose of this report is to review the key environmental pressures associated with the development of a CSG industry in the Galilee Basin, conceptualise the potential impacts of these pressures on surface-water dependant ecological receptors, and identify key knowledge gaps and priority receptors to inform future baseline environmental assessments in the region.

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.

The geographic area covered by this report extends to that portion of the Lake Eyre Basin drainage occurring within the Galilee subregion (Fig. 1). This area primarily includes the Thomson and Barcoo Rivers in the upper reaches of the Cooper Creek catchment and the adjacent headwaters of the Diamantina River. This report is not concerned with those fractions of the neighbouring Flinders, Burdekin, Fitzroy, Warrego and Bulloo catchments included in the wider Lake Eyre Basin bioregion (see Fig. 3 in Evans et al. 2014).

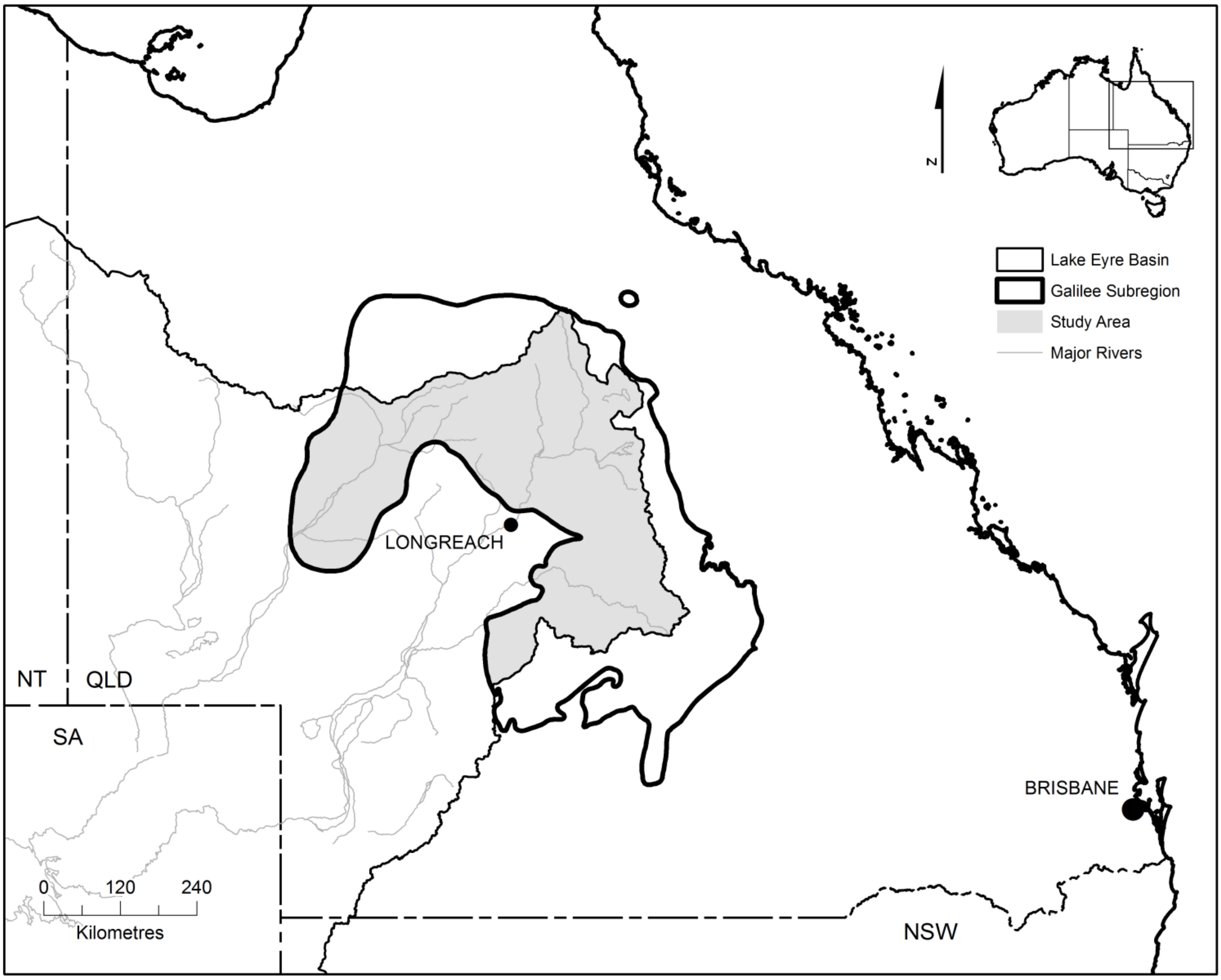

Figure 1: Study area (shaded) includes that portion of the LEB drainage occurring within the Galilee Subregion.

1.4 Background

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 thickest and most spatially extensive ‘Betts Creek beds’, however, recent evidence suggests coal seams in the Galilee Basin likely contain 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 in the contextual information 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 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.

1.4.1 Ecology of the Lake Eyre Basin Drainage

The LEB system shares its headwaters with those of four other major Australian drainage divisions, however, the area is characterised by a distinctive, yet specialised biota, including numerous species endemic to the area. Underpinning this diversity are the natural cycles of wetting and drying which see the typically arid landscape transformed into highly productive grasslands following irregular and spatially variable rainfall events. During wetter periods, the riverine ecosystem expands to a vast network of interconnected floodplain and channel habitats stimulating large ‘booms’ of aquatic and terrestrial productivity. The majority of species are adapted to take advantage of the 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). Alternatively, prolonged periods of no-flow reduce the river network to 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. 2006b). These ‘bust’ periods also represent important life-history cues for a number of specialised dryland species including fish, invertebrates, plants and algae. The natural cycles of wetting and drying, and the associated ‘boom and bust’ ecology, are critical for maintaining biodiversity throughout riverine and floodplain areas of the Galilee Basin.

1.4.2 Existing monitoring work

Given its geographical isolation and relatively low levels of human interference, the LEB has received comparatively little research and baseline assessment of ecology, geomorphology and water quality. The Queensland Government has conducted a number of regional aquatic ecosystem assessments with focus given to a wide range of ecological, hydrological and morphological attributes (Table 1). These have provided an initial, broad-scale characterisation of the condition and diversity of aquatic species present in the Galilee Basin, however, these studies are somewhat limited in their specificity towards CSG development. There have also been a number of other important projects in the wider LEB (*e.g.* Dryland Refugia, and ARIDFLO) which have contributed to the conceptual and baseline understanding of unregulated dryland river systems. However, these did not cover the spatial area of the current study, rather they have focussed more on the Channel Country bioregion to the south-west of the Galilee Basin.

Table 1: Existing and previous riverine ecology, geomorphology and water quality monitoring programs undertaken in the Galilee Basin study area.

Project title	Data collected	Year collected
Lake Eyre Basin Rivers Assessment (LEBRA)	Fish assemblage and population structure, hydrology and water quality.	2011-current
Stream & Estuary Project (SEAP)	Fish, crustaceans, molluscs, riparian vegetation condition including weed species, presence and impact from introduced fauna (e.g. pigs), *in-situ* water quality.	2011
State of the Rivers (SoR) Assessment	49 river attributes covering: reach condition, bank condition, bed and bar condition, channel habitat diversity, riparian vegetation condition, aquatic vegetation condition, aquatic habitat condition, scenic and recreational value, conservation value.	1994
Monitoring River Health Initiative (MRHI)	Macroinvertebrates, water quality (both *insitu* and laboratory analysis), aquatic habitat parameters, site reference scores.	1997-2004
Surface Water Ambient Network (SWAN)	Maximum of 49 water quality variables (both *insitu* and laboratory analysis).	1965-current
Framework for the Assessment of River Wetland Health (FARWH)	Physical form, water quality and soils, aquatic biota, hydrological disturbance, fringing zone, catchment disturbance.	2009
Aquatic Conservation Assessments (ACA) for LEB and Bulloo River wetlands	68 measures of riverine and non-riverine wetland indicators including naturalness (aquatic & catchment), diversity and richness, threatened species and ecosystems, priority species and ecosystems, special features, connectivity, representativeness and relative wetland conservation values within a specified area.	2010-2011

1.4.3 Pressure-stressor-response 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 purposes of this report, definitions in the forthcoming PSR framework include:

- Pressure: any human related surface-water disturbance associated with CSG developments in the Galilee Basin.

- Stressor: any physicochemical, hydrological, or morphological vector by which CSG pressures materially affect surface-water dependent receptors in the Galilee Basin.

- Response: any ecological, biological or physical alteration directly resulting from CSG developments in the Galilee Basin.

- Receptor: a species, guild, community or process known to occur in the Galilee Basin with the potential to materially respond to CSG development.

- Specificity: the sensitivity of possible receptors to CSG development irrespective of background variation. High (H) = variation likely to be solely related to CSG pressures and/or highly responsive to change. Medium (M) = variation in part due to both CSG pressures and background variability and/or moderately responsive to change. Low (L) = variation likely to be hard to separate between CSG pressures and background variability and/or weakly responsive to change.

- Confidence: a qualitative assessment of the level of knowledge underpinning the conceptual linkages in the PSR framework. High (H) = documented evidence within the LEB system and/or specific to dryland river CSG development usually with multiple lines of evidence. Medium (M) = evidence documented for CSG developments in other ecosystems or specific to the LEB system but not related to CSG development. Low (L) = documented qualitative or conceptual evidence related to CSG development and/or water-dependent ecosystems.

2 A PSR Framework for Surface Water-Dependent Receptors Associated with CSG Development in the Galilee Basin

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, 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 physical and chemical attributes of the receiving environment; 2) alteration to the natural cycles of wetting and drying, and the natural flow regime; 3) inter-basin transfers from external beneficial use schemes; and 4) infrastructure associated with the development of a CSG industry, were identified as potentially having a material impact on aquatic receptors in the Galilee Basin (Fig. 2).

