Lake Eyre Basin Rivers Monitoring Project

Integrated science and management framework

DEWNR Technical report 2015/11

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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Department of Environment, Water and Natural Resources

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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
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The Lake Eyre Basin River Monitoring project was funded 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.

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Summary

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 Independent Expert Scientific Committee (IESC) in its role under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and support jurisdictional assessment and approvals processes.

The Integrated Science and Management Framework (ISMF) proposes to leverage existing standards and approaches to ecosystem asset management and risk management as an organising principle for the assessment processes and knowledge base assembled by projects underpinning the bioregional assessments. The approaches adopted include Strategic Adaptive Management (Kingsford & Biggs 2012), the methodology for bioregional assessments of the impacts of CSG and coal mining developments on water resources (BRAM) (Barrett et al., 2013), the Australian National Aquatic Ecosystem (ANAE) classification framework (AETG, 2012) and the AS/NZS ISO 31000:2009 risk management guidelines (Joint Technical Committee OB-007, 2009). It is intended that by bringing together these approaches, the body of knowledge developed and collated under the auspices of the bioregional assessment will facilitate assessments that are fit for purpose and address the needs of multiple stakeholders. In doing so, it is proposed the ISMF will encourage risk-based management of natural resources whereby government, proponents and stakeholders work together to achieve sustainable development outcomes consistent with community expectations.

Key features of the ISMF include:

- Adoption of the concepts and processes of the AS/NZS ISO 31000:2009 risk management guidelines as a driver for the organisation and representation of ecological models, information and knowledge gathered by the ISMF
- Adoption of the Pressure-Stressor-Response (PSR) framework (Marshall et al. 2006) to describe the impacts of CSG and coal mining developments, the pathways through which these impacts are linked to assets and potential ecological responses.
- An asset-based approach to identifying, classifying and attributing aquatic ecosystems, where assets are defined as discrete, aquatic ecosystems, or biophysical units that possess unique suites of hydro-ecological attributes (components and processes). This approach provides consistency with jurisdictional resource management systems and databases and the Bioregional Assessment methodology
- An asset typology that allows for the generalisation of knowledge and models across groups of ecological assets of similar type. This system aims to promote efficient and consistent assessments for particular sites and habitats that may have different levels of data availability
- Attribution of assets according to ecological components, processes and services in accord with the Ramsar wetlands convention (DSE 2005). This facilitates an understanding of why we value particular assets and how those assets might respond to stressors caused by CSG and coal mining developments. It also provides the Bioregional Assessment Programme with candidates for receptors, which are responsive components of ecosystem assets that may be measurably impacted by changes in water quality or quantity stemming from coal mining developments.
- Highlight key assumptions in our understanding of how assets respond to CSG and coal mining Pressures that will underpin assessments of environmental impact
- Identification of asset values, indicator rules and Thresholds of Potential Concern (TPC) consistent with a Strategic Adaptive Management (SAM) framework (Kingsford & Biggs 2012). This focuses attention on the tipping points, beyond which ecosystem function resilience or viability are threatened

- Identification of conceptual ecological models indexed according to the asset typology. Conceptual models provide a communication tool for use in risk assessments. They may also form the basis of numerical ecosystem response models for more detailed risk analyses where required.
- Creation of a scientific knowledge base with ongoing maintenance processes (i.e. updates where existing knowledge is verified; insertion of new knowledge as acquired) that supports the adaptive management process.

Jurisdictional NRM Agencies are moving towards risk-based management of water resources, based on the AS/NZS ISO 31000:2009 risk management guidelines (e.g. Risk Management Framework for Water Planning and Management: DEWNR 2012). Risk-based approaches focus investigations and interventions on issues where uncertainty impacts stakeholder objectives. The ISMF aims to facilitate this process by explicitly focussing on uncertainty in data and knowledge and making inferences on the basis of this uncertainty.

It is proposed the ISMF provides a means for mining proponents to develop best practice approaches to Environmental Impact Assessments in the region. It is also intended to guide infrastructure planning, research and monitoring approaches that will optimise project design to reduce environmental risks and to better inform regulators of the potential risks and ameliorative actions incorporated into mining development applications. By also providing a common system to inform both proponents and regulatory agencies, the framework may enhance the communication of potential environmental impacts and requirements. This would thereby improve the efficiency of mining approvals processes and help to support the sustainable development of coal mining industry into the future.

Glossary of terms

Attribute – A quality or feature that is an inherent part of an asset. Ecological assets can be characterised by a number of physical and functional ecosystem attributes. These attributes can be classified as components or processes, many of which are common across multiple assets – particularly those of the same Asset Type.

Component – Bio-physical attribute of an asset. For example, substrate, biota, hydrology.

Consequence – Outcome of an event affecting objectives (AS/NZS ISO 31000:2009 risk management standard).

Ecological Asset – Discrete, spatially defined functional aquatic ecosystem units, e.g. a waterhole, wetland or lake.

Ecological Asset Type – A category for ecological assets sharing common characteristics such as attributes. Assets may be classified according to the Australian (ANAE) and the South Australian (SAANE) National Aquatic Ecosystem classification system. Asset types may be based on hydro-geomorphology (e.g. waterholes, swamps, springs and salt lakes). They may be further broken down based on regional, climatic or biophysical properties into smaller sub-units. For the purposes of the ISMF, the higher level classification (i.e. Imgraben and McNeil 2015) is used.

Indicator – A generic term for measurable attributes that provide information on the status or condition of a thing. For the purposes of the ISMF, indicators may i) show or be sensitive to asset responses to pressures and stressors, and ii) inform how human values for an asset are affected by response to pressures and stressors. In the context of the BRAM (Barrett et al., 2013), a *receptor* (described below) is a specific type of indicator having a specific purpose.

