Lake Eyre Basin Rivers Monitoring Project

Conceptual Modelling Approach

DEWNR Technical report 2015/42

Government of South Australia
Department of Environment, Water and Natural Resources

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

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

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Funding for this project has been provided by the Australian Government through the Department of the Environment as part of the Bioregional Assessment Programme. See www.bioregionalassessments.gov.au for further information.

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Summary

The Lake Eyre Basin River Monitoring (LEBRM) project was developed to collate a baseline of scientific knowledge related to the hydrology and ecology of aquatic ecosystems in the LEB, and to improve knowledge in regions where coal-bearing deposits are located. The overarching goal of the LEBRM project is to establish an advanced and up-to-date platform of hydrological and ecological knowledge that can form part of the detailed modelling, impact and risk analysis needs of the LEB, thus informing the Bioregional Assessment Programme[1].

The LEBRM Project uses a conceptual modelling approach to illustrate the key aquatic ecosystem types in the Lake Eyre Basin and their potential vulnerability to Coal Seam Gas (CSG) and Large Coal Mining Development (LCM) related activities. Models developed as part of this approach guided the development of *Hydroecology of water-dependent ecosystems of the western rivers, Lake Eyre Basin* (Hooper, 2015), as well as assisting to evaluate knowledge and data gaps within the LEB.

Two types of models have been developed as part of the LEBRM conceptual modelling task including:

- Hydro-ecological models describing the components and processes attributes of key aquatic ecosystem asset types (consistent with the *Ramsar Wetlands Convention*, DSE 2005, and *National Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands* (DEWHA 2008).
- Pressure-Stressor (PS) models identifying the impacts specific to key CSG/LCM activities (*pressures*) and the mechanisms through which these pressures cause stress to the environment (*stressor*).

This report describes the scope of the conceptual models and the methodology used to develop them as part of the LEBRM project. Key outputs arising from this work include:

- An aquatic ecosystem classification for the project specific to the Lake Eyre Basin
- The identification of major components and sub-components for the aquatic ecosystem types
- The identification of key CSG and LCM-related activities and stressors
- The development of control models for Lake Eyre Basin aquatic ecosystem types and stressor models for key CSG and LCM-related activities
- A set of recommendations for future work.

The development of the models and expert consultation raised key issues for future consideration including connectivity and the 'mosaic' of aquatic habitats in a regional or landscape context; varying the focus to model impacts rather than assets; and connectivity and interaction with groundwater.

The LEBRM models provide an advanced and up-to-date platform of hydrological and ecological knowledge, which forms part of more detailed modelling, impact and risk analysis needs of the LEB via the LEB Bioregional Assessment. These models are intended to guide the development of indicators and thresholds of potential concern, as well as assisting to evaluate knowledge and data gaps within the LEB.

An accompanying document, *Conceptual Models of the Lake Eyre Basin Rivers Monitoring Project* (Imgraben and McNeil, 2015) contains a copy of all the outputs and products developed as part of the LEBRM Project.

[1] The Australian Government is undertaking Bioregional Assessments to elucidate the potential impacts of coal seam gas and coal mining on water resources and related assets. Refer http://www.bioregionalassessments.gov.au/.

1 Bioregional Assessment Programme and IESC

The Bioregional Assessment Programme (BAP) 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 http://www.bioregionalassessments.gov.au.

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.

1.1 Lake Eyre Basin Rivers Monitoring projects

The Lake Eyre Basin (LEB) presents unique challenges to assessing and managing the risks that may arise from coal seam gas (CSG) and coal mining developments. It is characterised by a high degree of hydro-climatic variability and unpredictability, with patterns of water availability occurring over annual and decadal scales. There are considerable knowledge gaps regarding the hydrology and ecology of surface water assets and their vulnerabilities during different phases of the hydro-climatic cycle.

The Lake Eyre Basin River Monitoring (LEBRM) project aims to address these knowledge gaps for areas potentially impacted by CSG or coal mining activities. The LEBRM project will form a key input into the Bioregional Assessment work for the LEB, and will, in turn, provide information and tools to assist the IESC.

This report is part of a series of studies forming the Lake Eyre Basin Rivers Monitoring (LEBRM) project. The LEBRM project is one of three water knowledge projects undertaken by the South Australian Department of Water, Environment and Natural Resources (DEWNR) to inform the Bioregional Assessment Programme in the Lake Eyre Basin region. The three projects are:

- Lake Eyre Basin Rivers Monitoring
- Arckaringa and Pedirka Groundwater Assessment
- Lake Eyre Basin Springs Assessment.

1.2 LEBRM conceptual modelling

This report describes the scope of the conceptual models and the methodology used to develop them as part of LEBRM project. The LEBRM models are documented in the accompanying document, *Conceptual Models of LEBRM* (Imgraben and McNeil, 2015) which describe hydro-ecological and pressure-stressor relationships that are typical of the aquatic ecosystems types found across the arid Lake Eyre Basin.

This report presents the conceptual models developed as part of LEBRM activities. Ecological responses to the pressure stressors were not captured within this project, although are developed as part of *Hydroecology of water-dependent ecosystems of the western rivers, Lake Eyre Basin* (Hooper & Miles, 2015), including biota, water quality and flow responses to mining related pressures.

The LEBRM Project uses a conceptual modelling approach to illustrate the key aquatic ecosystem types in the Lake Eyre Basin and their potential vulnerability to Coal Seam Gas and Large Coal Mining Development (LCM) related activities. These conceptual models will provide a link between existing baseline knowledge and data, and a risk-based approach to identifying indicators and thresholds of potential concern for Lake Eyre Basin assets.

The literature review undertaken early in LEBRM has provided some initial information for the conceptual models and will allow evaluation of the models against current knowledge.

In the absence of detailed data in the Lake Eyre Basin (with the exception of fish and vegetation data) the conceptual models used in this project frame the hypotheses generated around ecological interactions of aquatic ecosystems and key functional groups of fauna. By using the models to identify which relationships and interactions are known and unknown, as well as the likely strength of the interactions, testable hypotheses were generated. These hypotheses informed the types of data that need to be collected or modelled as part of desktop and field investigations (e.g. *Hydroecology of water-dependent ecosystems report*, Hooper and Miles 2014).

The conceptual models can be applied to:

- Communicate with stakeholders and programs in the LEB
- Synthesise current baseline knowledge and providing a base to build on when new knowledge becomes available
- Support decision-making processes including risk assessment
- Support numerical and ecological modelling

The models will also be provided as a key input to the Bioregional Assessment (BA) team as a fundamental synthesis of information and understanding about LEB aquatic ecosystems and the potential impacts of CSG and LCM activities. This synthesis informed the Hooper and Miles (2014) study and provides:

- More detailed modelling, impact and risk analysis needs of the LEB Bioregional Assessment, and
- A record of assumptions about the key ecological processes underpinning LEB aquatic ecosystem function that could be impacted by CSG and LCM development.

As part of the wider LEBRM project, the conceptual models provide a framework for assessing knowledge and data gaps. The models may also provide tools and context for interpreting the results of field sampling, and should applied as part of an iterative process to be updated once sampling has been undertaken and new knowledge obtained. In this respect, the models produced under this project may either support or conflict with new data, thereby facilitating better understanding about LEB aquatic ecosystems and the impact of CSG and LCM related activities.

Two types of models have been developed as part of the LEBRM conceptual modelling task including:

- Hydro-ecological models describing the components and processes attributes of key aquatic ecosystem asset types (consistent with the Ramsar Wetlands Convention ,DSE 2005, and National Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands, DEWHA 2008).[2,3]
- Pressure-Stressor (PS) models identifying the impacts specific to key CSG/LCM activities (*pressures*) and the mechanisms through which these pressures cause stress to the environment (*stressor*).

1.3 How to use the models developed for the LEBRM project

The models presented in the sister document *Conceptual Models of LEBRM* report describe hydro-ecological and pressure-stressor relationships that are typical of the aquatic ecosystems types found across the arid Lake Eyre Basin.

The LEBRM models provide an advanced and up-to-date platform of hydrological and ecological knowledge, which forms part of more detailed modelling, impact and risk analysis needs of the LEB via the LEB Bioregional Assessment. These models are intended to guide the development of indicators and thresholds of potential concern, as well as assisting to evaluate knowledge and data gaps within the LEB.