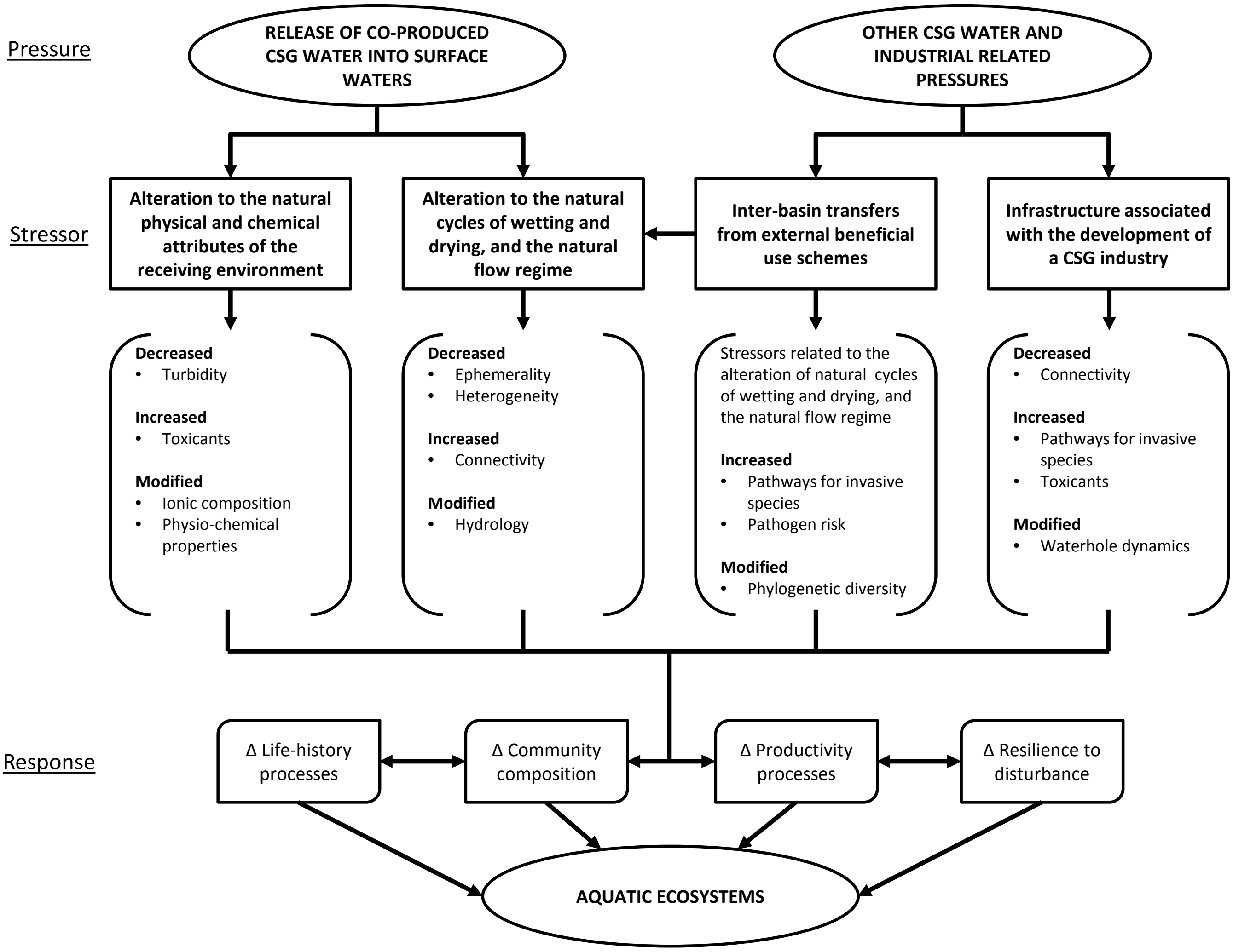

Figure 2: General conceptual model outlining two main surface water-dependent pressures arising from CSG developments and the associated stressor and response linkages to aquatic ecosystems in the Galilee Basin.

2.1 Potential impacts resulting from release of co-produced CSG water into surface waters

The Queensland Governments CSG Water Management Policy states that co-produced water should be used for a purpose that is beneficial to the environment, other water users, or water-dependent industries (DEHP 2012). This can include, for example, irrigation, stock watering, recreational use, or recharge into depleted aquifers. Coal-seam gas water is considered waste under the EP Act and therefore its release into surface streams is considered a secondary management option under the CSG Water Management Policy (DEHP 2012).

Given the low to very low gas saturation levels in Galilee coal deposits, relatively high volumes of co-produced water are likely to be produced in order to reach critical desorption pressure. Where this water is in excess of the demand for treated CSG water for beneficial use, certain regulations may allow it to be discharged into surface waters. Discharge may occur during natural flow-events over a certain flow-magnitude; however, the LEB system is highly ephemeral - typified by low-flow spells and a high number of zero-flow days, interspersed with irregular flow-events of unpredictable magnitude. This may lead to the release of CSG water during low or no-flow periods potentially causing the following environmental stressors.

2.1.1 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. In addition to the direct impacts of these individual components on aquatic ecosystems, the resultant modification to the receiving environment can potentially cause secondary or cumulative impacts from the interaction between complex mixtures of chemicals.

Dilution of the naturally turbid dryland rivers by the release of treated water low in TSS has the potential to directly alter the light and thermal regimes of the receiving environment (Fig. 3). Primary productivity in the LEB system is considered to be ‘light-limited’ with higher rates of production attributed to high light intensity and temperatures (Bunn et al. 2006a). Algal blooms are likely to result from increased light intensity and therefore primary production, particularly where local land-use exacerbates nutrient loads (Takahashi et al. 2012a). Modified physiochemical properties coupled with higher light intensity can cause increased stress in some biota, ultimately lowering fungal and parasitic immunity (Bhaskar & Govindappa 1986) (Fig. 3). These physiochemical alterations also potentially modify the behaviour of soluble ions in the receiving environment, further modifying ionic composition (Fig. 3). Altered ionic composition has been documented to cause toxicity to sensitive taxa (Rogers et al. 2011; Takahashi et al. 2012a). For example, low calcium cation (Ca2+) concentrations can affect the exoskeletal strength and somatic growth of some macroinvertebrates (*e.g.* crustaceans and molluscs) (Zalizniak et al. 2009) (Fig. 3). Some long lived species of benthic macroinvertebrates, as well as other flora and fauna, may also suffer from acute or chronic exposure to potential recalcitrant toxicants (e.g. boron and ammonia) occurring in RO treated water (Takahashi et al. 2012b) (Fig. 3). These toxicants can also accumulate in sediments and potentially mobilise during subsequent floods resulting in downstream physiological responses (Takahashi et al. 2012a).

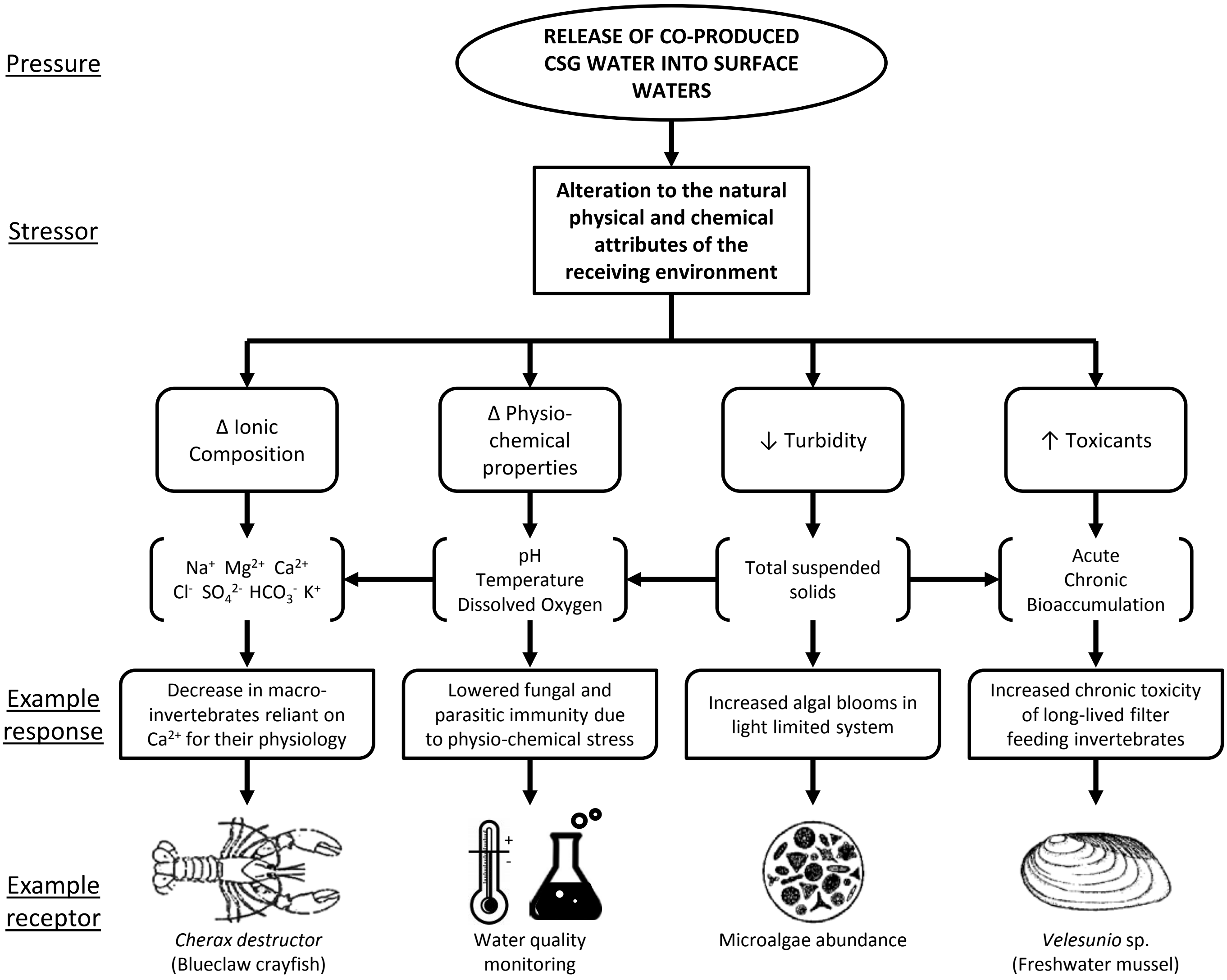

Figure 3: Conceptual linkages resulting from alteration to the physical and chemical attributes of the receiving environment from the release of co-produced CSG water into surface waters.