Indicator Rules – Describe the range of indicator conditions suggestive of the asset having low risk of lost or degraded value. Where data or knowledge is available, specific thresholds of potential concern can be developed to apply indicator rules to assets in space and time.

Likelihood – The chance of an occurrence or change of a particular set of circumstances affecting objectives (AS/NZS ISO 31000:2009 risk management standard).

Pressure – Human activities that, directly or indirectly, modify the biophysical conditions experienced by ecosystems and their constituents, thus giving rise to a stressor.

Process – Represent the functioning of ecosystem components that drive interactive and complex ecosystem mechanics including water, nutrient and biotic community dynamics.

Pressure Stressor Response (PSR) model – A type of model describing how human activities could impact asset value. It incorporates state variables describing pressures, stressors and responses, with the pressures representing the model inputs, and the responses the model's outputs. PSR models also incorporate a conceptual or mathematical representation of the interactions between these state variables.

Receptors – Discrete attributes or component of a water-dependent asset that may be measurably impacted by a change in water quality or quantity resulting from coal seam gas or coal mining development. Receptors are the response unit (ecological and otherwise) underpinning the Bioregional Assessment (see Barrett et al., 2013).

Response – Change in the status or condition of an asset caused by exposure to a stressor. A response can be detected through observed changes in key attributes (indicators). Responses may be registered by a single attribute, or may affect multiple attributes (e.g. via trophic cascade effects) to modify entire ecosystems.

Risk Assessment – The process of identifying risks, analysing the likelihood and consequences of risk events, and evaluating the tolerability of risk level according to risk criteria. In the context of the ISMF, a risk assessment may consider the potential for pressures to cause loss of values thus leading to societal objectives for an asset not being achieved. The risk identification and analysis step may consider PSR models, indicators, indicator rules, TPCs, components, processes and other features of the ISMF.

Stressor – A change to the state of a set biophysical attributes directly or indirectly caused by exposure to a pressure. This, in turn, potentially elicits an ecosystem response. Also termed vectors (Marshall et al 2006)

Threshold of Potential Concern (TPCs) – Indicator conditions marking an asset's transition from low to high risk of lost or degraded value, for example tipping points beyond which ecosystem function, resilience or viability are threatened. TPCs typically represent the limits of indicator rules.

Value – Importance, worth, or usefulness of an ecological asset or attribute to individuals or the community

Value Class – Defined groups of values and nested sub-values as identified for outback water resources and aquatic ecosystems (Macdonald and McNeil 2012)

List of abbreviations

AVIRA	Victorian Aquatic Value Identification and Risk Assessment
BA	Bioregional Assessment
CSG	Coal Seam Gas
DEWNR	SA Department of Environment, Water and Natural Resources
FLOWS	Finding Long Term Outback Water Solutions
GLEB	Goyder Institute Lake Eyre Basin Project
EPBC	*Environment Protection and Biodiversity Conservation Act 1999*
IESC	Independent Expert Scientific Committee
IIESC	Interim Independent Expert Scientific Committee
ISMF	Integrated Science and Management Framework
ISO	International Organisation for Standardization
LEB	Lake Eyre Basin
LEBRA	Lake Eyre Basin Rivers Assessment
LEBRM	Lake Eyre Basin Rivers Monitoring Project
LCM	Large Coal Mining
LEBMF	Lake Eyre Basin Ministerial Forum
LEB SAP	Lake Eyre Basin Scientific Advisory Panel
LEB CAC	Lake Eyre Basin Community Advisory Committee
MDB	Murray-Darling Basin
NRM	Natural Resource Management
NPA	National Partnership Agreement on Coal Seam Gas and Large Coal Mining Projects
OWS	Commonwealth Office of Water Science
PSR	Pressure-Stressor-Response
SAAL	South Australian Arid Lands, NRM Board
SAM	Strategic Adaptive Management
SOE	State of the Environment Reporting
TPC	Threshold of Potential (or Probable) Concern

1. Introduction

1.1. Lake Eyre Basin Knowledge Projects

The Lake Eyre Basin (LEB) contains some of Australia's most important onshore petroleum resources. Extraction of oil and natural gas from the Cooper Basin, which lies under the LEB, has occurred over a number of decades. There are also significant undeveloped coal bearing basins including the Arckaringa, Pedirka and Galilee Basins (Figure 2) located within the LEB. These have been identified for potential developments such as coal seam gas (CSG), large scale coal mining, coal to liquids (CTL) and underground coal seam gasification (USG) projects.

In 2012 the Australian Government acted to address nationwide community concerns regarding the potential impacts of CSG and large coal mining (LCM) on water resources. To this end the National Partnership Agreement (NPA) on Coal Seam Gas and Large Coal Mining Development was established with participating jurisdictions to promote transparent decision making and improvements in the scientific knowledgebase regarding the potential impacts of these types of developments.

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

The Lake Eyre Basin River Monitoring (LEBRM) project was developed to collate a baseline of scientific knowledge around the hydrology and ecology of aquatic ecosystems in the LEB and to improve knowledge in regions where coal-bearing deposits are located and therefore where CSG or coal mining activities are most likely to occur in the foreseeable future. The overarching goal of the LEBRM project is to provide an advanced and up-to-date platform of hydrological and ecological knowledge that can support the detailed modelling, impact and risk analysis needs of LEB bioregional assessments. The LEBRM project background, purpose, approaches and links to the bioregional assessment is described in more detail in Lake Eyre Basin Water Knowledge Projects Summary (DEWNR, 2015). This document is closely aligned to the following LEBRM deliverables:

- LEBRM Overview report (DEWNR, 2015)
- Knowledge review (Miles and McNeil, 2015)
- Draft conceptual models (Imgraben and McNeil, 2015)

This document (the Integrated Science Management Framework) is structured as follows:

- Introduction to the ISMF model structure and purpose in detail (Section 1)
- Discussion on the application of the framework to support risk management (Section 2)
- Presentation of ecological approach required for applying the framework under the highly variable climatic and hydrological environment present in the Lake Eyre Basin (Section 3).