[2] National Guidelines http://www.environment.gov.au/water/wetlands/ramsar/implementing-national-framework

[3] See terminology in http://www.ramsar.org/sites/default/files/documents/pdf/res/key_res_ix_01_annexa_e.pdf

2 Conceptual models

2.1 What are conceptual models

Conceptual models are a valuable element of many environmental monitoring and management programs. They may be used as a basis for discussion and planning, to help identify gaps in knowledge, and to prioritise areas that require further research or monitoring (Roman & Barrett 1999). Conceptual models provide a representation of the current knowledge of an asset, or resource, in this case an aquatic ecosystem, and they should integrate current understanding of system dynamics with the important processes and functions (Gross 2003). Fundamentally, they are working hypotheses about system form and function, resting on clearly-stated assumptions that are open to review (Wilkinson *et al*. 2007).

Conceptual models may be presented in many formats, such as diagrams, tables and flow-charts, and may have accompanying narratives or contextual information. In many cases, it may be useful to use a combination of different conceptual model formats, tailored to the objectives, audience and intended uses of the outputs (Hierl *et al*. 2007).

The LEBRM Project required models that describe aquatic ecosystem types and their ecological attributes, as well as models that identify how CSG and LCM activities could impact these systems and what likely ecological responses to these impacts may be (presented in Hooper & Miles, 2015. These models will:

- Represent the main aquatic ecosystem types found in the LEB
- Identify the important attributes (components and processes) of each aquatic ecosystem type
- Record key assumptions about how LEB aquatic ecosystems function (and how they may differ in each of the focus regions)
- Record key assumptions about how CSG and LCM related activities could impact on aquatic ecosystems in the LEB
- Highlight areas where data and knowledge are lacking.

2.2 Types of conceptual models

Two types of models were developed in LEBRM, control models and stressor models.

A Control Model is a representation of the drivers, interactions and feedbacks responsible for the dynamics of a system (Gross 2003), and is intended for understanding ecosystem functioning and processes. These models identify the key drivers and attributes of each aquatic ecosystem type and aim to summarise what is known (at the time of model development) about each type. Hydro-ecological models were prepared that describe the components and processes attributes of key aquatic ecosystem asset types (consistent with the Ramsar Wetlands Convention ,DSE 2005, and National Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands, DEWHA 2008)[4,5]. One pictorial and one flow-chart model has been developed for each aquatic ecosystem type (aquatic ecosystem types are explained in Section 4.2).

A Stressor Model (or Pressure-Stressor (PS) model) is designed to demonstrate the relationship between pressures and stressors for ecosystem components. The intent is to illustrate the sources and nature of stresses on a system which can then be used to inform ecological responses of the attributes of interest (Gross 2003). These models identify the impacts specific to key CSG/LCM activities (pressures), the mechanisms through which these pressures cause stress to the environment (stressor). One flow-chart model will be developed for each identified key pressure (key pressures are explained in Section 4.3).

[4] National Guidelines http://www.environment.gov.au/water/wetlands/ramsar/implementing-national-framework

[5] See terminology in http://www.ramsar.org/sites/default/files/documents/pdf/res/key_res_ix_01_annexa_e.pdf

2.3 Existing models for Lake Eyre Basin

A number of existing conceptual models Table 2.1) relevant to LEB aquatic ecosystems were been incorporated where appropriate.

Table 2.1 Existing conceptual models relevant to the Lake Eyre Basin

Reference	Scale	Relevant LEBRM aquatic ecosystem types	Description
Scholz and Fee (2008)	Aquatic ecosystem type (not LEB specific)	Connected basin systems (lakes, swamps)	Adobe® Illustrator® models titled: • Inland salt lakes • Arid zone lakes • Terminal depression lakes • Inland arid zone swamps The models identify the broad drivers, components and processes relevant to each type.
QLD DEHP (2013a)	Freshwater biogeographic province	Watercourse	Pictorial models at a landscape scale for the Lake Eyre and Bulloo province, one for each of: • General overview • Climate • Geology & topography • Hydrology • Water quality • Habitat
QLD DEHP (2013b)	Aquatic ecosystem type (not LEB-specific)	Connected basin systems (lakes and swamps) Isolated basin systems (lakes and swamps)	Adobe® Illustrator® models representing hydrology, geomorphology, fauna and flora of the following arid and semi-arid types: • Floodplain lakes • Non-floodplain lakes • Saline lakes • Tree swamps • Lignum swamps • Grass, sedge, herb swamps • Saline swamps
Sheldon et al. (2005)	Regional and habitat-scale (LEB-specific)	Connected systems: Watercourse Waterhole Floodplain Floodout	Pictorial and tabular models displaying spatial and temporal variation in hydrology, geomorphology and biological components for: • Headwaters • River channel and waterholes • Terminal wetlands
McKenzie-Smith *et al.* (2004) (cf. Sheldon *et al.* 2005)	Regional and habitat-scale (LEB-specific)	Connected systems: Watercourse Waterhole Floodplain Floodout	Animated Adobe® Flash® models (CD-ROM format) describing hydrologic and geomorphic processes at different geographic levels within the LEB catchment. Also describe temporal variation. The models describe processes in headwater, channel, waterhole and terminal wetlands, and in different hydrologic phases.

McNeil *et al.* (2011)	Neales catchment	Connected systems: Watercourse Waterhole Floodplain Floodout	Diagrammatic conceptual models for fish ecology in the LEB, presenting interrelated models with an overarching model that combines them. The models cover such factors as: • Climate • Hydrology • Connectivity • Refuges and refugia.

3 Methodology

3.1 Scope

The conceptual models have been developed specifically for the Lake Eyre Basin, comprising three focus regions (Pedirka, Arckaringa, Cooper and Galilee Basins), and are focussed on generic surface-water asset types and impacts. The models do not specifically apply to any on-ground geographic location; rather they illustrate the representative types of surface water ecosystems that may be found. Groundwater ecosystem function, impacts on sub-surface aquatic ecosystems (such as aquifers), and spring ecosystems are not captured in the current project but are considered in the Lake Eyre Basin Springs Assessment Project undertaken as part of the Bioregional Assessments. The LEBSA project will advance the understanding of the Great Artesian Basin Springs typologies found within the Western region of the LEB, including conceptual models of the following classifications:

- Travertine mound springs;
- Sand mound springs;
- Flat depression springs;
- Astrobleme springs;
- Abutment springs;
- Large flowing mound springs;
- Diffuse discharge springs and;
- Small rocky vents and terracing springs.

These conceptual models capture natural and human induced drivers and impacts, with specific focus upon coal seam gas and coal mining. Connectivity, water chemistry and knowledge gaps are also presented for these springs typologies in pictorial conceptual model format. In addition, alluvial/hyporheic water (i.e. mixing of surface and groundwater in the shallow sediment alongside rivers/aquifers) is captured as part of LEBSA, including a conceptual model as part of a GDE mapping component of LEBSA, focussing upon the Arckaringa and Cooper Basins.

There are a number of more general natural or anthropogenic pressures which may also be relevant to the management of LEB aquatic ecosystems, such as climate change, introduced species and land management practices. These pressures are incorporated through the use of 'modifiers', or additional factors or pressures that may change how a stressor acts on a system and influence the nature of the impact. Such modifiers are identified in the PS models for each key pressure.

3.2 Methodology

A number of steps were taken to develop conceptual models. These included:

- Travertine mound springs;
- Review of existing knowledge, literature and conceptual models
- Documentation of the scope of models:
  - Goals and objectives
  - Target audience
  - Spatial and temporal bounds of the system of interest

- Identification of critical model components, sub-components and interactions between them
- Identification of key activities and pressures relating to coal-seam gas and large coal mining development
- Development of draft models
- Consultation and expert review of the conceptual framework and models (workshops)
- Review and refinement of existing models
- Recommendations for future work.

3.3 Workshops

As part of the development of conceptual models for the LEBRM project, expert consultation workshops were held with stakeholders from Queensland, Northern Territory and South Australia. In this respect, a workshop focussed on the Galilee focus region was held in Brisbane on the 27th and 28th May 2013, and a workshop focussed on the Arckaringa and Pedirka basin focus areas was held in Adelaide on the 30th and 31st May 2013. All outputs were presented to stakeholders for review and refinement.