Alteration to the physical and chemical attributes of surface-waters is a major threat to ecosystem health and the structure and function of ecological communities in the Galilee Basin. Possible receptors can respond to one or a number of primary stressors and/or from complex interactions among water quality parameters and ecosystem feedback loops, ultimately making it difficult to characterise causal pathways with high confidence. These multi-level responses are conceptualised in Figure 4 with Galilee Basin specific receptors and baseline survey priorities highlighted.

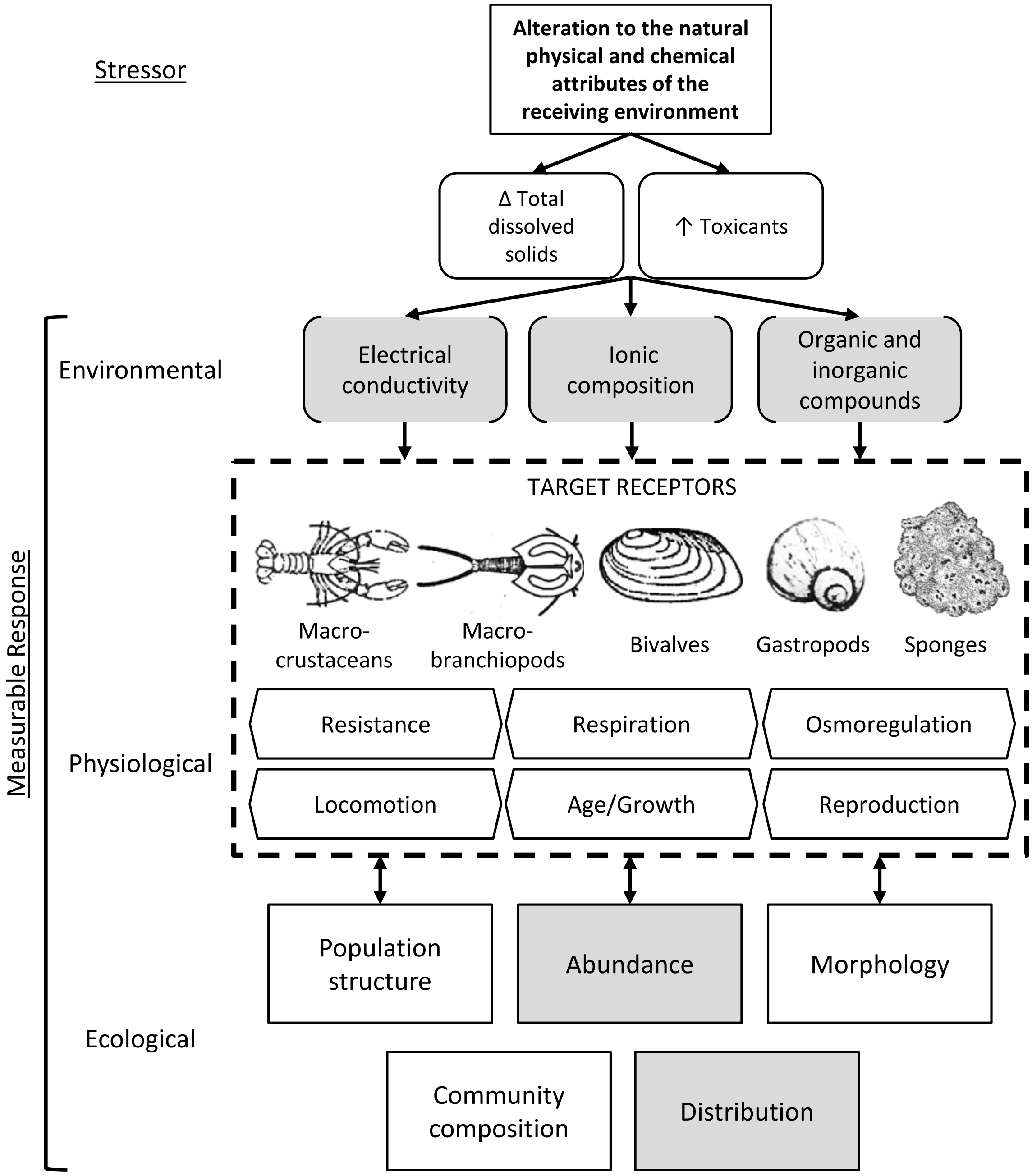

Figure 4: Galilee Basin specific target receptors and multi-level responses to changes in the physical and chemical attributes of the receiving environment from the release of co-produced CSG water into surface waters. Shaded areas indicate survey priorities for baseline monitoring and assessments.

Key Knowledge Gaps: The development of a baseline understanding of the natural spatial and temporal water quality patterns and toxicant levels.

Priority Receptors: Turbidity; physiochemical properties (including EC); macro-invertebrate abundance and distribution.

Table 2: A 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 due to alteration of the natural physical and chemical attributes of the receiving environment. See Section 1.2.3 for definition of table headings.

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
THE 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.** **Decreased** • Electrical conductivity (EC). • Turbidity. **Increased** • Light penetration. **Modified** • Ionic composition. • Toxicants (cumulative). • Temperature. **Measurement of Stressor** Water Quality Parameters • EC level in water. • Ionic concentrations and composition of water e.g. Na, Mg, Ca, Cl, SO4, HCO3, K. • Turbidity of water. • Light penetration of water. • Toxicants.	**Invertebrates**			
		• Alteration to invertebrate community composition and individual species abundance (Resh et al. 1995).	Change in macroinvertebrate community structure and species abundance.	L	M
		• Decrease in macroinvertebrates that are sensitive to low EC (Takahashi et al. 2012a).	*Macrobrachium australiense* (Shrimp), *Cherax destructor* (Blueclaw crayfish), *Cherax quadricarinatus* (Redclaw Crayfish), *Austrothelphusa transversa* (Crab), *Notopala sublineata* (Snail), *Velesunio* spp. (Mussel).	M	M
		• Decrease in macroinvertebrates that rely on Ca for their physiology (Zalizniak et al. 2009).	*Notopala sublineata* (Snail), *Velesunio* spp. (Mussel), *Cherax destructor (*Blueclaw Crayfish*).*	H	M
		• Increase in acute and chronic toxicity on various sensitive taxa (Takahashi et al. 2012a).	Zooplankton community structure and biomass.	M	L
		Macrophytes			
		• Increase in acute and chronic toxicity on various taxa (Takahashi et al. 2012a).	Submerged macrophytes *e.g. Potamogeton* sp. and emergent macrophytes *e.g. Typha domingensis* (Bullrush), *Phragmites australis* (Cane Grass), *Cyperus gymnocaulos* (Spiny Sedge).	L	L
		Fish			
		• Alteration of fish community composition and individual species abundance (Davies et al. 1996).	Change in fish community structure and species abundance.	L	L
		• Increase in acute and chronic toxicity on various sensitive taxa (Takahashi et al. 2012a). • Increased susceptibility to disease and parasites due to toxic stress (Bhaskar & Govindappa 1986).	Concentration of contaminants/toxicants in tissue.	H	L

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
		Amphibians/Reptiles			
		• Alteration to normal patterns of growth in externally fertilised taxa (ANZECC/ARMCANZ 2000).	Native frog species *e.g. Limnodynastes, Platyplectrum, Neobatrachus, Myobatrachidae.*	H	L
		Processes			
		• Decrease in microphytobenthic and algal taxa which may be sensitive to altered ionic composition (Takahashi et al. 2012a). • Increase in acute and chronic toxicity on various sensitive microphytobenthic and algal taxa (Takahashi et al. 2012a).	Algal and phytoplankton community structure and biomass.	H	M
		• Increase in algal blooms (Takahashi et al. 2012a).	Primary production.	H	M

2.1.2 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). Low-flow hydrology is considered to be a major driver of ecological community composition in dryland river systems (Arthington and Balcombe 2011). Further, any releases triggered by high-flow events are likely to artificially inflate floods, extend flood duration and length of flood recession (Bunn and Arthington 2002). In addition to the direct impacts of these individual components on aquatic ecosystems, secondary and cumulative impacts arising from complex interspecific interactions and alterations to the food-web are likely to occur.

A reduction in environmental heterogeneity is likely to result from the constant release of co-produced water into surface streams (Fig. 5). Water held in drying ephemeral pools contributes to overall channel complexity by creating depressions and this loss of periodic cease-to-flow events may limit sediment consolidation and the breakdown of organic matter buried in the streambed (Reich et al. 2010; Commonwealth of Australia 2014). Under a constant-flow scenario, increased soil moisture in the riparian zone may potentially cause a shift towards more mesic riparian species and facilitate the encroachment of woody vegetation into the riverine environment resulting in a reduction in riparian heterogeneity (Stromberg et al. 2007; Arthington et al. 2012; Belmar et al. 2013). These alterations are likely to modify habitat availability/heterogeneity for some aquatic and water-dependent terrestrial biota (Fig. 5). Constant release of water may also be associated with modified stream hydraulics including increased flow velocity - which is known to cause increased bank scouring and the build-up of unconsolidated sediments (Bjornsson et al. 2003; Ryder et al. 2006) (Fig. 5). Rivers with unstable substrates tend to be characterized by low species diversity (Bunn and Arthington 2002). Constant release of water is also likely to cause a reduction in flow seasonality and variability, and an increase in flow predictability. Ultimately, this will contribute to a general loss of ephemerality (Fig. 5). Decreased ephemerality is likely to impact species life-history dynamics such as spawning, nesting, migration, aestivation and metamorphosis, however, an associated increase in longitudinal connectivity along the river network may allow native species increased dispersal routes and improved access to permanent in-stream and floodplain refugia.

Arid and semi-arid inland lakes and swamps form part of an important network of aquatic habitat in the otherwise dry landscape (Jaensc and Young 2005). The systems can experience highly variable inundation regimes resulting from erratic and unpredictable water inputs from year to year and support a range of species, some of which are specifically adapted to survive in variable fresh to saline water regimes and through times when the systems dry out (Gardiner 2005). In the Galilee Basin, semi-arid depressional lakes such as Lake Galilee and Lake Buchanan are situated within close proximity to the majority of CSG exploration wells (DRNM 2014).Their conservation values are poorly known (Jaensc and Young 2005).