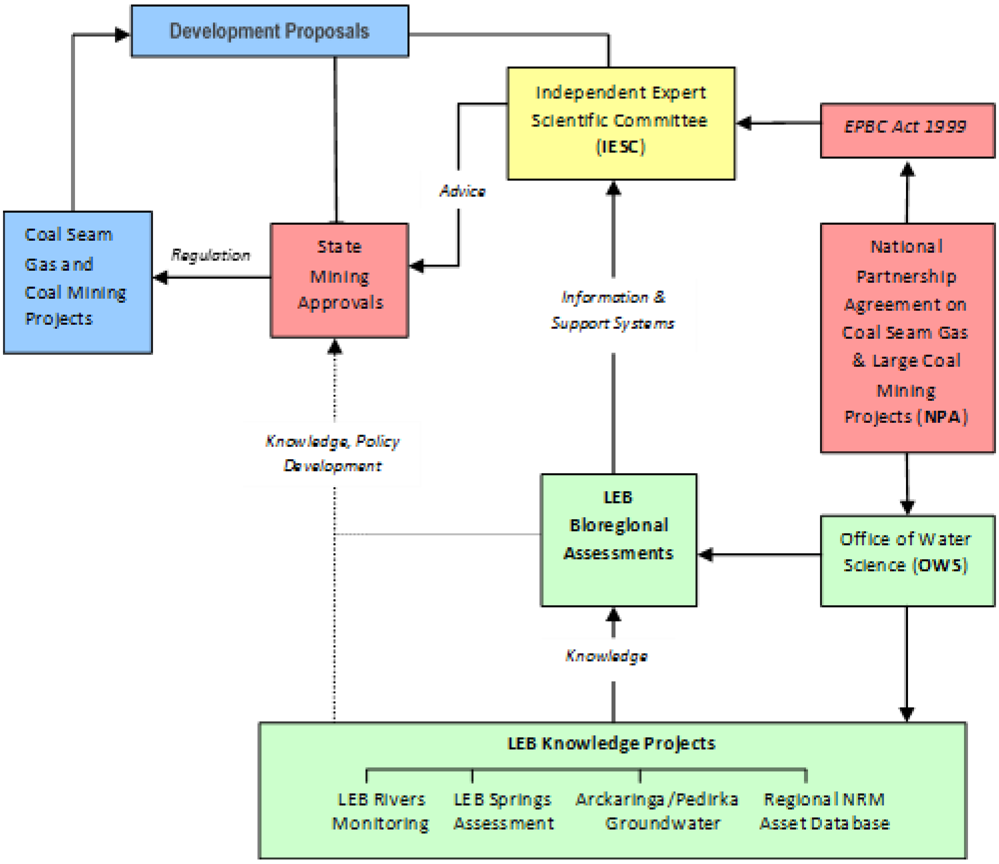

Figure 1. LEB priority region - relevant authorities, agreements, assessments, processes and information flows

1.2. Delivering the ISMF for the Strategic Adaptive Management of the Lake Eyre Basin

1.2.1. Natural Resource Management Linkages

The delivery of BA and LEBRM outputs under the ISMF can be optimised by ensuring consistency with current NRM practices, policies and processes for science-based management of the LEBs waterways. This requires also that the framework reflect other Natural Resource Management (NRM) processes beyond management of CSG and mining impacts.

NRM is concerned with management of natural resources with particular focus on how management affects the quality of life for both present and future generations. In the LEB context it covers a set of national, jurisdictional, regional and local management and administrative arrangements. Regardless of scale or jurisdiction, NRM generally includes the following functions:

- Community engagement to identify natural resources valued by the community and to set agreed goals with respect to the management of these resources taking into account environmental, social and economic aspirations
- Planning at the appropriate scale to identify the most effective means by which NRM goals can be achieved alongside social and economic objectives
- Establishing the appropriate mandate and commitment to access resources and establish policy settings required to put plans into action
- Monitoring, evaluation, reporting and improvement processes to facilitate ongoing adaptive management and assure good governance.

A platform of sound scientific knowledge is a key enabler for successful prosecution of each of these functions as it is required to:

- Understand and communicate natural resource values and the risks to these values posed by human and natural processes
- Facilitate design and evaluation of management options for achieving natural resource management goals
- Provide an evidence base to support the required mandate and commitment for implementing management plans and policy settings
- Support ongoing monitoring, evaluation, reporting and improvement processes for plans and policy settings.

1.2.2. Environmental Context Lake Eyre Basin

The LEB is an endorheic (internally-draining) basin in central Australia covering almost one sixth (1.14 million km^2) of the continent's land mass (Kotwicki and Allen 1998). The river systems of this region are subject to some of the most variable climatic and hydrological conditions globally (Puckridge et al. 1998, 2000) and are unique in being one of the last unregulated dryland river systems in the world (Walker et al 1997).

Large flood events driven by the La Niña phase of the El Niño–Southern Oscillation (ENSO) phenomenon, are interspersed with periods of severe seasonal wet/dry cycles characterised by extended and severe drought (Allen 1985, Kotwiki and Isdale 1991). The ecology of the LEB accordingly cycles through massive 'booms' following large floods, through to 'bust' during periods without flow (Puckridge et al. 1998, Bunn et al. 2006).

Knowledge of the ecological and hydrological processes within the LEB are based on limited and patchy data sources, with far less data available compared to more developed neighbouring basins such as the Murray-Darling (LEBSAP 2008, 2009a, 2009b). This relative lack of knowledge combined with the inherent complexity of the dynamics of hydro-ecological systems in the LEB pose significant challenges to characterising and modelling these systems for the purposes of environmental management.