The workshops were designed to:

- Introduce the LEBRM project objectives and approach;
- Review and refine the draft conceptual models to best display the assumptions about LEB ecosystem processes, connectivity and potential coal seam gas impacts;
- Record, synthesise and incorporate expert opinion regarding ecosystem function and the potential impacts of coal seam gas activities;
- Identify how the conceptual models (and assumptions) may need to be altered for specific focus areas;
- Identify the need for additional sub-models or supporting data to increase the robustness of the conceptual models;
- Identify indicators for focus areas and explore an approach to developing thresholds of potential concern; and
- Identify key aquatic types and indicators in relation to different mining pressures.

Outcomes of the workshops are reported in Appendix A (Brisbane) and Appendix B (Adelaide). It is important to note that these Appendices are records of discussions that occurred during the workshop and are not verified facts or the views of the Department. Instead they are a direct record of statements and key points made in the workshops and may be inaccurate, incorrect or without context.

Wherever possible, the outcomes of the workshops were either incorporated into the relevant section of this report, the conceptual models presented in the accompanying Conceptual Models of LEBRM report (Imgraben, S. and McNeil, D. 2014), or presented as recommendations for future work. It can therefore be assumed that the information presented in this report and the Conceptual Models of LEBRM report (Imgraben, S. and McNeil, D. 2014) takes into account the outcomes of the workshop.

4 Conceptual modelling approach for LEBRM

4.1 Integrated conceptual model approach for the Lake Eyre Basin

Collectively, there is a large spatial area that the models need to relate to, plus a broad range of aquatic ecosystem types and mining-related pressures that need to be covered. As such, *generality* is needed to adequately characterise the broad aquatic ecosystem asset types in the LEB. However, in order to identify potential changes that may occur in a system, the models need to be robust and *realistic* enough to identify potential indicators and thresholds that may guide a monitoring program or underpin a risk assessment. Following Levins (1966), no model can simultaneously maximise generality, realism and precision. Consequently, an integrated framework of conceptual models (Figure 4.1) has been developed for the LEBRM project, using specific models nested within general models, to characterise and represent the complexity of the LEB. Some components have been developed as part of the wider LEBRM Integrated Science and Management Framework, whilst others have been undertaken as part of the conceptual model development of the LEBRM Project. Additional conceptual models have been identified through workshops and modelling activities. These are highlighted in orange in Figure 4.1.

When used together, the components of the integrated conceptual model framework provide a hierarchy of information which may be used for a number of purposes. At a broad scale, the models represent basic assumptions about system functioning, whilst at a more detailed scale they provide contextual information to support decision making and the development of indicators and thresholds. At an even finer scale, it may be possible to develop models relating to specific components and processes or aquatic ecosystem sub-types.

There are three primary concepts that underpin the integrated conceptual model framework for LEBRM. These are explained in the following section and involve the use of:

- Aquatic ecosystem types;
- CSG and LCM related pressures; and
- Attributes (in the form of components and processes).

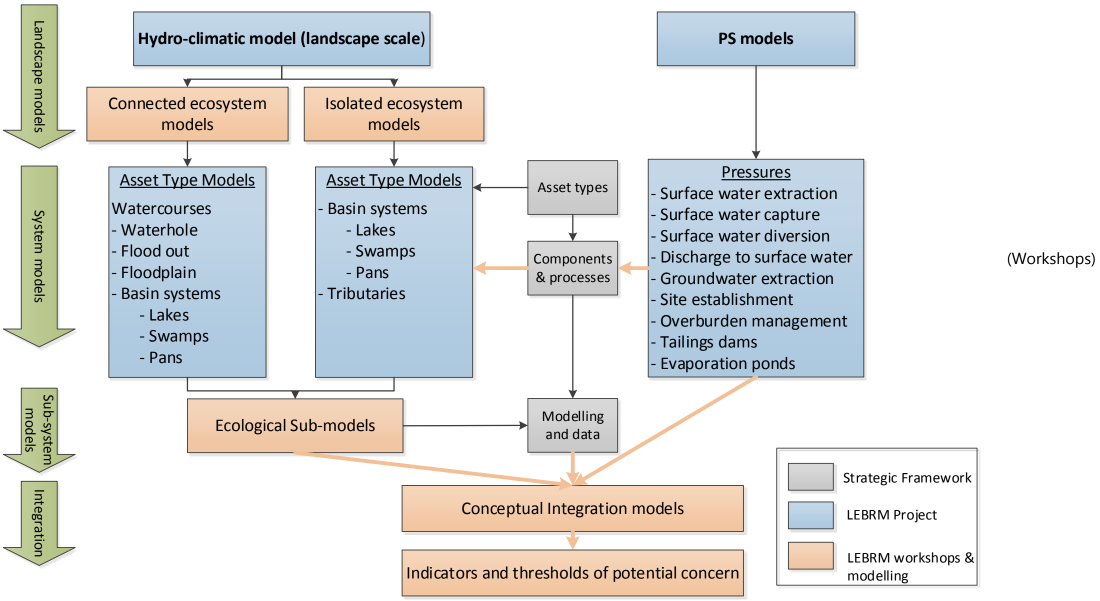

Figure 4.1 Integrated conceptual model framework for the LEBRM conceptual models showing the different types and scales of models, and how they correspond.

4.2 Aquatic ecosystem types

The relevant aquatic ecosystem types were initially identified using the South Australian Aquatic Ecosystem Classification (Scholz and Fee 2008; Fee and Scholz (unpublished)) and aligned with the *Australian National Aquatic Ecosystem Classification System* (Aquatic Ecosystems Task Group 2012a). A number of aquatic ecosystem sub-types were also identified to capture information at the Basin scale.

A draft list of types was presented at the workshops and subsequently refined to reflect the landscape setting and unique habitats within the Lake Eyre Basin (see Appendices A-B). The refined list is presented in Table 4.1.

Some aquatic ecosystem types are particularly important for providing refuge for aquatic biota during dry periods. Sub-models could be constructed for these types and linked to the relevant ecosystem types (Table 4.1).

For each LEBRM aquatic ecosystem type, a hydro-ecological model has been constructed in the form of a flow-chart. These models depict the drivers (such as climate, hydrology and geomorphology) of each aquatic ecosystem type, along with the key components (Table 4.1) and processes relevant to that type. A top-down approach is used, whereby the models are constructed for asset types from a broad landscape perspective in the first instance, with additional detail added through development of sub-type models. The highly unpredictable nature of hydro-climatic drivers within the LEB, with many embedded temporal fluctuations (daily, seasonal, inter-annual etc.) poses a challenge when trying to characterise aquatic ecosystems. Sub-model types (e.g. permanent waterholes that provide refuge versus semi-permanent waterholes) are often distinguished, based on the context of the hydro-climatic environment specific to the LEB. In contrast, models concerned with 'types' (e.g. waterholes) are *static* models, intended to illustrate the components and processes that are generally expected in an ecosystem without specific reference to permanence, or a supra-seasonal wetting/drying cycle. In this respect it should be noted that static models for the different 'types' can be developed for the different phases as needed which would capture the temporal changes within individual system types.

Changes to conceptual models stemming from the application of the Hydro-Climatic Model (refer to LEBRM Integrated Science and Management Framework) therefore need to be carried out at the sub-type level. These models need to identify how components, processes, values and ecological thresholds specific to sub-types might vary in relation to four hydro-climatic phases (*boom, bust, resistance and recovery*).

The aquatic ecosystem type flow-charts have accompanying picture models, which have been developed primarily for communication purposes. These have been developed in Adobe® Illustrator® and summarise pictorially the broad features, components and processes of an aquatic ecosystem.