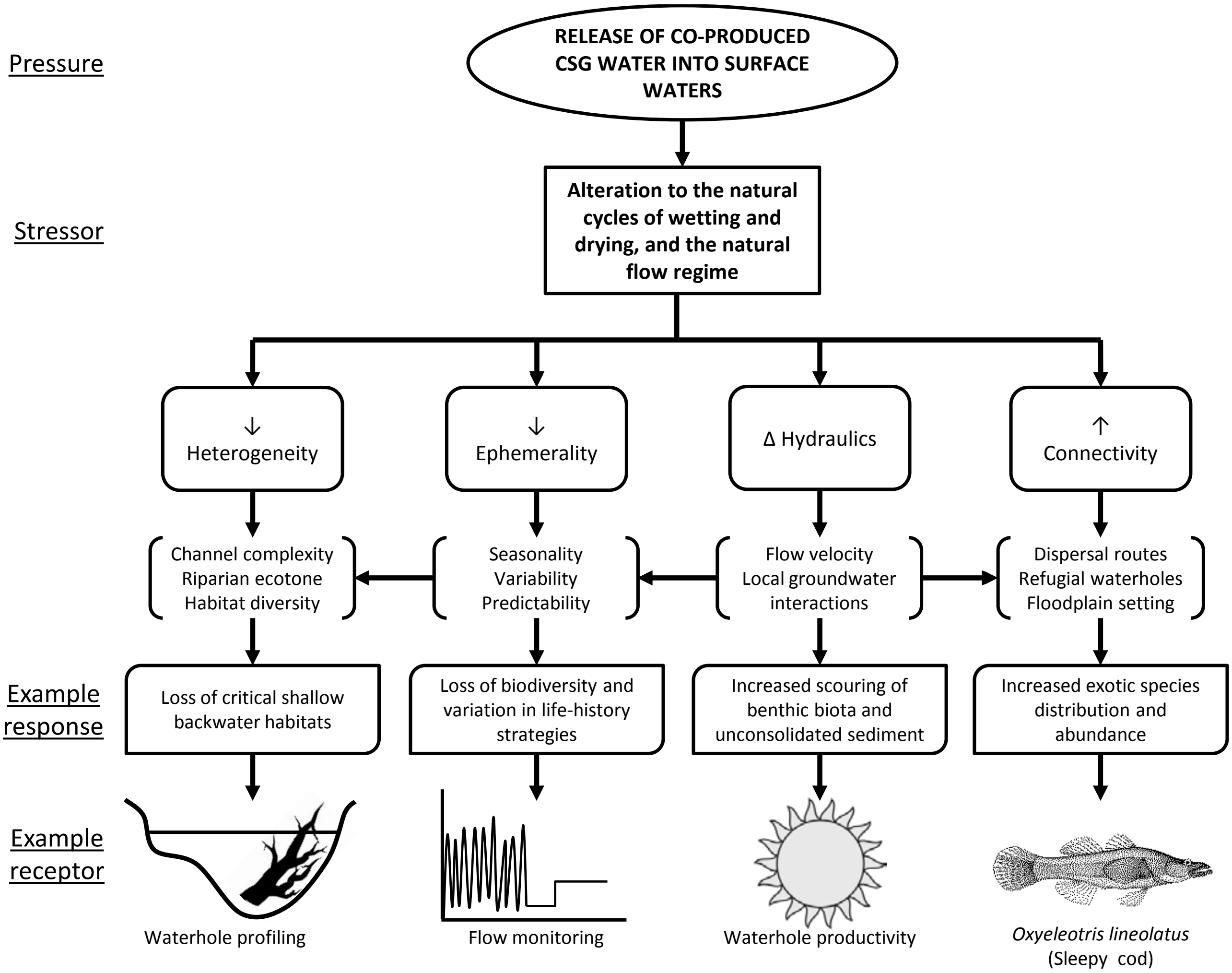

Figure 5: Conceptual linkages resulting from alteration to the natural cycles of wetting and drying, and the natural flow regime from the release of co-produced CSG water into surface waters.

Spatial and temporal variability in the natural wetting and drying patterns of ephemeral waterholes underpin local and regional biodiversity throughout the LEB (Costelloe et al. 2004; Arthington et al. 2005; Bunn and Arthington 2002). While alterations to native species abundance and distribution may have limited consequences for ecosystems processes, 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 (Gehrke and Harris 2001; Marchetti and Moyle 2001; Tyler et al. 2012; Marufu et al. 2014; *but see* Costelloe et al. 2010). Galilee Basin specific invasive species (receptors) and baseline survey priorities are highlighted in Figure 6.

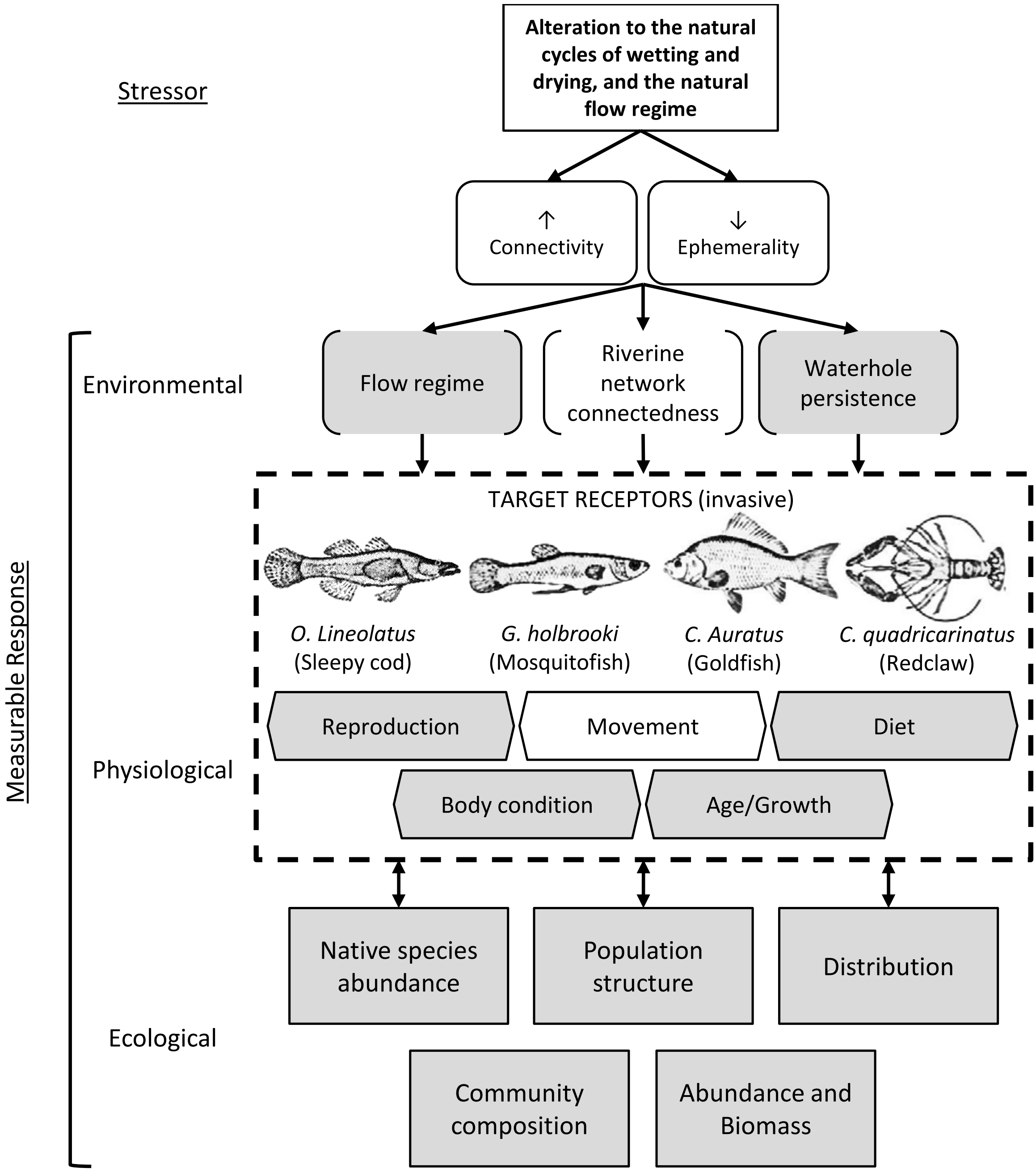

Figure 6: Galilee Basin specific target receptors and multi-level responses to changes in the natural cycles of wetting and drying from the release of co-produced CSG water into surface waters. Shaded areas indicate survey priorities for baseline monitoring and assessments.

Predicting the potential ecological responses to altered flow regimes, particularly a decrease in heterogeneity and ephemerality is complicated by various interactions between flow and the ecosystem components, and by the multiple spatio-temporal scales at which they occur (McGregor et al. 2011). However, reduced ephemerality has the potential to cause a wide range of ecological and physical aquatic ecosystem responses of both short and long-term duration and is likely to be a major driver of both secondary and cumulative changes throughout the system. Primary and secondary productivity processes are a particularly important component of this cumulative change, being responsive to both physical changes in flow and morphology, while driving concomitant shifts in local food webs and abundance and diversity of higher trophic organisms. These hierarchical receptors and complex productivity processes are conceptualised in Figure 7, with target receptors and baseline survey priorities highlighted.