1.2.3. Strategic Adaptive Management in the LEB

Adaptive management (Holling, 1978) has emerged as a key response to the challenges of managing natural systems where there is significant uncertainty regarding the effect of management interventions. Put simply, adaptive management is 'learning by doing' – that is, it aims to achieve natural resource management objectives while accruing information to support improved decision making in future.

Adaptive management is an important principle guiding environmental management throughout much of Australia including the LEB. It underpins relevant NRM frameworks such as the Australian Government NRM MERI framework (Australian Government, 2009) and jurisdictional NRM initiatives. More specifically, in April 2010 the LEB Ministerial Forum endorsed the Strategic Adaptive Management framework for the purposes of guiding the Lake Eyre Basin Rivers Assessment (LEBRA).

Strategic Adaptive Management (SAM) (Kingsford and Biggs, 2012) is an adaptive management framework developed to address the challenges of large scale catchment management. Like all adaptive management approaches, SAM focusses on identification of assumptions underpinning decisions and then testing these through targeted monitoring and evaluation activities in order to progressively improve management over time. SAM also recognises that environmental management over large spatial and temporal scales must account for the needs of multiple stakeholders including traditional owners, holders of property rights, jurisdictional authorities, natural resource management programs and the broader community. Thus it is also focused on the engagement of stakeholders, identification of community values regarding the natural environment and the setting of common goals against which to align environmental programs and decision making that affects the environment.

Understanding the drivers of NRM investment and applying scientific knowledge to understand environmental systems and their responses to impacts enables managers to build a clear picture of what they are trying to achieve, how this might be done and how the effectiveness of these actions can be measured and demonstrated. A system that can clearly link environmental impacts and responses to community priorities and objectives to drive effective and efficient management policies, regulations, responses and investment is critical for conceptualizing and affecting optimized NRM investment.

At the core of the SAM approach is the bringing together of biophysical, economic and social aspects of environmental and natural resource management to consider how, what, why, and when various aspects of NRM should be brought together to optimize the meeting of relevant NRM objectives (Kingsford et al 2012). Importantly, the process requires the integration of stakeholder visions and objectives with scientific research into a long term framework whereby visions, goals/objectives, monitoring and assessment approaches and management interventions can be considered and re-assessed in an ongoing manner through short (1–5 years), medium (5–10 years) and long (10–20 year) timeframes.

The resulting SAM process therefore reflects ongoing modification and adaption that is informed both by a changing platform of scientific knowledge (informed by long term monitoring) as well as a changing background of community and socio-economic values and understanding. Consistent with its holistic approach, SAM has a broad and complex job to do in guiding NRM programs and practices and as a result, practitioners are often find it difficult to comprehend, or engage fully with the on ground realization of the SAM process—specifically, what does all this mean for them in delivering their ongoing role?

The ISMF therefore attempts to capture how current scientific and NRM processes can be co-ordinated into an integrated framework for delivering SAM in the context of Natural resource Management in the LEB. Whilst the current application is for the management of coal seam gas and large coal mining impacts, the adaptive capability of the model could allow the integration of the framework into the ongoing management of the waterways of the LEB and provide flexibility for applying the framework to other BA areas outside the LEB.