Table 4.1 Existing conceptual models relevant to the Lake Eyre Basin

Landscape context	LEBRM type	LEBRM sub-types	SAAE Type[1]	QLD WHCS Type[2]	NT Type[3]	Applicable sub-models
Connected (part of major drainage system)	Watercourse (in-channel habitats and riparian)	n/a	Ephemeral watercourse reach Permanent watercourse reach	Riverine	WU2 Upland channels WL2 Temporary (generally dry) lowland channels	Queensland Lake Eyre and Bulloo Freshwater Biogeographic Province models (DEHP 2013) Conceptual models for LEB Rivers (McKenzie-Smith *et al.* 2004) Conceptual models for LEB Rivers (Sheldon *et al.* 2005)
	Floodout	n/a	Floodplain	n/a	F0001 Bare flood-prone flat F0002 Wooded flood-prone flat F0003 shrubby flood-prone flat F0004 Grassy flood-prone flat	
	Floodplain	n/a	Floodplain	n/a	F0001 Bare flood-prone flat F0002 Wooded flood-prone flat F0003 shrubby flood-prone flat F0004 Grassy flood-prone flat	
	Waterholes	n/a	Ephemeral watercourse waterhole	n/a	WU1 Upland waterholes WL1 Lowland waterholes	LEBRM Waterhole refuge type models Conceptual models for LEB Rivers (McKenzie-Smith *et al.* 2004) Conceptual models for LEB Rivers (Sheldon *et al.* 2005)
	Basin systems	Swamps	Inland swamps Inter-dunal wetlands	Arid and semi-arid saline swamps of all substrates, water regimes, topographic types and vegetation	B1 Open water basins B2 Swamps: water basins with emergent vegetation	

Landscape context	LEBRM type	LEBRM sub-types	SAAE Type[1]	QLD WHCS Type[2]	NT Type[3]	Applicable sub-models
				communities Arid and semi-arid fresh tree swamps of all substrates, and water regimes and topographic types Arid and semi-arid lignum swamps of all substrates, and water regimes and topographic types Arid and semi-arid grass, sedge, herb swamps of all substrates, water regimes and topographic types		
		Lakes	Inland lakes Terminal lakes Salt lakes Dune lakes	Arid and semi-arid, saline lakes of all substrates, topographic types and water regimes Arid and semi-arid, floodplain lakes of all, substrates and water regimes	B1 Open water basins	LEBRM Lake sub-types (fresh, terminal, saline, inter-dunal)
		Pans	Clay pans	n/a	B1 Open water basins	
	Farm dams	n/a	n/a	n/a	A1 stored rainfall runoff	
Isolated	Channels and tributaries	n/a	n/a	n/a	WU2 Upland channels WL2 Temporary (generally dry) lowland channels	
	Basin systems	Swamps	Inland swamps Inter-dunal wetlands	Arid and semi-arid saline swamps of all substrates, water regimes, topographic types and vegetation communities Arid and semi-arid fresh non-floodplain tree swamps of all substrates and water regimes Arid and semi-arid fresh non-floodplain lignum swamps of all substrates and water regimes Arid and semi-arid fresh non-floodplain grass, sedge, herb swamps of all substrates and water	B1 Open water basins B2 Swamps: water basins with emergent vegetation	

Landscape context	LEBRM type	LEBRM sub-types	SAAE Type[1]	QLD WHCS Type[2]	NT Type[3]	Applicable sub-models
				regimes		
		Lakes	Inland lakes Salt lakes Dune lakes	Arid and semi-arid, saline lakes of all substrates, topographic types and water regimes Arid and semi-arid, non-floodplain Lakes of all substrates and water regimes	B1 Open water basins	Lake types (saline, inter-dunal)
		Pans	Clay pans	Arid/ semi-arid, non-floodplain (clay pans) lakes of all substrates and water regimes	Open freshwater basins	
	Farm dams	n/a	n/a	n/a	A1 stored rainfall runoff	

1. South Australian Aquatic Ecosystem Classification: Fee and Scholz (Unpublished)

2. Queensland Wetland Habitat Classification Scheme: Department of Environment and Heritage Protection (2013c)

3. Wetlands of the Arid Northern Territory: Duguid et al. 2005

4.3 Impacts of CSG and LCM activities pressures (PS models)

Pressure-Stressor (PS) models link potential mining pressures and stressors through a causal-relationship pathway. PS models are designed to demonstrate the association between pressures, stressors, ecosystem components and in form predicted effects. The intent of a stressor model is to illustrate the sources of stress on a system, which can then be used to inform the ecological responses of the attributes of interest (Gross 2003). The source of stress is termed an environmental pressure and a range of activities associated with CSG or LCM developments can be considered as environmental pressures.

A list of pressures was developed in consultation with the 'National Partnerships Agreement Natural Resource Management Asset Database and Vulnerability Project' (Wilson et al 2014) undertaken for South Australia by DEWNR in partnership with regional NRM agencies. In this context the Asset Database and Vulnerability Project also provided a wealth of information and knowledge on the evidence base, assumptions, exceptions and impact ratings all of which was collated and stored within a database thereby providing a structured process for easy access and querying.

The list of pressures was based on an understanding of the location of coal deposits and the general direct impacts associated with CSG and large coal mining development. Subsequently, the list was reviewed in consultation with managers and scientific experts and was adapted for the current project.

PS models have initially been developed for the following key pressures:

- **Surface water extraction** is the extraction or removal of any surface water whether on-stream or off-stream. This includes any losses to the system due to coal mining development, for example pumping (either on-stream or from an off-stream diversion)
- **Surface water diversion** is the re-routing, via physical structures, that result in changes to the natural surface water flow path or flow regime (timing, magnitude and duration of flow events). It does not include on- or off-stream storage as these are part of surface water capture pressure.
- **Surface water capture** covers any structure that captures run-off or in-channel flows, and may include both on-stream and off-stream storage.
- **Discharge to surface water** covers the discharge of water to any surface-water body as part of an authorised activity. It is assumed that discharged water is treated where necessary in accordance with relevant requirements; however it is acknowledged that these requirements may differ between jurisdictions and may be difficult to enforce. This does not include the accidental spillage of tailings dams or evaporation ponds, as these are covered under the relevant pressures.
- **Groundwater extraction** or removal of groundwater from aquifers through wells (either pumped or through natural pressure).
- **Site establishment and traffic** includes the site presence, clearing, development and existence of infrastructure (including roads and pipelines), site traffic (both foot and vehicular), pit excavation, and any other physical disturbance associated with the establishment of a mine site. This activity should focus on the more localised aspects of site establishment. Activities such as site run-off, water diversion, flow capture and water extraction are excluded from this definition as they are covered in other activities. Indirect effects (such as those associated with increased occupation) are not covered in this activity and have been flagged as an area for further development.
- **Evaporation ponds** are used for the storage of mine waste water. Waste water may be generated through mine dewatering or coal seam gas activities. It is assumed that the ponds are approved and have the required standards in place such as appropriate lining; however it is acknowledged that spillages and other accidents may occur.
- **Tailings dams** are used for the storage of mine tailings in surface storage facilities. Tailings are the materials left over after the process of separating the valuable fraction from the uneconomic fraction during the mining process (also known as mine dumps). It is assumed that these storage facilities are approved and have the required standards in place such as appropriate lining; however it is acknowledged that spillages and other accidents may occur.

- **Overburden management** refers to the soil or rock overlying a mineral deposit that is displaced during mining without being processed (including rock storage facilities). This material needs to be stored or deposited elsewhere, usually in a surface storage facility.

Material collated within the Asset Database and Vulnerability Project (2014) provides a repository of information on status of the existing evidence base, assumptions, exceptions and impact ratings for CSG and LCM activities, effects and impacts.

A review of this list of pressures during the consultation aspect of the project and was found to be adequate for this project. In addition to these pressures, the expert engagement process suggested that further work that could be undertaken to develop PS models in the future, including:

- Indirect impacts arising from CSG and LCM (such as effects of having an increased population living in the area)
- Mine closure and rehabilitation activities
- Socio-economic impacts of CSG and LCM activities.

4.4 Components and processes

Rather than developing a PS model for each combination of aquatic ecosystem type and pressure, which would result in a very large number of models, the two are linked using the major 'attributes' (components and processes) of a system and an integration model (Table 4.2). These attributes are consistently used in both types of models, and allow comparison of the attributes that are important in different aquatic ecosystem types with those that may be affected by the CSG and LCM activities. The attributes provide a 'building block' approach, whereby the relevant attributes can be pulled out and used to build models where necessary, yet be omitted if they are not appropriate.

The Ramsar concept of 'Components, Processes and Services' (Department of Sustainability and Environment 2005 and DEWHA, 2008) can be used to structure the list of attributes. This ensures consistency with Ramsar and the National High Ecological Value Aquatic Ecosystems Framework (Aquatic Ecosystems Task Group 2012b), in addition to work that is being undertaken by the Aquatic Ecosystems Task Group and Australian Government Department of the Environment to develop an Integrated Ecological Condition Assessment Framework. The attribute classes also correspond with (or can be translated to) the Framework for the Assessment of River and Wetland Health indicators (National Water Commission 2007).