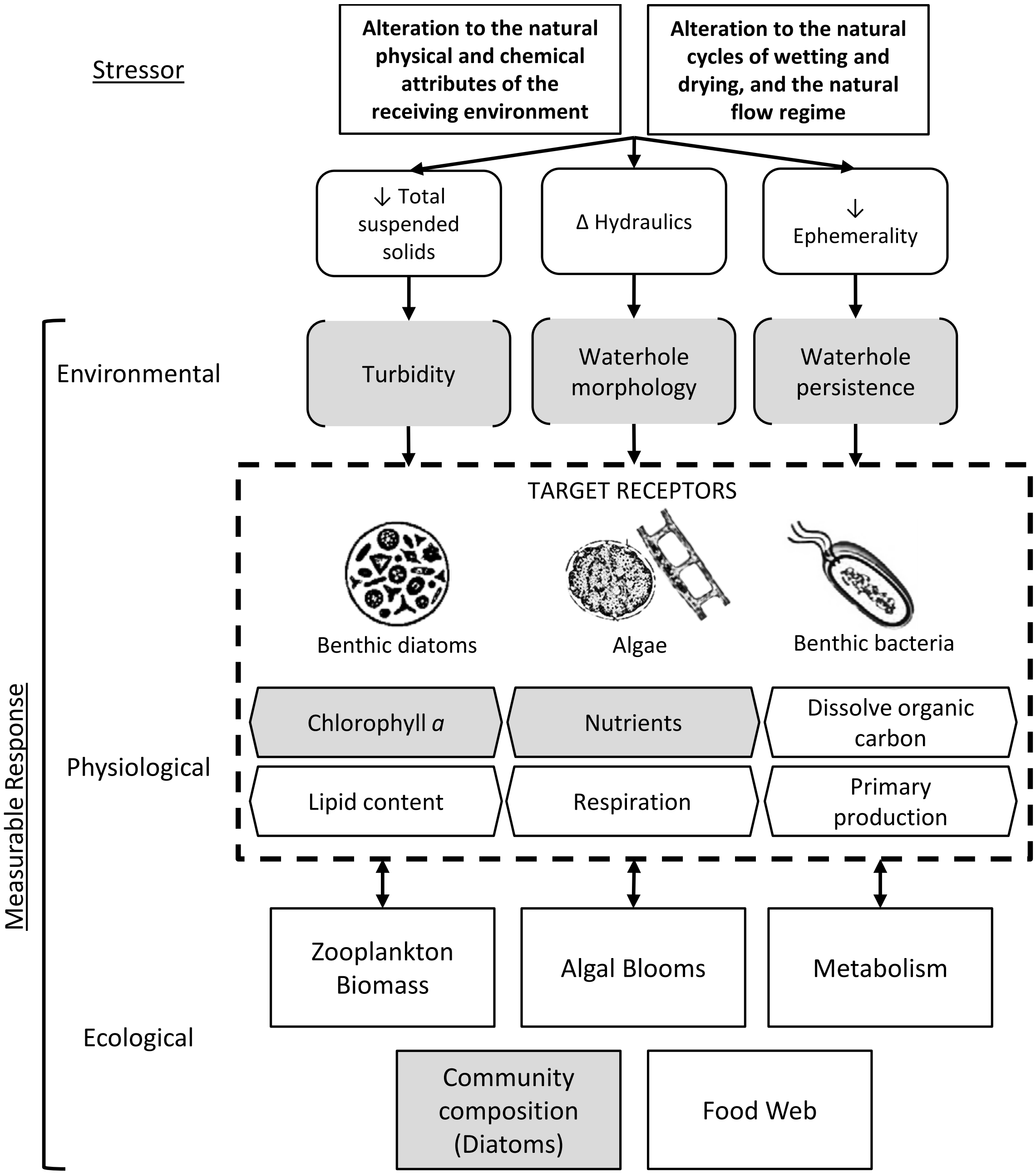

Figure 7: Primary productivity processes and hierarchical responses to changes in the natural cycles of wetting and drying and the physical and chemical attributes of the receiving environment from the release of co-produced CSG water into surface waters. Shaded areas indicate survey priorities for baseline monitoring and assessments.

Key Knowledge Gaps: The development of a baseline understanding of the 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.

Priority Receptors: Oxyeleotris lineolatus (Sleepy Cod); Cherax quadricarinatus (Redclaw Crayfish); Lake Buchanan and Lake Galilee; the endangered Coolibah-Black Box Woodlands; flow regime; waterhole morphology; waterhole persistence modelling; diatom community composition.

Table 3: A 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 due to alteration of the natural cycles of wetting and drying and the natural flow regime. See Section 1.2.3 for definition of table headings.

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
THE RELEASE OF CO-PRODUCED CSG WATER INTO SURFACE WATERS OF THE GALILEE BASIN (LAKE EYRE BASIN)	**Alteration to the natural cycles of wetting and drying and the natural flow regime.** **Decreased** • Ephemerality. • Habitat heterogeneity. • Flow seasonality. • Flow variability. **Increased** • Connectivity. • Flow predictability. • Flow velocity. • Flow event duration. **Measurement of stressor** Low-Flow metrics • Low-flow magnitude. • Frequency of low-flows. • Duration of low-flows. • Timing of low-flows. • Seasonal variations in flows.	**Invertebrates**			
		• Alteration of invertebrate community composition and individual species abundance (Sheldon et al. 2002; Marshall et al. 2006).	Change in macroinvertebrate community structure and species abundance.	L	L
		• Decrease of taxa that require desiccation or benefit from it (Smythe-McGuiness et al. 2012; Reich et al. 2010). • Modification of positive rheotaxis, dormancy, and burrowing behaviours (Larned et al. 2010).	"Permanent Refugial" invertebrate guild *e.g. Triops australiensis* (Shield shrimp), *Notopala sublineata* (Snail), *Velesunio* spp. (Mussel), *Austrothelphusa transversa* (Crab).	M	M
		• Increase in taxa that prefer high flow (Smythe-McGuiness et al. 2012; Sheldon et al. 2010). • Reduced aerial and overland dispersal between wide spread aquatic habitats (Larned et al. 2010).	"Network" invertebrate Guild *e.g. Macrobrachium australiense* (Shrimp)*, Cherax destructor* (Blueclaw Crayfish).	M	L
		• Increased exotic/translocated invertebrate distribution and abundance (Marufu et al. 2014).	Translocated *Cherax quadricarinatus* (Redclaw Crayfish).	H	M
		• Loss of drifting taxa from excessive or frequent drift (Commonwealth of Australia 2014). • Decrease in taxa that rely on seasonal cues for emergence/drift/movement (Bunn and Arthington 2002).	*e.g.* Nematodes, Copepods, Ostracods and Chironomid flies.	L	L
		Macrophytes			
		• Loss of macrophyte species susceptible to increased bed and bank sheer stress and scouring (Mackay et al. 2003).	Emergent macrophytes e.g. *Typha domingensis* (Bullrush), *Phragmites australis* (Cane Grass), *Cyperus gymnocaulos* (Spiny Sedge).	L	L

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
		• Increase in aquatic macrophytes in permanent pools and backwaters (Takahashi et al. 2012a).	Submerged macrophytes *e.g. Potamogeton* sp.	L	M
		Fish			
		• Alteration to fish community composition and individual species abundance (Arthington et al. 2005).	Change in fish community structure and species abundance.	M	H
		• Increased exotic/translocated taxa distribution and abundance (Bond et al. 2010).	Exotic and translocated fish *e.g. Gambusia holbrooki* (Mosquito fish), *Oxyeleotris lineolatus* (Sleepy Cod), *Carassius auratus* (Goldfish).	H	H
		• Decrease in taxa or guilds that quickly colonise newly inundated waterholes (Arthington and Balcombe 2011).	*Hypseleotris* spp. (Carp gudgeons), *Ambassis mulleri* (Glassfish), *Melanotaenia splendida tatei* (Rainbowfish).	L	L
		• Increase in taxa or guilds with migratory spawning strategies (Commonwealth of Australia 2014).	*Leiopotherapon unicolor (*Spangled perch), *Macquaria sp.* (Golden perch), *Nematalosa erebi* (Bony herring).	M	L
		• Decrease in taxa or guilds that are adapted to drying waterholes (Reich et al. 2010).	*Neosiluroides cooperensis* (Cooper Creek catfish), *Neosilurus Hyrtlii* (Hyrtl's tandan), *Porochilus argenteus* (Silver tandan).	L	L
		• Decrease in taxa or guilds that require shallow backwaters for spawning and juvenile recruitment (King et al. 2003).	*Hypseleotris* spp. (Carp gudgeons), *Ambassis mulleri* (Glassfish), *Melanotaenia splendida tatei* (Rainbowfish), *Retropinna semoni* (Australian smelt).	L	M
		• Decrease in species that rely on seasonal low-flow spawning cues (Humphries et al. 1999).	*Neosilurus hyrtlii* (Hyrtl's tandan), *Porochilus argenteus* (Silver tandan), *Melanotaenia splendida tatei* (Rainbowfish), *Ambassis mulleri* (Glassfish).	L	M
		• Decrease nesting and nest-guarding taxa (Cockayne et al. 2009).	Plotosid catfishes.	L	L

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
		Amphibians/Reptiles			
		• Reduced egg survivorship/juvenile recruitment in shallow slow flowing backwaters (Tyler et al. 2011).	Native frog species *e.g. Limnodynastes, Platyplectrum, Neobatrachus, Myobatrachidae.*	L	L
		• Increased exotic species distribution and abundance (Phillips et al. 2007).	*Rhinella marina* (Cane toad).	L	L
		• Reduced habitat area for riparian nesting (Spencer 2006).	*Emydura* spp. (Freshwater turtle).	L	M
		Vegetation			
		• Die-back of waterlogged riparian vegetation (Takahashi et al. 2012a).	*Eucalyptus camaldulensis* (River Redgum); *Eucalyptus coolabah* (Coolabah); *Acacia* spp. (Wattle).	M	M
		• Alteration of riparian vegetation assemblages (Poff and Zimmerman 2010).	*Lomandra* spp. (Matrush), *Juncus* spp. (Rush).	M	L
		• Increased riparian exotic species richness and abundance (Busch and Smith 1995).	Riparian weed species e.g. *Xanthium pungens* (Noogoora Burr), *Parkinsonia aculeata* (Parkinsonia), *Vachellia nilotica* (Prickly Acacia).	L	L
		• Encroachment of woody vegetation under stable flows (Belmar et al. 2013).	Annual and Perennial Plant species composition.	M	M
		Processes			
		• Accumulation of unconsolidated sediments (Ryder et al. 2006).	Spatial and temporal waterhole profile dynamics *e.g.* waterhole bathymetry.	M	M
		• Increased bed and bank erosion (Bjornsson et al. 2003).	Taxa that predate on benthic algae and detritus e.g. Crustacea, "Scraper" and "Grazer" invertebrate guild, *Nematalosa erebi* (Bony herring).	L	L