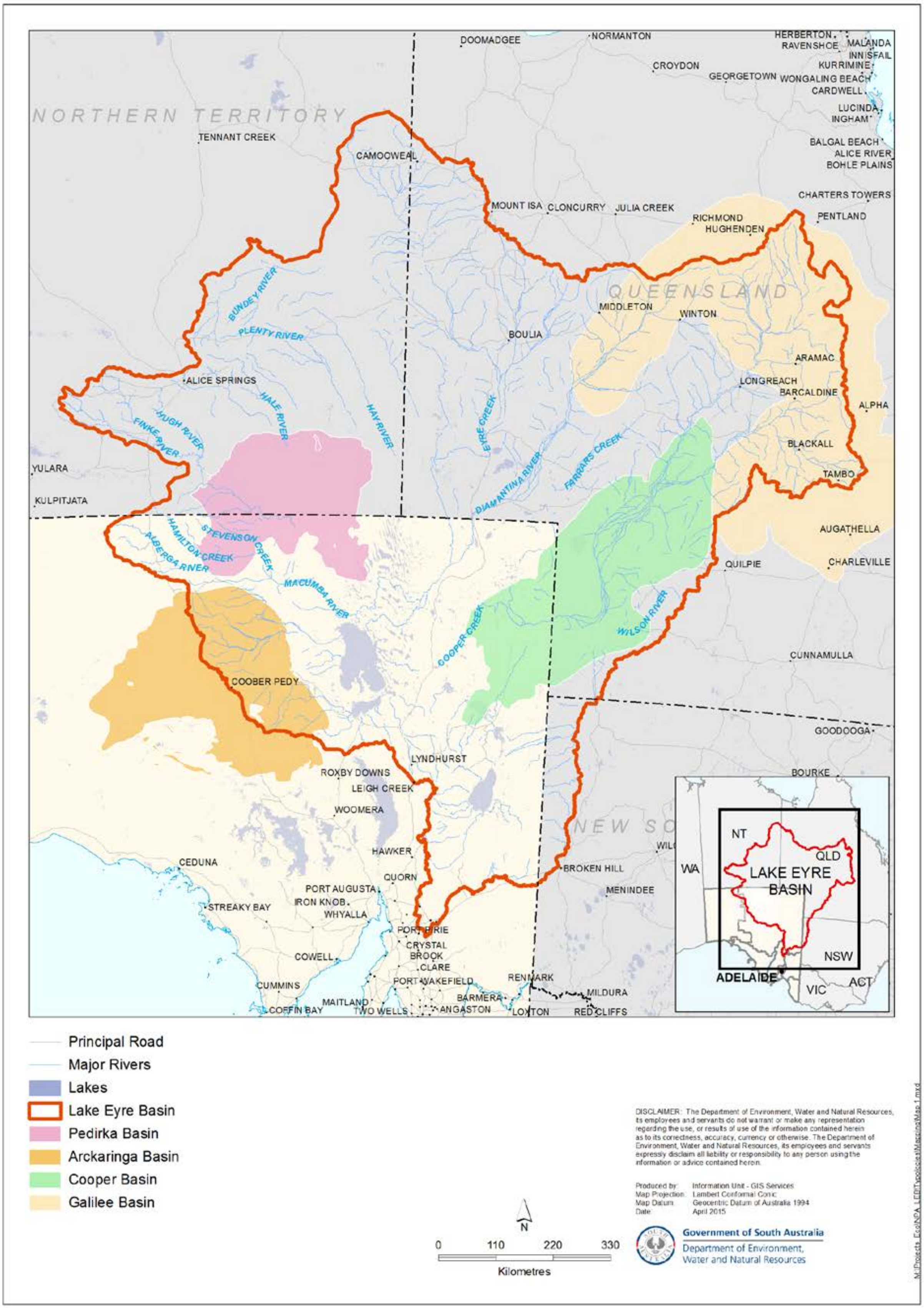

Figure 2. Lake Eyre Basin showing Arckaringa, Cooper, Galilee and Pedirka Basins

2. Framework model

2.1. Framework Structure

The ISMF (Figure 1) integrates a number of established approaches and methodologies that can operate at different spatial scales and deal with data and information of varying confidence and completeness, and can be applied across a range of different purposes. The framework builds on the following key elements:

- Integration of the Pressure-Stressor-Response (Marshall et al. 2006) and the risk assessment process (based on the AS/NZS ISO 31000:2009 risk management guidelines) frameworks to identify and assess the likelihood of impacts specific to mining pressures, the mechanisms through which these pressures cause stress to the environment (stressors) and the ecological responses that are likely to eventuate.
- An asset-based approach for identifying, classifying and attributing aquatic ecosystems. This is consistent with jurisdictional resource management systems and databases (e.g. SA water resources database) and the BRAM (Barrett et al., 2013), and it allows the classification of ecological assets into aquatic ecosystem typologies such as the Australian National Aquatic Ecosystem (ANAE) classification framework (AETG 2012).
- Attribution of asset characteristics to capture the ecological components and processes at the asset scale, consistent with the Ramsar Wetlands Convention (DSE 2005).
- Identification of asset values and indicator rules to inform the development of Thresholds of Potential Concern (TPC) that identify potential tipping points beyond which ecosystem function, resilience or viability are threatened, consistent with Strategic Adaptive Management (Kingsford and Biggs 2012). These factors provide a measure of consequence that can be used in conjunction with the likelihood information under point 1 to complete risk assessments for assets.

The framework (Figure 1) outlines a process cycle that steps through the various requirements for delivering science and value-based Strategic Adaptive Management. Impact pathways can be initiated from the top left of the model (blue text) leading to the development of asset attribution, conceptual and empirical modelling resulting in the identification of indicators and thresholds that best represent ecological impact responses.

The model links these indicators and thresholds to explicit human values that in turn allow the assessment of risk through likelihood and consequence analysis. Indicated by black text, the model presents a number of key tasks that are required to ensure that the process clearly identifies the target assets and identifies the ecological attributes make up those assets. Subsequent tasks (black text) include the development of conceptual models, the application of knowledge and data, the parameterisation and analysis of models and data and the explicit statement of indicators and thresholds that link to human values and management responses.

Through the lens of value classification, the model demonstrates how management policy and planning further links indicators and thresholds through to management responses including management approvals, NRM intervention and monitoring strategies (red arrows).

Importantly the model also acknowledges the role of stakeholder and community engagement cycles in linking values, policy and management responses under the SAM framework.

The following subsections describe each component of the framework in greater detail, with particular reference to how the framework will support the LEBRM and Bioregional Assessment projects in delivering an ecological asset-based risk assessment approach for assessing and approving mining development proposals for the coal mining industry. This is followed by a section outlining how the framework can be applied to support a risk management approach to assessment of mining approvals in the LEB. Finally, the report addresses applications of the framework within the highly variable climatic environment of the Lake Eyre Basin.