Components are defined as "….*the actual entities, features and physical characteristics of a wetland*" (DSE 2005). These are the things that make up an aquatic ecosystem, and may include biological, physical or chemical features.

Processes are defined as the *"….dynamic forces within an ecosystem. They include all those processes that occur between organisms and within and between populations and communities, including interactions with the non-living environment, that result in existing ecosystems and bring about changes in ecosystems over time"* (DSE 2005). These may include species interactions, processes which maintain flora and fauna populations, and energy and nutrient dynamics.

Services are not explicitly be dealt with in the current suite of conceptual models. It is however, anticipated that they will be picked up through value identification and the vulnerability/risk assessment processes as outlined in the ISMF.

Table 4.2 describes the list of draft components to be used in the conceptual models. This list was reviewed as part of the workshops and has been amended accordingly. It should be noted that the physical habitat and geomorphology attributes, and the flow regime and water regime components of hydrology attributes were highlighted during the workshops as requiring further development.

Table 4.2 Attributes, components and sub-components used in the LEBRM modelling

Attribute	Component	Sub-component
Hydrology	Flow regime	
	Water regime (persistence, within waterbody)	
	Connectivity	Longitudinal (in-channel)

Attribute	Component	Sub-component
		Latitudinal (out of channel)
		Vertical (groundwater – surface water)
		Cross- catchment
		Phreatic evaporation
Geomorphology	Landform type	Basin
		Riparian/shore line
		Channel
		Floodplain
	Landform characteristics	Size
		Surface area
		Shape
	Valley boundaries	Confinement
		Valley floor and edges
	Cease-to-flow depth	
Physical habitat	Substrate	Permeability
		Structure/texture
		Contaminants
	Vegetation structure types	Woody debris
		Floodplain and watercourse vegetation structure (macrophytes etc.)
		Riparian structure
	Bank and shore stability	Stability
		Morphology
		Rock bars
		High adjacent terrain
Water quality regime	Natural chemical components	Salinity (EC)
		Ionic composition
		pH
		Dissolved Oxygen
		Dissolved Organic Carbon
	Sediments	Turbidity
	Climatic influences	Temperature
	Nutrients	Nutrients
	Chemical pollutants	Contaminants
Wetland biota	Fauna	Microinvertebrates
		Macroinvertebrates
		Amphibians
		Reptiles
		Fish
		Birds
		Mammals
	Flora	Algae
		Biofilms
		Macrophytes
		Riparian vegetation
	Fungi	

Attribute	Component	Sub-component
Terrestrial biota	Fauna	Macroinvertebrates
		Reptiles
		Birds
		Mammals
	Flora	Terrestrial responders
		Algae
	Fungi	

5 Conclusions and recommendations

This report has described the conceptual modelling component of LEBRM outlined the development of an asset typology for aquatic ecosystem assets in the LEB, drafted a list of component attributes for these ecosystems, and developed a conceptual modelling approach for building hydro-ecological models that capture important attributes and PS models that track potential impact pathways of CSG and LCM related pressures on aquatic ecosystem assets. In addition a range of LEBRM conceptual models have been suggested that could be further refined and developed, building on the additional scientific and management outputs of the hydro-ecological and risk assessment tasks of the broader project.

In this context, two overarching concepts were identified throughout the project that requires further development.

The consideration of connectivity and the 'mosaic' of aquatic habitats in a regional or landscape context. The behaviour, ecological function and resident biota of an aquatic ecosystem are likely to be largely determined by the habitat's location and connections to other systems (especially refuges), which may vary given the unpredictable and variable nature of hydro-climatic drivers in the Lake Eyre Basin.

Varying the focus to model impacts rather than assets was supported at the workshops. Whilst an asset-based approach is being applied in the Bioregional Assessment, concurrently modelling the impacts and their interactions (especially with drivers and stressors associated with natural forces, climate change and human activities other than CSGCM) would give this impact-focused perspective. This would also align the results more closely with the published literature and enable more confident assertions about likely responses (see Hooper and Miles, 2015) to one or more impacts for a given system or component.

An additional gap in the LEBRM modelling was consideration of groundwater interactions and processes. The LEBSA project progresses conceptual understandings of the eight GAB spring types found in the western LEB. In addition, conceptual representations of the alluvial GDEs in South Australian LEB. The consideration of groundwater is crucial as many watercourse refuges in dryland systems may be maintained by subsurface flow that would be affected by groundwater drawdown as a result of CSGCM activities. In particular there are likely to be important microbial and nutrient transformations occurring in wetted alluvial sediments, and the sequence of wetting and drying of these sediments could dictate microbial activity, germination and recruitment of vegetation, and the emergence of resting stages of fauna from the sediments.

A number of steps for future conceptual model development have been identified and can serve as an additional set of objectives for future work. These include:

1) **Incorporation of field sampling:** Useful and robust conceptual models should be iterative and continually updated. The models developed for the LEBRM project can be re-evaluated and updated as new field sampling information is available, and once any assumptions have been formally tested using numerical modelling.
2) **Geomorphic, physical habitat and hydrology components:** Further development of the physical habitat, geomorphology attributes and the flow regime and water regime components of hydrology attributes (components and processes) is needed. Feedback stemming from the workshops indicated that, in particular, the selected components and subcomponents should be reviewed by additional experts in this field to ensure they were appropriate and inclusive of all key aspects.
3) **Processes:** The processes in the conceptual models are necessarily broad Further development, particularly to incorporate investigations that have been undertaken in other projects may refine these.
4) **Additional conceptual models:** There are more detailed conceptual model products that could be developed as part of the integrated conceptual model framework:

    a. *Landscape-scale models:* During the workshops it was identified that aquatic ecosystems should be viewed in the context of either being connected to the major drainage system in the LEB, or being isolated. One general graphic model is required for each scenario to explain the landscape scale context of these aquatic ecosystem types.

    b. *Hydro-climatic model:* A four-phase hydro-climatic model will provide temporal context for the current conceptual models as well as providing crucial information about how CSG and LCM related activities may impact LEB aquatic ecosystems at different flooding phases (boom, bust, recovery and collapse). This information is necessary for developing robust indicators and thresholds of potential concern. In particular this could be crucial for understanding when (within the hydro-climatic cycle) certain stressors may have the greatest impact, how cumulative impacts may occur, and when conditions may be set around the timing of certain mining activities. Future discussion is required as to who would fund and facilitate such a model or whether it would take place under the Bioregional Assessments.

c. *Integration models:* An approach is needed to integrate all of the current information and conceptual models, linking them more closely to the Integrated Science and Management Framework and the development of indicators and thresholds of potential concern. This will provide a strong basis and first step for future modelling projects. Additionally, an integration model (in the form of a table) is needed to link the components and processes in the aquatic ecosystem models with the specific CSG and LCM PS models.

d. *Additional PS models:* It was suggested at the workshop that additional models could be developed relating to:

   i. Exploration activities

   ii. Indirect impacts arising from CSG and LCM (such as the effects of having an increased population living in the area)

   iii. Mine closure and rehabilitation activities

   iv. Socio-economic impacts of CSG and LCM activities

However it should be noted that any additional PS models should be considered in terms of the project's goal of providing knowledge to support the modelling etc. in the bioregional assessments, and noting that the concern in the BA is the water-related impacts.

e. *Sub-models:* It is possible that a number of sub-models be developed to provide more detailed information about certain components of the ecosystem, or particular aquatic ecosystem types. This will need to be guided by an examination of knowledge and data gaps, as well as priorities for indicator development.

6 Appendices

A. Workshop outcomes report

LEBRM Conceptual Model Workshop (Galilee Focus Basin)

Monday 27th and Tuesday 28th May

DSITIA Ecosciences Precinct

41 Boggo Rd, Dutton Park, Brisbane.

This Appendix is a record of discussions that occurred during the workshop and are not verified facts or the views of the Department. Instead they are a direct record of statements and key points made in the workshops and may be inaccurate, incorrect or without context.