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
		• Reduction in biofilm production (Boulton and Brock 1999).	Microphytobenthic algal abundance and diversity.	M	L
		• Alterations to local groundwater discharge and recharge patterns (Evans et al. 2014).	Waterhole persistence modelling.	M	M
		Ecosystems			
		Arid and Semi-Arid Lakes and swamps • Local and/or regional hydrology affected by water regulation or extraction (WetlandInfo 2014).	*e.g.* Lake Buchannan, Lake Galilee, Mitchel Swamp, Cauckingburra Swamp.	H	L
		Permanent Waterholes • Modification to important refugia for aquatic and terrestrial biota (Takahashi et al. 2012a).	*e.g.* Lammermoor Waterhole, Avington Waterhole, Aberfoyle Waterhole.	M	H
		Coolibah - Black Box Woodlands • Disruption to periodic waterlogging (Evans et al. 2014)	Coolibah-Black Box Woodlands.	H	L

2.2 Other CSG water and industrial related pressures

Coal-seam gas extraction typically involves a large number of well pads positioned in a grid, interconnected by roads and tracks. Footprint size is related to well intensity and the location of the resources. Collectively, CSG activities have the potential to create a web of disturbance across the landscape (Marshall et al. 2013). These landscape disturbances are often difficult to quantify, or are not immediately recognised as threats to surface-waters, however, may significantly impact the natural values of the river and floodplain ecosystem, particularly in a cumulative sense, resulting in the following environmental stressors.

2.2.1 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 riverine main channels, major tributaries, and extensive floodplain areas 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 (Fig. 8).

Floodplain communities in arid catchments are primarily structured by the frequency and duration of inundation events which create a complex hydrological gradient across the floodplain (*e.g.* Capon 2003). Disruptions to this flow regime by fragmentation in the form of levees, culverts, river diversions, roads and pipelines has the potential to isolate portions of rivers and floodplains, disrupt lateral and longitudinal connections among aquatic habitats, interfere with the energy and nutrient transfer, and movement of biota throughout the landscape (Balcombe et al. 2007; Mashall et al. 2013). A reduction in species and communities reliant on occasional/seasonal floodplain inundation, and those that migrate within the stream network are likely to be affected by a decrease in connectivity (Fig. 8). Much of this infrastructure provides a potential conduit for the movement of invasive species by both animals (zoochory) and humans (anthropochory) (Pickering and Mount 2010; Tyler et al. 2012) (Fig. 8). However, paved roads embedded in the terrestrial landscape also provide ideal basking sites for ectothermic water-dependent biota which are commonly subjected to vehicular strikes (Ashley et al. 2007). These roads, as well as work and chemical storage sites, accumulate incidental pollutants, which ultimately provide an acute source of diffuse contaminants to surface-waters during rainfall-runoff events (Marshall et al. 2013) (Fig. 8). Brine waste from RO treated co-produced water which has been disposed into landfill can also potentially re-enter the system, providing a chronic impact to surface-water ecosystems (Clifford et al. 2010). Allochthonous sources of sediment, disturbed by associated CSG infrastructure and transported to the river network by flow events and floods, can potentially modify the persistence of refugial waterholes when deposited over time (Fig. 8).

The surface-water dependent responses to infrastructure associated with the development of CSG industry are likely to occur gradually, over long-time periods, and affect primarily terrestrial species with a surface water dependency.

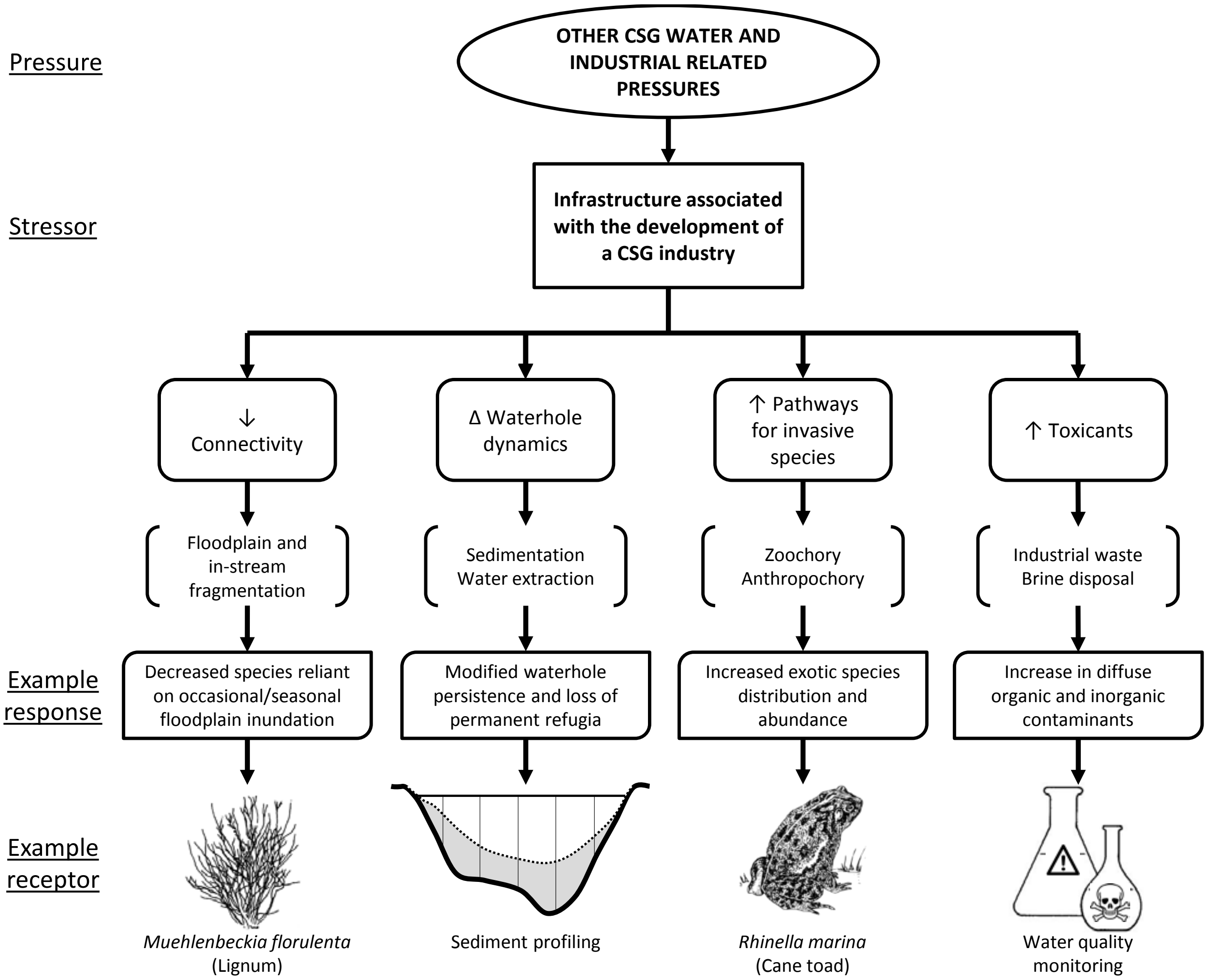

Figure 8: Conceptual linkages between infrastructure associated with the development of a CSG industry and surface-water dependent receptors in the Galilee Basin.

Key Knowledge Gaps: The development of a baseline understanding of floodplain inundation frequency and waterhole persistence in the Galilee Basin.

Priority Receptors: Waterhole spatial profile and sediment characteristics; floodplain vegetation; background toxicant levels.

Table 4: A PSR framework for surface water-dependent receptors associated with water-dependent CSG and industrial related pressures in the Galilee Basin and the resulting stress placed on aquatic ecosystems due to increased infrastructure associated with the development of a CSG industry. See Section 1.2.3 for definition of table headings.

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
OTHER CSG WATER AND INDUSTRIAL RELATED PRESSURES **• Water Diversions** **• Bridge and Culvert Construction** **• Stormwater runoff** **• Roads, Pipelines and Rail** **• Transport, Machinery and Industrial Spills.**	**Increased infrastructure associated with the development of a CSG industry.** **Decreased** • Lateral connectivity (stream network - floodplains/wetlands). • Longitudinal connectivity (in-stream habitat patches). **Increased** • Pathways for invasive species. • Physical and chemical toxicants. • Sedimentation **Measurement of stressor** Development Specific • Terrestrial subsidies to in-stream food-webs.	**Vegetation**			
		• Reduced species reliant on occasional/seasonal floodplain inundation (Capon 2003).	*Eucalyptus coolabah* (Coolabah), *Eucalyptus camaldulensis* (River Redgum), *Muehlenbeckia florulenta* (Lignum), *Chenopodium auricomum* (Queensland bluebush), *Marsilea drummondii* (Nardoo).	H	M
		• Decreased downstream seed dispersal (Thomson et al. 2010).	Seeds of some Fabaceae, Myrtaceae, and Asteracae.	L	L
		• Increased exotic species richness and abundance (Pickering and Mount 2010).	Weed species *e.g. Xanthium pungens* (Noogoora Burr), *Parkinsonia aculeata* (Parkinsonia), *Vachellia nilotica* (Prickly Acacia).	H	L
		Fish			
		• Constrained distribution of migratory species within the channel network during channel flow events (Fullerton et al. 2010).	Potadromous fish species *e.g. Macquaria* sp. (Golden perch), Terapontids, Plotosids.	L	M
		• Increase in acute and chronic toxicity on sensitive taxa (Takahashi et al. 2012a).	Fish Tissue.	H	L
		• Constrained distribution of migratory species during floodplain inundation (Balcombe et al. 2007).	Floodplain fish biomass and recruitment indices.	L	M
		Amphibians			
		• Potential vehicle strike on basking individuals (Ashley et al. 2007).	*Emydura* spp. (Turtle), typical ectothermic fauna.	H	L
		• Increased exotic species distribution (Phillips et al. 2007).	*Rhinella marina* (Cane toad).	M	L
		• Increase in acute and chronic toxicity on various sensitive taxa (Takahashi et al. 2012a).	Native frog species *e.g. Limnodynastes, Platyplectrum, Neobatrachus, Myobatrachidae.*	L	L
		Processes			
		• Increased sediment deposition in waterholes following mobilisation of disturbed sediment (Marshall et al. 2013).	Waterhole persistence modelling.	M	H

2.2.2 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 Basins 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) (Fig. 9).