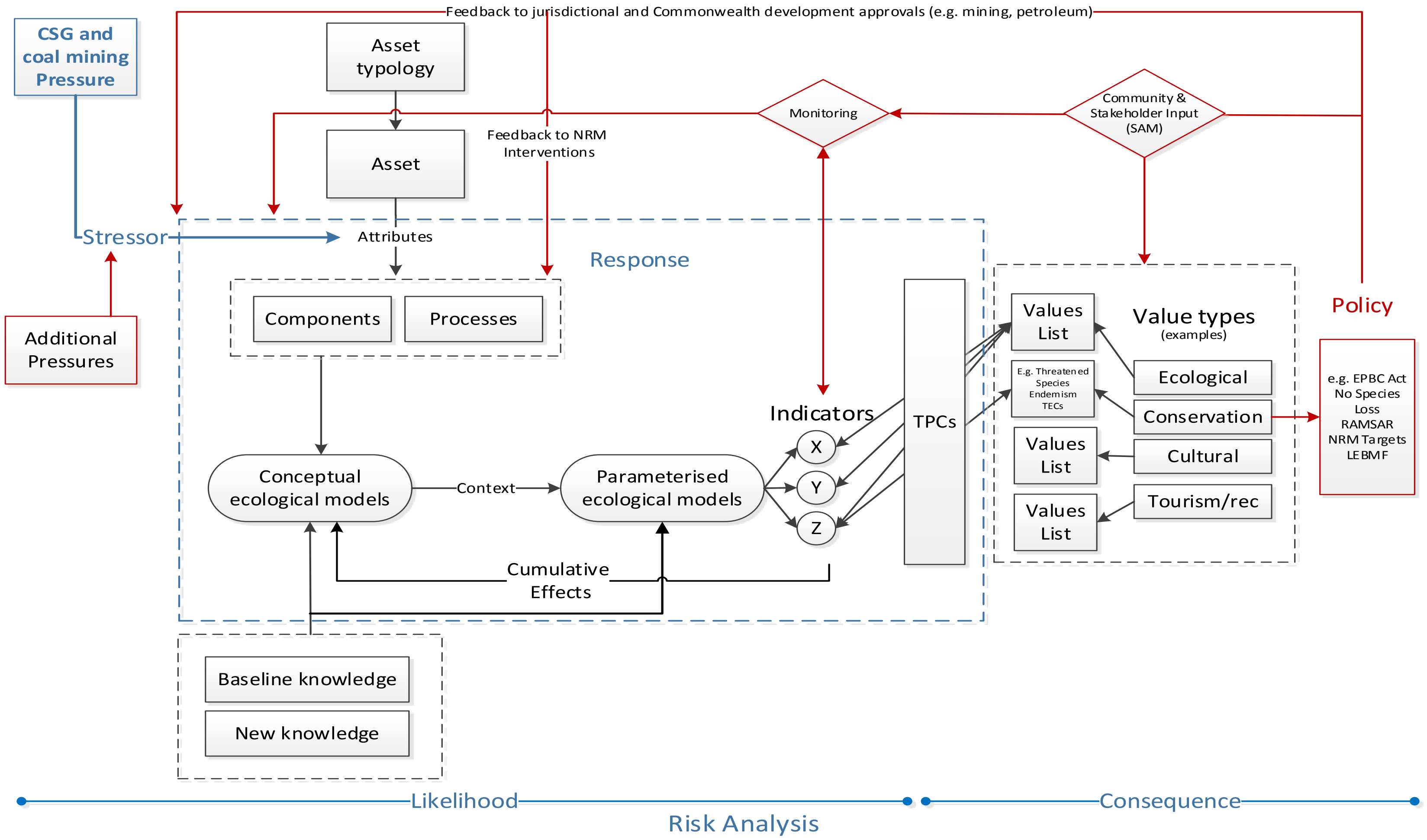

Figure 3. LEBRM Integrated Science & Management Framework Model.
Blue features indicate Pressure-Stressor-Response and Risk Assessment Framework components; red items identify key NRM linkages external to LEBRM project delivery

2.2. Identifying Impacts: Pressure-Stressor-Response

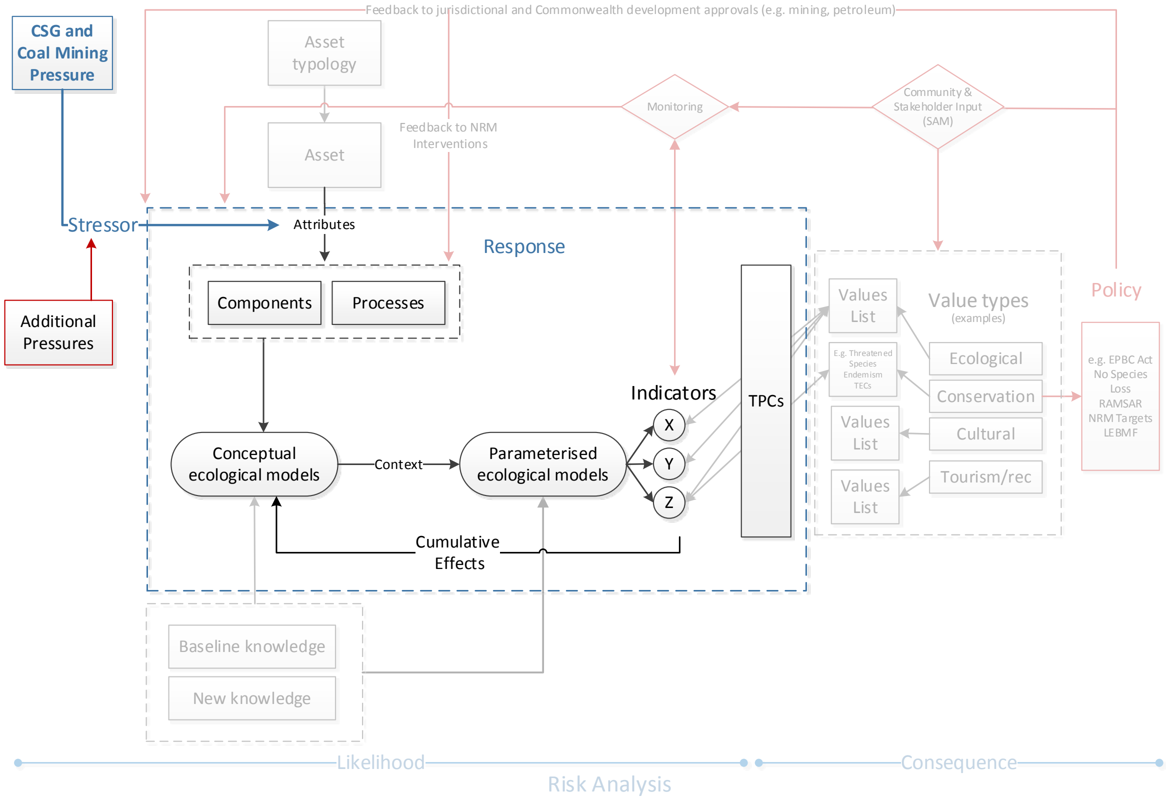

Figure 4. ISMF model highlighting pressure-stressor-response pathways including attributes, detailed ecological response modelling and development of indicators and thresholds

In general, natural resource management (NRM) involves a process of multi-stakeholder engagement to identify the community's goals with respect to the natural environment and planning how these goals are to be achieved. A key step for NRM is identification of processes that threaten native biota and ecosystems, and then developing and implementing the policies, plans and on-ground interventions to manage the impacts of those threats consistent with the agreed goals for the natural environment.