Attendees:

Affiliation	Name
DNRM	Bernie Cockayne
DNRM	Kate Burndred
DSITIA	Jon Marshall
DSITIA	Peter Negus
DSITIA	Satish Choy
DSITIA	Bruce Wilson
DSITIA	Tim Ryan
Bush Heritage/Griffith University	Adam Kerezsy
Griffith University	Angela Arthington
Griffith University	Fran Sheldon
DEWNR	Dale McNeil
DEWNR	Hugh Wilson
DEWNR	James Paull
Miles Consulting	Catherine Miles
Auricht Projects	Sarah Imgraben

Apologies:

Rod Fensham (DSITIA), Mike Ronan (EHP), Stuart Bunn (Griffith University), Stephen Balcombe (Griffith University), Jane Hughes (Griffith University), Sam Capon (Griffith University), Glenn McGregor (DSITIA).

Workshop objectives:

- Introduce the Lake Eyre Basin Rivers Monitoring project objectives and approach
- Review and refine the draft conceptual models to best display the assumptions about Lake Eyre Basin ecosystem processes, connectivity and potential coal seam gas impacts
- Record, synthesise and incorporate expert opinion regarding ecosystem functioning and the potential impacts of coal seam gas activities

- Identify how the conceptual models (and assumptions) may need to be altered for the specific focus regions in the Lake Eyre Basin
- Identify the need for additional sub-models or supporting information to increase the robustness of the conceptual models
- Identify indicators for focus areas and explore thresholds of potential concern
- Identify the key aquatic types and indicators in relation to different mining pressures

Agenda:

Item	Description
1.	Introduction and welcome
2.	Background to the LEBRM Project
3.	LEBRM Integrated Science and Management Framework
4.	Hydro-climatic model
5.	Conceptual model approach
6.	CSG and LCM activities and stressors (PS Models)
7.	Galilee focus basin
8.	Aquatic ecosystem types (control models)
9.	Values and indicators

Workshop notes:

1) **Introduction and welcome**
   There was no discussion about this agenda item.

2) **Background to the LEBRM Project**
   Attendees expressed the need for the LEBRM project to align with current work being done in the LEB (especially LEBRM).

3) **LEBRM Integrated Science and Management Framework**
   The draft LEBRM Integrated Science and Management Framework was presented and following feedback was given:
   a. There is a need to consider cumulative impacts, in the sense that there may be many mines operating at the same time with multiple pressures on the same system. May also be cumulative impacts over time (i.e. the same pressure happening over a cumulative period).
   b. Indicators need to be carefully selected to reflect the PS models and need to be sensitive enough to reflect changes over realistic timeframes.
   c. Arid ecosystem biota is a poor indicator of disturbance as they are characteristically able to survive extreme conditions.
   d. More of a focus is needed on impacts rather than assets.
   e. Assets and values need to be linked more closely within the Framework.
   f. Assets need to be considered in a connectivity context otherwise impacts will be assessed in isolation of the whole system (this is believed to be the role of the Bioregional Assessments).
   g. Alternative pressures (such as land use, climate change etc.) may be relevant but will not be dealt with through the LEBRM Project; however the Framework should allow expansion to cover these pressures if necessary.
   h. Whilst consistency in data collection is needed, it may be necessary to use different methodology or sampling times for different LEB regions, species or CSG/LCM activities and stressors.

4) **Hydro-Climatic Model**
The proposed Hydro-Climatic Model was presented and the following feedback was given regarding its use:
  a. There is merit in using a Hydro-Climatic Model, however mining impacts may last much longer than a single hydro-climatic phase.
  b. Alternatively the precautionary approach (i.e. 'worst case scenario') may be used.

5) **Conceptual model approach**
The approach used for developing the draft conceptual models was presented and the following feedback was given:
  a. It is difficult to separate springs and alluvial groundwater linked aquatic ecosystems across this project and the LEB Springs Assessment (LEBSA); clearer rules are needed to describe the split. Perhaps if groundwater is recharged by the river it needs to be considered in LEBRM, however if recharge is more regional then it is incorporated into LEBSA.
  b. Conceptual models should be a fall-back position in the absence of data.
  c. There may be limited usefulness in separating aquatic ecosystems into types; rather the focus could be on broad scale impacts throughout a catchment/wider system.

6) **CSG and LCM activities and stressors (PS Models)**
The list of proposed CSG and LCM related activities was discussed and the following feedback was given:
  a. Impacts of roads and pipelines are important and are considered as part of the activities 'site establishment and traffic' and 'surface water diversion'. They could be considered as an activity in their own right.
  b. Under the current list there is no consideration of the indirect or flow-on effects of increased populations around mines (e.g. local tourism, increased water use, building of villages, recreation, fishing etc.).
  c. Mine closure and rehabilitation should also be considered in some manner (and is included in the development application process); although the range of methods is so diverse it may only be considered at a broad scale.
  d. Inter-basin transfer of water could be added as an activity.

The group was asked to brainstorm the likely stressors arising from each CSG and LCM activity (including the suggested additional activities, denoted by italic font). The following list will be used to refine the PS conceptual models:

Activity	Possible stressors
Site establishment and traffic	Spread of weeds and pests Altered floodplain flow patterns Increased sedimentation (especially in waterholes)
Surface water diversion	Altered groundwater recharge (+ or -) Erosion Increased turbidity Aridification Loss of critical waterholes Change in connectivity (+ or -) Floodplain fragmentation & isolation
Discharge to surface water	Bank and channel erosion Change in ionic composition Decreased turbidity (clean water pollution) Cumulative water quality impacts Ephemeral streams impacted by increased flow Change in connectivity (+)
Surface water capture	Loss of stream flows Accidental spills of contaminated water Habitat for invasives Inter-basin transfers of water to supply mines

Activity	Possible stressors
	Increased groundwater levels
Surface water extraction	Loss of flood peaks (floodplain inundation) Decreased persistence of waterholes Increased drawdown
Groundwater extraction	Great Artesian Basin drawdown Habitat loss for threatened ecological communities/ Groundwater Dependent Ecosystems De-pressurisation of aquifers Loss of surface water – ground water interactions
Overburden management	Changes in water quality Increased local recharge Sedimentation Changes to flow patterns (floodplains and channels) Introduction of weeds and spread of seed sources
Evaporation ponds	Changes in salinity and ionic concentration Point source pollution Weeds and invasive species (e.g. toads, *Gambusia*) Heavy metals Accidental spills
Tailings dams	Altered downstream flow regime Heavy metals Seepage and overflow (accidental) Increased downstream salinity
Mine closure and rehabilitation	Contaminants, pollutants and toxins Invasive species and weeds Spread of tailings Artificial connectivity created through leakage of wells Water regime changes Mine pits left in landscape
Effects of increased occupation	Tourism and recreation pressure (e.g. fishing, pollution) Spread of weeds and invasive species Increased demand for urban water
Inter-basin transfer of surface water	Altered groundwater recharge Biological introductions (species and genotypes) Pathogens Changes in chemistry Altered geomorphology Channel erosion
Other indirect effects	Increased agricultural development (increased nutrients and herbicides, invasive species, sedimentation) Frontier development (pioneer species)

7) **Galilee and Cooper focus basins**

Attendees were asked to share their local knowledge about the Galilee and Cooper Basins. It was noted that the Galilee was the priority for the LEBRM project due to the likelihood of development occurring.