The amount of genetic differentiation between populations is dependent on the length of evolutionary and geographical isolation and degree to which extant environmental conditions drive local adaption (Page et al. 2010). Species in the LEB are highly adapted to the unpredictable cycles of wetting and drying which suggests high potential for the loss of genetically distinct populations and or adaptive characteristics following re-contact with neighbouring populations (Fig. 9). This population mixing may also expose native species to a range of novel parasites and bacterial flora when host species invade receiving waterways (Burke and Rodgers 1981; Davies et al. 1992). This is likely to cause increased stress and or mortality in sensitive biota (Fig. 9). Invasive pathways associated with inter-basin transfers also extend to a number of highly aggressive flora and fauna known to occur in neighbouring catchments (Lonsdale, 1993) (Table 5) (Fig. 9).

While this stressor and the associated responses are relatively unlikely to occur, the proximity of the Galilee Basin region to the headwaters of four major drainage divisions poses an increased risk to surface water receptors through both hydrological and biological stressors.

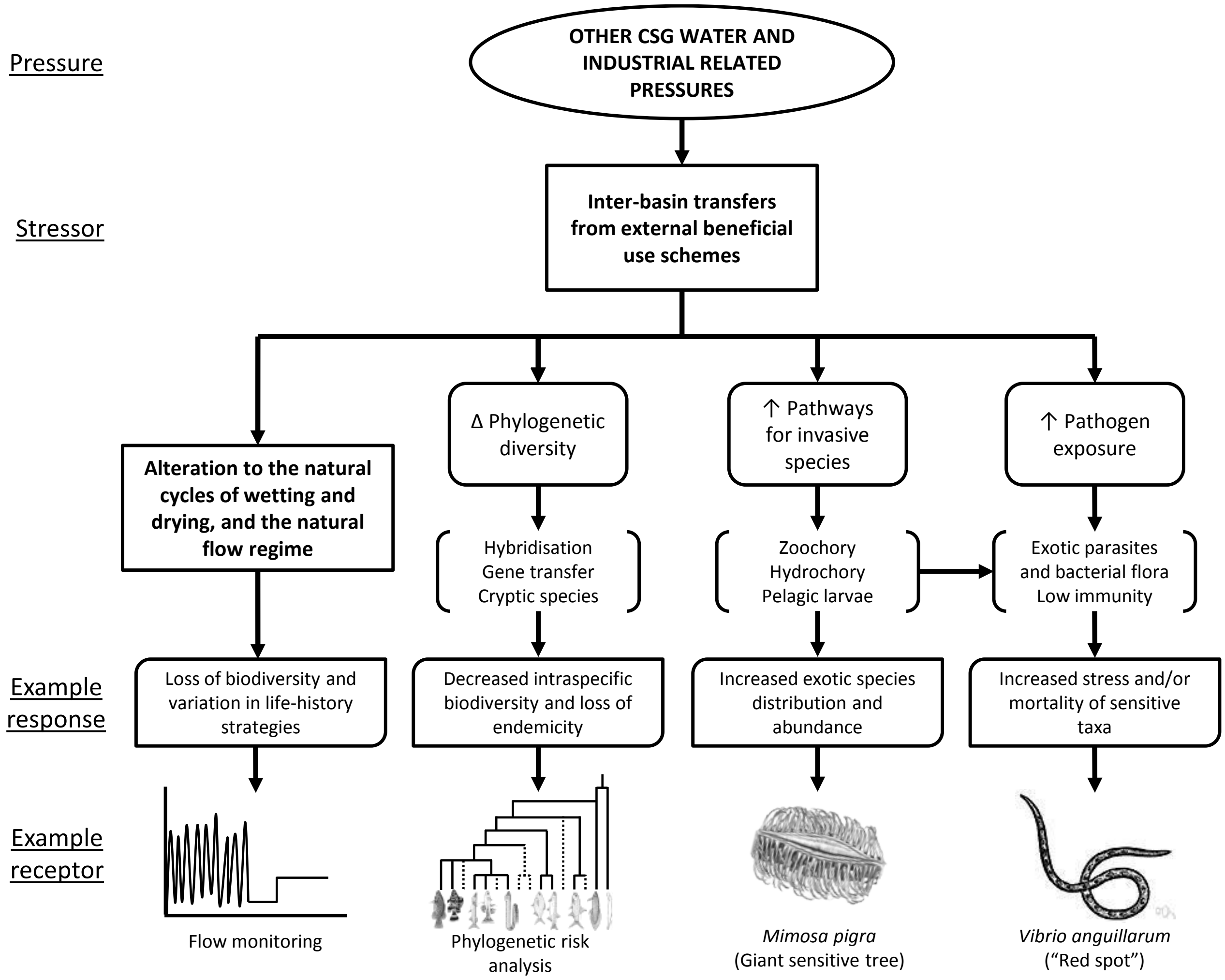

Figure 9: Conceptual linkages between potential inter-basin transfers from external beneficial-use schemes and surface-water dependent receptors in the Galilee Basin.

Key Knowledge Gaps: Baseline understanding of the 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.

Priority Receptors: Flow monitoring; stressed or diseased taxa.

Table 5: A PSR framework for surface water-dependent receptors associated with water-dependent CSG and industrial related pressures in the Galilee Basin and the resulting stress placed on aquatic ecosystems due to increased infrastructure associated with the development of a CSG industry. See Section 1.2.3 for definition of table headings.

Pressure	Stressor	Response	Receptor (*e.g.*)	Specificity	Confidence
OTHER CSG WATER AND INDUSTRIAL RELATED PRESSURES **• Water Diversions** **• Bridge and Culvert Construction** **• Stormwater runoff** **• Roads, Pipelines and Rail** **• Transport, Machinery and Industrial Spills.**	**Inter-basin transfers from external beneficial use schemes** See above PSR review of alteration to the natural cycles of wetting and drying and the natural flow regime for hydrological stressors. **Increased** • Pathways for invasive species. • Pathogen risk **Measurement of stressor** Development Specific	**Fish**			
		• Increased exotic species distribution (Davies et al. 1992).	*Oreochromis mossambicus* (Tilapia).	H	L
		• Potential genetic intermixing of once separated populations (Page et al. 2010).	*Macquaria sp.* (Golden perch).	H	L
		• Potential for exotic aquatic parasite (Burke and Rodgers 1981).	*Vibrio anguillarum* ("Red spot").	H	L
		Vegetation			
		• Increased exotic species distribution (Davies et al. 1992).	*Mimosa pigra* (Giant Sensitive Tree).	H	L

3 Discussion

The Galilee Basin is home to a diverse range of unique and highly specialised biota. However, as with all ecological systems, this biota does not act independently within the environment, and so impacts to one entity typically cause concomitant impacts to another. The nested, spatio-temporal relationships among ecosystems, among biota, and among ecosystems and biota, are therefore a key synthesis gap for the relatively unstudied and complex dryland river systems found throughout the LEB and Galilee subregion. Consequently, there is a growing need to quantify the strength of the relationships between the individual components making up these systems to better understand how dryland river ecosystem processes and functions may be affected by changes in land use and the likely cumulative response of biota to this change.

Currently, the LEB and Galilee subregion remain relatively undisturbed by human alterations and invasive species, and not surprisingly, is lauded for its inherent natural beauty and tourism potential. Vast underground coal and gas resources also highlight the economic potential of the area. Given our rudimentary understanding of the critical hydrological and physio-chemical requirements of biota and ecosystems in this area, and the uncertainty surrounding co-produced water volumes into the future, the PSR framework outlined in this report should form part of an adaptive management regime which: 1) provides an initial baseline assessment of priority monitoring outcomes; and 2) subsequently monitors priority receptors with a program of appropriate frequency, duration, spatial coverage, and sampling size to capture the potential effects of future CSG developments.

4 References

ANZECC/ARMCANZ. (2000) Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand. Australian Government, Canberra.

Arthington, A.H. and Balcombe, S.R. (2011) Extreme flow variability and the ‘boom and bust’ ecology of fish in arid-zone floodplain rivers: a case history with implications for environmental flows, conservation and management. *Ecohydrology*, **4**, 708-720.

Arthington, A.H., Balcombe, S.R., Wilson, G.A., Thoms, M.C. and Marshall, J. (2005) Spatial and temporal variation in fish-assemblage structure in isolated waterholes during the 2001 dry season of an arid-zone floodplain river, Cooper Creek, Australia. *Marine and Freshwater Research*, **56**, 25-35.

Arthington, A.H., Mackay, S.J., James, C.S., Rolls, R.J., Sternberg, D., Barnes, A. and Capon, S.J. (2012) *Ecological limits of hydrologic alteration: a test of the ELOHA framework in south-east Queensland*, Waterlines report, National Water Commission, Canberra.

Ashley, E.P, Kosloski, A. and Petrie, S.A. (2007) Incidence of intentional vehicle-reptile collisions. *Human Dimensions of Wildlife*, **12**, 137 - 143.

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.

Belmar, O., Bruno, D., Martínez-Capel, F., Barquín, J. and Velasco, J. (2013) Effects of flow regime alteration on fluvial habitats and riparian quality in a semi-arid Mediterranean basin. *Ecological Indicators*, **30**, 52-64.

Bhaskar, M. and Govindappa, S. (1986) Effects of environmental acidity and alkalinity on the physiology of *Tipapia mossambica* during acclimation. *Biochemical Systematics and Ecology*, **14**, 439-43.

Bjornsson, K.T., Ostendorf, B. and Recknagel, F. (2003) *Using wetland nutrient modelling to estimate River Murray and floodplain wetland water exchange*. *In* MODSIM 2003 International Congress on Modelling and Simulation. pp. 404-409.