With respect to aquatic environments, jurisdictions have developed methodologies for identifying and prioritising threats as part of a broader risk assessment strategy. Examples of established frameworks include AVIRA in Victoria (Peters 2009) and Pressure-Stressor-Response (PSR - previously Pressure-Vector-Response) in Queensland (Marshall et al 2006), the latter being applied for the Qld LEB under the SEAP program (Clifford et al. 2010). The PSR method considers human values as an element informing a risk based approach to prioritisation of assets and management responses (Clifford et al. 2010, McNeil et al 2011b). It is therefore proposed that it is extended and adapted to the South Australian and Northern Territory portions of the Basin to:

- Facilitate basin-wide consistency with respect to environmental risk assessment
- Link to societal goals with respect to protecting or enhancing environmental values consistent with the directions of jurisdictional NRM arrangements
- Account for the specific pressures presented by the Coal Seam Gas and coal mining industry to facilitate the goals of LEBRM and the overarching BA process.

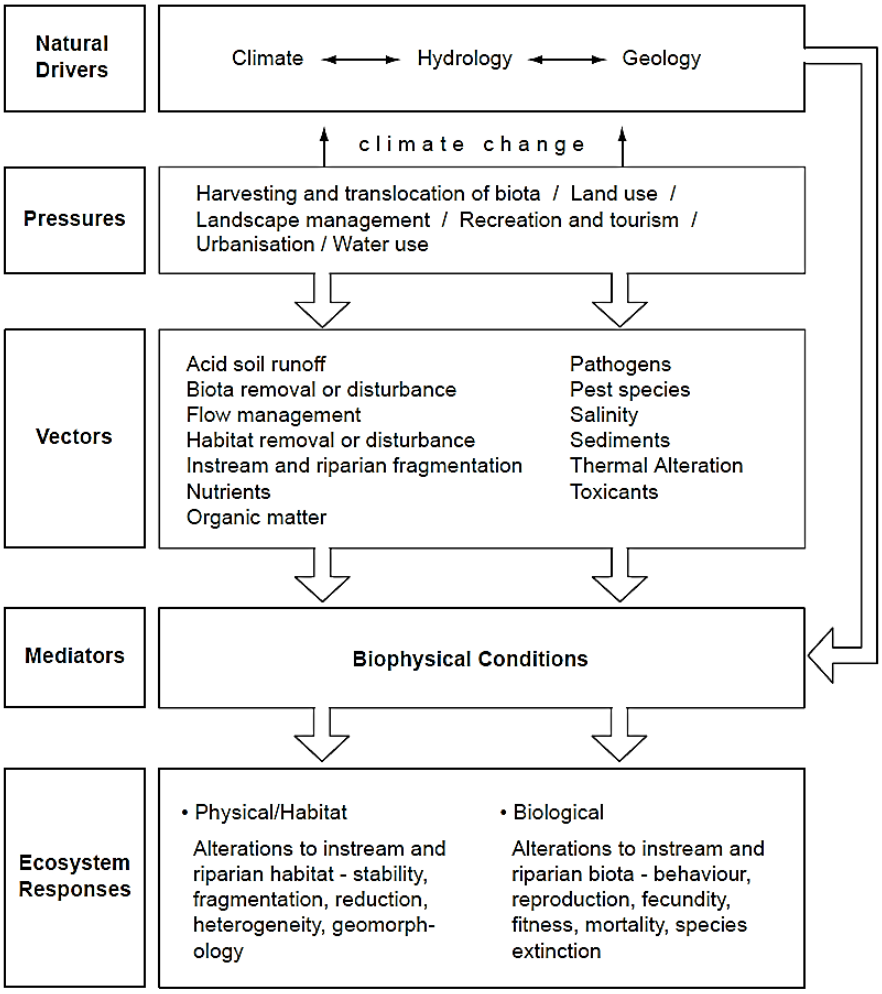

Figure 5. Pressure-Vector-(Stressor)-Response framework showing the impacts of human activities on biophysical drivers, leading to ecological response. Reproduced from Marshall et al. (2006).

The Pressure-Stressor-Response framework illustrated in Figure 5 differentiates:

- Pressures that human activities place on environmental systems
- Stressors (or vectors) through which human pressures directly impact on environmental systems and biota
- Responses, which describes the way ecosystems are impacted, in turn, by the stressor.

The PSR framework can model the impacts of both human development and natural disturbances such as climatic variability. This flexibility is a key feature of the PSR framework as it means it can be applied across a wide range of NRM issue. It is proposed this makes it a particularly useful approach in the Strategic Adaptive Management context.

Previous applications of PSR have generally involved a qualitative modelling approach driven by expert elicitation (e.g. Clifford et al 2010) as opposed to numerical models. It is proposed that for the purposes of the ISMF the analysis underpinning the PSR framework should be fit for purpose, and may incorporate both qualitative and quantitative models as required (Figure 4).

Conceptual Pressure-Stressor response models focussing on the key pressures associated with the CSG and large coal mining industries have been developed for each of the ecosystem asset types identified under the LEBRM project (Imgraben and McNeil, 2015). Whilst these models can identify the types of ecosystems, and the ecological attributes of those systems that may be impacted, detailed ecological response models are still required to provide scientifically accurate and detailed information about how systems might respond to stressors, particularly in aquatic ecosystems where interactive processes make clearly defined ecological responses hard to generalise.