Galilee:

a. Not much known here, large knowledge/data gaps
b. Highest rainfall in the LEB, therefore it contributes a lot of water
c. Has three major endorheic (closed, internally draining) lakes which are all locally fed and ephemeral but can hold water for a long period

i. Lake Galilee: salty
ii. Lake Buchanan: very salty by QLD standards (although not compared to SA salt lakes)
iii. Lake Dunn: Fresh and used by locals for water skiing, may be a refuge and often used by large numbers of waterbirds

d. Different topography to rest of LEB, Desert Uplands and Mitchell Grass Downs Bioregions
e. Few permanent waterholes/waterbodies, many are degraded and silted up
f. High level of clearing (and on-going clearing) when compared to the rest of the LEB
g. No notable fish species, *Gambusia* is present often in high numbers
h. One coal deposit in the top corner of the Galilee
   i. Sandstone country
   ii. Long-neck turtles present (only place in LEB although widespread nationally)
   iii. No fish distribution data
   iv. All ephemeral waterbodies
   v. Developments here are close to the top of the catchment and the Great Dividing Range so proponents are likely to consider using water from adjacent catchments. If this was to happen there could be introductions of new species and genotypes
i. Another coal deposit in the southern Galilee (Barcoo)
   i. Diversity of fish at a site scale, 3 or 4 fish sites sampled
   ii. Heavy clearing (especially Gidgee), sheep grazing
   iii. Flows every year and gets a lot of rain

Cooper:

a. Much more is known about this area, there is a good idea of what the baseline is when compared to Galilee
b. Level of risk to CSG and LCM development is lower therefore not a priority for LEBRM
c. Braided systems with big permanent waterholes. Many ephemeral systems that rely on connectivity with upper catchment to survive so these may be affected by development in the upper catchment

8) Aquatic ecosystem types (hydro-ecological models)

The proposed aquatic ecosystem types were discussed and feedback given, however it should be noted that the group felt that an asset-based approach was less useful than concentrating on broader-scale CSG/LCM impacts. In the context of using aquatic-ecosystem types, it was noted that connectivity should be a primary consideration rather than considering discrete types in isolation. The following feedback was given regarding the specific types:

a. Clay pans, inter-dunal lakes and dune lakes are all the same in the QLD context (note: the QLD Wetland Classification does separate these out somewhat). They should be considered in the context of connected versus unconnected:
   i. Connected systems of this type have more fish and fewer invertebrates
   ii. Unconnected/isolated systems have more invertebrates and more waterbirds
b. Billabongs should be included in floodplain systems
c. Many of the types may fluctuate between 'states' (e.g. from a lake to a swamp) depending on connectivity, flow regime and stage in the hydro-climatic cycle.
d. ARI could be used to define connected and unconnected systems

Based on the above discussion, the following grouping of types was suggested:

a. Lakes
   i. Connected
   ii. Isolated
b. Salt lakes
   i. Connected
   ii. Isolated
c. Claypans/swamps/inter-dunal systems
   i. Connected
   ii. Isolated
d. River channel

e. Waterholes
f. Floodplains (including billabongs)
g. Farm dams

The individual control models were reviewed by each participant and suggested additions and changes were recorded on hard copy versions of the models. These will be scanned and retained for future reference, and relevant changes will be made to the models, however each individual's feedback will not be presented in this report. In addition, some of these modelling suggestions will be undertaken under the LEBSA project.

9) Values and Indicators

The group was asked to discuss potential values and indicators of both the focus basins in general and in the context of the aquatic ecosystem types. (Please note that Fran Sheldon was not present for this session and may have additional information to contribute.)

Indicators:

a. As we don't know exactly what activities are likely to occur it should be a priority to identify potential indicators and collect baseline data on these before the activities occur to allow identification of impacts due to CSG/LDM versus naturally occurring changes
b. Any indicators need to be carefully considered in the context of CSG/LCM and fit-for-purpose
c. The five potential major indicators for the LEB (irrespective of aquatic ecosystem type) were identified by the group as:
   i. Water quality
   ii. Hydrology
   iii. Macroinvertebrates
   iv. Fish
   v. Vegetation

These indicators would require further development to provide measureable and robust indicators, it should be noted that this was a discussion only.

a. The Road Map on CSG could give an idea of key indicators for focus areas
b. Indicator development should consider cumulative impacts

Values (of waterholes):

a. Biodiversity and habitat value
b. Maintenance of populations and species
c. Headwater waterholes will have different values to waterholes in the lower catchment (see Fran Sheldon's models)
d. Waterholes also have value in the context of the whole LEB, in that the value of an individual system contributes the functioning of the whole LEB

B. Workshop outcomes report

Adelaide, 30th and 31st May

This Appendix is a record of discussions that occurred during the workshop and are not verified facts or the views of the Department. Instead they are a direct record of statements and key points made in the workshops and may be inaccurate, incorrect or without context.

LEBRM Conceptual Model Workshop (Arckaringa and Pedirka Focus Basins)

Thursday 30th and Friday 31st May

National Wine Centre

Hackney Rd, Adelaide

Attendees:

Affiliation	Name
DLMR	Angus Duguid
Wakelin Associates	Gresley Wakelin-King
Melbourne University	Gini Lee
Consultant	Simon Fulton
Consultant	Bob Read
DMITRE	Malcolm Walton
Melbourne University	Justin Costelloe
SARDI	David Schmarr
DSEWPaC	Sonia Colville
DEWNR	Jeff Foulkes
DEWNR (SAAL)	Henry Mancini
DEWNR	Glen Scholz
DEWNR	Dale McNeil
DEWNR	Hugh Wilson
DEWNR	James Paull
Auricht Projects	Sarah Imgraben

Apologies:

Volmer Berens, Julian Reid, Peter Goonan, Keith Walker, Catherine Miles, Paul Wainwright.

Workshop objectives:

- Introduce the Lake Eyre Basin Rivers Monitoring project objectives and approach
- Review and refine the draft conceptual models to best display the assumptions about Lake Eyre Basin ecosystem processes, connectivity and potential coal seam gas impacts

- Record, synthesise and incorporate expert opinion regarding ecosystem functioning and the potential impacts of coal seam gas activities
- Identify how the conceptual models (and assumptions) may need to be altered for the specific focus regions in the Lake Eyre Basin
- Identify the need for additional sub-models or supporting information to increase the robustness of the conceptual models
- Identify indicators for focus areas and explore thresholds of potential concern
- Identify the key aquatic types and indicators in relation to different mining pressures

Agenda:

Item	Description
1.	Introduction and welcome
2.	Background to the LEBRM Project
3.	LEBRM Integrated Science and Management Framework
4.	Conceptual model approach
5.	CSG and LCM activities and stressors (PS Models)
6.	Arckaringa and Pedirka focus basins
7.	Components and Processes
9.	Aquatic ecosystem types (control models)

Workshop notes:

1) **Introduction and welcome**
   There was no discussion about this agenda item.

2) **Background to the LEBRM Project**
   There was no discussion about this agenda item.

3) **LEBRM Integrated Science and Management Framework**
   The draft LEBRM Integrated Science and Management Framework was presented and the following feedback was given:
   a. The framework specifically addresses the 'likelihood' component of a risk assessment; however it would need more context to make it specific to individual developments and proposals.
   b. Clear definitions are needed throughout the Framework (for example CSG pressure could relate to a physical attribute of an aquifer as well as a pressure resulting from mining)
   c. The Framework should be transferrable to pressures and values other than those relating to CSG and LCM, however further work would be needed to tailor outputs to the circumstances

4) **Conceptual model approach**
   The approach used for developing the draft conceptual models was presented and the following feedback was given:
   a. The Framework and conceptual modelling report needs to be very clear about the applicability of the current models outside of the LEB, particularly the aquatic ecosystem models
   b. Pictorial models need to have more information/text describing what each aquatic ecosystem type name means. There are a number of different names used to refer to these systems (both scientific and cultural) across the community, and some people may not understand the current language without further explanation

c. Need a clear explanation of how groundwater and springs fit into the models. The group suggested the following:
   i. Alluvial/hyporheic (i.e. mixing of surface and groundwater in the shallow sediment alongside rivers/aquifers) water may be considered in the LEBRM project (however, there will not be a conceptual model developed)
   ii. Fluvial associated springs and groundwater discharge that influences surface water ecology may be considered in the LEBRM project (however, there will not be a conceptual model developed)
   iii. GAB springs and non-fluvial associated groundwater discharge will be considered as part of the Lake Eyre Basin Springs Assessment (LEBSA) Project and will not be covered in the LEBRM project

5) **CSG and LCM activities and stressors (PS Models)**

The list of proposed CSG and LCM related activities was discussed and the following feedback was given:

a. Vegetation clearance could be added an as activity, although there is legislation around this in South Australia. This may also be incorporated as a stressor in the PS Models so might not require its own activity.
b. Accidental damage and spills need to be considered
c. The effects of increased population and other indirect effects should be incorporated somehow
d. Exploration activity may not be adequately covered under current list of activities
e. Mine closure and rehabilitation is an important consideration and may need to be considered
f. There is a lack of data to assess many of these activities/risks adequately and set thresholds

The group was asked to brainstorm the likely stressors arising from each CSG and LCM activity (including the suggested additional activities, denoted by italic font). The following list will be used to refine the PS conceptual models:

Activity	**Possible stressors**
Site establishment and traffic	Altered flow patterns Change in connectivity Erosion Compaction Landscape fragmentation Introduced weeds and fauna
Surface water diversion	Change in connectivity Change in natural hydrology of a system Change in flow/water regime Change in flow volume Increased stream energy (erosion) Erosion Loss of habitat Alienated river reach or waterbody
Discharge to surface water	Change in flow/water regime Change in flow volume Change in connectivity Potential spread of invasive species Sedimentation Changes to habitat Loss or alteration of breeding cues for birds and fish Landform change
Surface water capture	Reduced natural recharge Decrease in connectivity
Surface water extraction	Loss of connectivity Change in water quality Decreased persistence

Activity	Possible stressors
	Decreased habitat availability
Groundwater extraction	Lowering of water table Decreased persistence of waterholes Decline in ground water dependent habitats and fauna Subsidence Damage to or loss from sub-surface aquifer
Overburden management	Dust Acid mine drainage Sedimentation
Evaporation ponds	Change in water quality Increased salinity Introduction and support of invasive species
Tailings dams	Contamination Erosion from a spill Seepage and spills
Mine closure and rehabilitation	Alteration of aquifer
Vegetation clearance	Siltation of waterholes Habitat loss Erosion Decrease of nutrients and carbon Change in shading of waterbodies Spread of weeds
Other indirect effects	Sewerage/refuse management Introduction of species Increased tourism and recreation Disposal of rubbish Trampling and compaction Social changes Loss of aesthetic value

6) **Arckaringa and Pedirka focus basin**
Attendees were asked to share their local knowledge about the Arckaringa and Pedirka Basins.

Arckaringa:

a. The main surface catchment is the Neales (of which Arckaringa Creek is a tributary); there are 1-2 flow events a year with a large flood every 10 years. There is not much data for flows in Arckaringa Creek
b. There are many springs throughout the catchment, and Algebuckina waterhole is considered a permanent instream waterhole
c. There are some saline areas and interaction with saline groundwater
d. Arckaringa Creek has higher run-off and steeper slopes; likely to have shorter flows but higher flow peaks than other creeks in the Neales.
e. Sediment transport happens in pulses so water releases could have a big impact here
f. Groundwater data in this region is scarce, there are some small pockets of data surrounding mines
g. Lots of bio-surveys have been carried out by DEH and work done on waterholes for the SAAL NRM Board
h. The Stony Plains Bioregion is unique and features gilgais
i. There are few naturally permanent systems in the region
j. Fish move in and out of the system, however not really sure where they are going
k. Farm dams connected to watercourses in this area could be an important refuge for fauna
l. The EPA have monitoring sites through this area, the water quality has high nitrogen and phosphorous and use for human and tourism use is limited

m. Oodnadatta track and Coober Pedy track has high cultural and tourism significance , as well as tourism plans for the painted desert
n. Anecdotally, many in the community are not happy about mining development plans
o. Coal Mining in the Arckaringa:
    i. There is a potential coal mine in this basin, as well as some existing mines
    ii. Linc Energy have an exploration license, CSG is not an option in this location
    iii. Only current project is Altona, with four potential deposits with coal to liquids project. This would involve a pit to remove the coal (resulting in overburden) and an adjacent processing plant where the coal is converted to liquid. The plan is to backfill the pit as they go
    iv. Would involve the construction of a village and other infrastructure, and a workforce occupation of around 800 people
    v. Dewatering is a huge issue and the current plan is to reinject, also considering beneficial use of water
    vi. Currently planned to be a 30 year mine with the potential of a 100 year mine

Pedirka:
a. Finke River has high biological value, particularly for fish, however the refuge sites are higher upstream and out of the focus basin
b. The Finke floodout is enormous, the Snake Creek flood-out contains inter-dunal swamps and lakes
c. In a big flood the end of the Finke River may connect up with the mega-spring complex at Dalhousie
d. There are a number of aboriginal communities, also tourism and National Park value
e. The important fish refugia are outside of the focus basin
f. Salinity varies greatly throughout the Finke
g. Waterbirds are significant in the Snake Creek area (Finke River), and the Snake Creek floodout is an excellent example of an episodic wetland
h. The sediment transport/bedload movement in the Finke is very different to other rivers in the LEB. In a big flow lots of sediment could be mobilised and transported, which could have implications for permanence and persistence of habitats.
i. The boundaries of Dalhousie Springs have recently been redefined and the source of these springs could be Pedirka rather than GAB which would be extremely significant
j. Potential for direct surface water – groundwater connection restricted to around the Finke River and Hale River floodouts
k. There is a significant recharge zone for the GAB around the Finke community (could also be recharging the Pedirka Basin too), groundwater quality in this area is potable
l. Little is known about the hydrology of the Macumba
m. In the upper west of the Pedirka there is a large complex of non-connected pans and swamps with significant biological value.
n. Pedirka coal is very deep and it appears it may not be suitable for CSG

7) Components and Processes

The draft list of components and processes was presented to the group and the following feedback was given:
a. There is merit in using attributes in the form of components and processes, however they need to be well considered and all at the same level
b. The geomorphic and physical habitat components need further development

The group was asked to modify the proposed list and the following list was constructed:

Attribute	Component	Sub-component
Hydrology	Flow regime	
	Water regime (persistence, within waterbody)	
	Connectivity	Longitudinal (in-channel)
		Latitudinal (out of channel)
		Vertical (groundwater – surface water)
		Cross- catchment

Attribute	Component	Sub-component
		Phreatic evaporation
Geomorphology	Landform type	Basin
		Riparian/shore line
		Channel
		Floodplain
	Landform characteristics	Size
		Surface area
		Shape
	Valley boundaries	Confinement
		Valley floor and edges
	Cease-to-flow depth	
Physical habitat	Substrate	Permeability
		Structure/texture
		Contaminants
	Vegetation structure types	Woody debris
		Floodplain and watercourse vegetation structure (macrophytes etc.)
		Riparian structure
	Bank and shore stability	Stability
		Morphology
		Rock bars
		High adjacent terrain
Water quality regime	Salinity (EC)	
	Ionic composition	
	pH	
	Turbidity	
	Temperature	
	Dissolved Oxygen	
	Dissolved Organic Carbon	
	Nutrients	
	Contaminants/toxins	
Wetland biota	Fauna	Microinvertebrates
		Macroinvertebrates
		Amphibians
		Reptiles
		Fish
		Birds
		Mammals
	Flora	Algae
		Biofilms
		Macrophytes
		Riparian vegetation
Terrestrial biota	Fauna	Macroinvertebrates
		Reptiles
		Birds
		Mammals

Attribute	Component	Sub-component
	Flora	Fungi
		Algae
		Other flora

8) Components and Processes

The proposed list of aquatic ecosystem types was discussed and the following feedback was given:

a. Extreme variability is a feature of the LEB and many types will be overlapping at different stages of flooding. It is difficult to put pragmatic boundaries around these ecosystems, however different parts of the connected system can be characterised individually.
b. Floodouts need to be added as a type (with possible sub-types, end of system and in-system)
c. Very clear definitions are needed for aquatic ecosystem types
d. The Australian Soil and Land Survey Field Handbook (Yellow Book) and Guidelines for Surveying Soil and Land Resources (Blue Book) may be useful for definitions, however there is some doubt over their suitability for the LEB
e. Hydrologically, swamps, pans and inter-dunal systems are the same so they can be lumped according to whether they receive flow from a major river system or whether they are isolated and filled locally. These could be called 'basin' systems as all are derived from basin landforms.
f. In the LEB (and other arid zones) it may not be useful to make a split between palustrine and lacustrine systems as systems may fluctuate between the two depending on frequency of inundation

The following nested structure was suggested for the aquatic ecosystem types:

a. Part of a major drainage/river system:
   i. Waterholes (in-channel and floodplain)
   ii. Floodouts
   iii. Floodplains
   iv. In-channel habitats (watercourses and riparian)
   v. Basin Systems (lakes, swamps, pans)
   vi. Dams
   vii. Springs (out of scope)

b. Isolated from major drainage/river system:
   i. Channels and tributaries (small watercourses that are disconnected)
   ii. Basin systems (lakes, swamps, pans)
   iii. Farm dams
   iv. Springs (out of scope)

The individual control models were reviewed by each participant and suggested additions and changes were recorded on hard copy versions of the models. These will be scanned and retained for future reference, and relevant changes will be made to the models, however each individual's feedback will not be presented in this report.

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