Bond, N., McMaster, D., Reich, P., Thomson, J.R. and Lake, P.S. (2010) Modelling the impacts of flow regulation on fish distributions in naturally intermittent lowland streams: an approach for predicting restoration responses. *Freshwater Biology*, **55**, 1997-2010.

Boulton, A. and Brock, M. (1999) *Australian freshwater ecology: processes and management.* Cambridge University Press, Cambridge.

Bunn, S.E. and Arthington, A.H. (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental management*, **30**, 492-507.

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.

Burke J. and Rodgers, L. (1981) Identification of pathogenic bacteria associated with the occurrence of ‘red spot’ in sea mullet, *Mugil cephalus* L., in south-eastern Queensland. *Journal of Fish Diseases*, **4**, 153–159.

Busch, D.E. and Smith, S.D. (1995) Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern US. *Ecological Monographs*, **65**, 347-370.

Capon, S. J. (2003) Plant community responses to wetting and drying in a large arid floodplain. *River Research and Applications*, **19**, 509-520.

Clifford, S., Blessing, J., Woods, R. and Negus, P. (2010) Stream and Estuary Assessment Program Lake Eyre and Bulloo Province Stressor Prioritisation Workshop Report. Water Planning Ecology, Environment and Resource Sciences, Department of Environment and Resource Management, Queensland, Australia.

COAG. (2012) National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development. Council of Australian Governments. Online www.coag.gov.au. Accessed 25/8/2014.

Cockayne, B., McGregor, G., Marshall, J., Lobegeiger, J. and Menke, N. (2009). Fitzroy WRP review: Technical report 3, Ecological risk assessment. TR3, Queensland Department of Environment and Resource Management, Queensland.

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

Costelloe, J.F., Hudson, P.J., Pritchard, J.C., Puckridge, J.T. and Reid, J.R.W. (2004) *ARIDFLOW Scientific Report: Environmental Flow Requirements of Arid Zone Rivers with Particular Reference to the Lake Eyre Drainage Basin.* Final Report to South Australian Department of Water, Land and Biodiversity Conservation and Commonwealth Department of Environment and Heritage. School of Earth and Environmental Sciences, University of Adelaide, Adelaide.

Costelloe, J.F., Reid, J.R.W., Pritchard, J.C., Puckridge, J.T., Bailey, V.E. and Hudson, P.J. (2010) Are alien fish disadvantaged by extremely variable flow regimes in arid-zone rivers? *Marine and Freshwater Research*, **61**, 857-863.

Davies, P., Mitchell, N. and Barmuta, L. (1996) The impact of historical mining operations at Mount Lyell on the water quality and biological health of the King and Queen River catchments, western Tasmania. Mount Lyell Remediation Research and Demonstration Program. Supervising Scientist Report 118, Supervising Scientist, Canberra.

Davies, B.R., Thoms, M. and Meador, M. (1992) An assessment of the ecological impacts of inter-basin water transfers and their threats to river basin integrity and conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, **2,** 325–349.

DEHP. (2012) *Coal seam gas water management policy*. Department of Environment and Heritage Protection, Brisbane.

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.

Evans, T., Tan, K.P., Magee, J. Karim, F., Sparrow, A., Lewis, S., Marshall, S. Kellett, J. and Galinec, V. (2014) Context statement for the Galilee subregion. Product 1.1 from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Fullerton, A.H., Burnett, K.M., Steel, E.A., Flitcroft, R.L., Pess, G.R., Feist, B.E., Torgersen, C.E., Miller, D.J. and Sanderson, B.I. (2010) Hydrological connectivity for riverine fish: measurement challenges and research opportunities. *Freshwater Biology*, **55,** 2215–2237.

Gardiner , S. (2005) *Wetland management profile: arid and semi-arid lakes*. Queensland Wetlands Program, QWP 2010/03, 29113.

Gehrke, P.C. and Harris, J.H. (2001) Regional-scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. *Regulated Rivers: Research & Management*, **17**, 369-391.

Humphries, P., King, A.J. and Koehn, J.D. (1999) Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes*, **56**, 129-151.

Jaensc, R. and Young, S. (2005) Wetland management profile: arid swamps. Queensland Wetlands Program, 2010 QWP 2010/05, 29113.

King, A.J., Humphries, P. and Lake, P.S. (2003) Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences*, **60**, 773-786.

Larned, S.T., Datry, T., Arscott, D.B. and Tockner, K. (2010) Emerging concepts in temporary-river ecology. *Freshwater Biology*, **55**, 717-738.

Lonsdale, W.M. (1993). Rates of spread of an invading species *Mimosa pigra* in northern Australia. *Journal of Ecology*, **81**, 513–521.

Mackay, S.J., Arthington, A.H., Kennard, M.J., & Pusey, B.J. (2003) Spatial variation in the distribution and abundance of submersed macrophytes in an Australian subtropical river. *Aquatic Botany*, **77**, 169-186.

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

Marchetti, M.P. and Moyle, P.B. (2001) Effects of flow regime on fish assemblages in a regulated California stream. *Ecological Applications*, **11**, 530-539.

Marshall, J.C., Clifford, S. and Choy, S. (2013) Hazards posed to riverine aquatic ecosystems in Lake Eyre Basin from future petroleum and gas mining activities. Department of Science, Information Technology, Innovation and the Arts. Queensland Government, Brisbane.

Marshall, J.C., Sheldon, F., Thoms, M. and Choy, S. (2006) The macroinvertebrate fauna of an Australian dryland river: spatial and temporal patterns and environmental relationships. *Marine and Freshwater Research*, **57**, 61-74.

Marufu, L. T., Phiri, C. and Nhiwatiwa, T. (2014) Invasive Australian crayfish Cherax quadricarinatus in the Sanyati Basin of Lake Kariba: a preliminary survey. *African Journal of Aquatic Science*, **39**, 1-4.

McGregor, G., Marshall, J. and Takahashi, E. (2011) Stream ecosystem health response to coal seam gas water release: Guidelines for managing flow regimes. Brisbane: Queensland Department of Natural Resources and Mines.

Page, T., Marshall, J., McGregor, G., Hughes, J. (2010) *An investigation of potential implications of inter-basin water transfers on the long-term genetic viability of populations of aquatic fauna.* Australian Rivers Institute, Griffith University, and Queensland Department of Environment and Resource Management, Brisbane.

Phillips, B.L., Brown, G.P., Greenlees, M., Webb, J.K. and Shine, R. (2007) Rapid expansion of the cane toad (*Bufo marinus*) invasion front in tropical Australia. *Austral Ecology*, **32**, 169-176.

Pickering, C. and Mount, A. (2010) Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. *Journal of Sustainable Tourism*, **18**, 239-256.

Poff, N.L. and Zimmerman, J.K. (2010) Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. *Freshwater Biology*, **55**, 194-205.

Reich, P., McMaster, D., Bond, N., Metzeling, L. and Lake, P.S. (2010) Examining the ecological consequences of restoring flow intermittency to artificially perennial lowland streams: Patterns and predictions from the Broken—Boosey creek system in northern Victoria, Australia. *River Research and Applications*, **26**, 529-545.

Resh, V.H., Norris, R.H. and Barbour, M.T. (1995) Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology*, **20,** 108–121.

Rogers, S., McGregor, G., Takahashi, E., Shaw, M. and McNeil, V. (2011). Stream ecosystem health response to coal seam gas water release: Salinity guidelines. Brisbane: Queensland Department of Natural Resources and Mines.

Ryder, D.S., Watts, R.J., Nye, E. and Burns, A. (2006) Can flow velocity regulate epixylic biofilm structure in a regulated floodplain river? *Marine and Freshwater Research*, **57**, 29-36.

Sheldon, F., Boulton, A.J. and Puckridge, J.T. (2002) Conservation value of variable connectivity: aquatic invertebrate assemblages of channel and floodplain habitats of a central Australian arid-zone river, Cooper Creek. *Biological Conservation*, **103**, 13-31.

Sheldon, F., Bunn, S.E., Hughes, J.M., Arthington, A.H., Balcombe, S.R. and Fellows, C.S. (2010) Ecological roles and threats to aquatic refugia in arid landscapes: dryland river waterholes. *Marine and Freshwater Research*, **61**, 885-895.

Smythe-McGuiness, Y., Lobegeiger, J., Marshall, J., Prasad, R., Steward, A., Negus, P., McGregor, G. and Choy, S. (2012). *Macroinvertebrate responses to altered low-flow hydrology in Queensland rivers*. National Water Commission, Canberra.

Spencer, R.J. (2006). The Murray River turtle, *Emydura macquarii*: population dynamics, nesting ecology and impact of the introduced red fox, Vulpes vulpes. Ph D Thesis, University of Sydney, Biological Sciences.

Stromberg, J.C., Beauchamp, V.B., Dixon, M.D., Lite, S.J. and Paradzick, C. (2007) Importance of low-flow and high-flow characteristics to restoration of riparian vegetation along rivers in arid south-western United States. *Freshwater Biology*, **52,** 651-679.

Takahashi, E., McGregor, G. and Rogers, S. (2012a) *Stream ecosystem health response to coal seam gas and water release: Biological monitoring guidelines*. Brisbane: Queensland Department of Science, Information Technology, Innovation and the Arts.

Takahashi, E., Rogers, S., McGregor, G. and Shaw, M. (2012b) *Stream ecosystem health response to coal seam gas and water release: Decision support system*. Brisbane: Queensland Department of Science, Information Technology, Innovation and the Arts.

Thomson, F.J., Moles, A.T., Auld, T.D., Ramp, D., Ren, S. and Kingsford, R.T. (2010) Chasing the unknown: predicting seed dispersal mechanisms from plant traits. *Journal of Ecology*, 98, 1310–1318.

Tyler, M.J., Wilson, S.G. and Emmott, A. (2011) *Frogs of the Lake Eyre Basin - A field guide*. Desert Channels Queensland, Longreach.

WetlandInfo. (2014) Department of Environment and Heritage Protection, Queensland, Online: http://wetlandinfo.ehp.qld.gov.au/wetlands/about-us/wetlandinfo.html. Accessed: 14/8/2014

Zalizniak, L., Kefford, B.J. and Nugegoda, D. (2009) Effects of different ionic compositions on survival and growth of Physa acuta. *Aquatic ecology*, **43**, 145-156.