2.3. Asset-based approach for identifying, classifying and attributing aquatic ecosystems

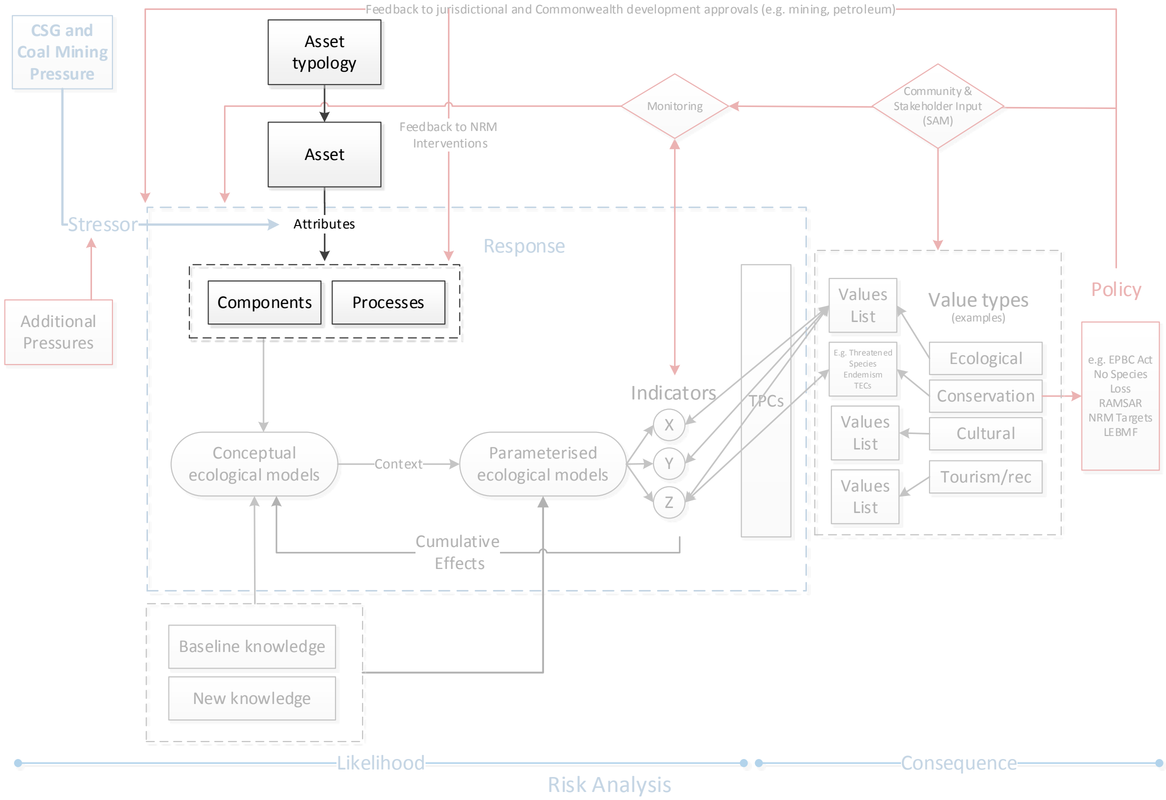

Figure 6. ISMF model highlighting asset typology, assets and attributes

The framework presents an asset-based approach, whereby discrete aquatic ecosystem assets are defined spatially (a unique location and extent). Imgraben and McNeil (2015) defines ecological assets as discrete, aquatic ecosystems, or functional ecological units (e.g. water holes, GAB springs) that possess unique suites of hydro-ecological attributes (components and processes) (Figure 6). This definition is targeted towards identifying pragmatic, manageable units, and is somewhat more prescriptive than broader water asset definition of the BA methodology, under which assets may include water resource systems such as bore fields, or even biological ecosystem components (e.g. an EPBC-listed fish species).

Under the LEBRM asset definition, biological components and processes are defined as attributes of the physical aquatic asset. This asset definition and approach includes:

- Definition of discrete, spatially-referenced units appropriate for assessment and management purposes across a range of scales
- Identification of spatial relationships between types of assets, data, information and models to ensure that individual assessments account for an appropriate landscape or regional context.

The asset approach enables discrete components and processes, ecological response models, indicators and values to be captured discretely for each asset at a scale that can be easily measured or monitored. It also provides a familiar and intuitive spatial interface for accessing and recording ecological and management information. This will improve our understanding of the specific characteristics of a site and the nature of responses to potential impacts at that site.

2.4. Classification of ecological asset types

The framework incorporates an asset typology to allow generalisation of information and models across different types of ecological assets with common ecological components and processes.

The LEBRM project aims to characterise assets at a discrete ecological habitat site (or meso-habitat after Walker et al. 1995) scale, and to develop a LEB Aquatic Ecosystems Typology in which all identified assets can be appointed. These types are being defined in consultation with scientific experts and linked closely to the development of conceptual and parameterised ecological models. Broad consultation is essential to establishing meaningful and generalisable asset types that are recognised across jurisdictions and environmental disciplines. In particular, distinction of individual assets versus networks or mosaics is important in the LEB context. For example, the connectivity among waterholes filled for different periods could be as crucial as the individual waterholes themselves as the landscape context can be a fundamental element of the ecology of these systems.

At the time of writing, draft LEB aquatic ecosystems types included:

- Waterholes
- In-channel habitats (watercourses)
- Connected basin systems
    - Lakes
    - Terminal lakes
    - Swamps
- Farm dams
- Isolated basin systems
    - Saline lakes
    - Clay pans

The asset typology is published separately in Imgraben and McNeil (2015). It is anticipated that sub-types will be developed to more accurately define the wide range of habitats in the LEB, but these will need to be nested within the agreed, broader asset types. This approach facilitates efficient and consistent assessments by allowing key context and risk criteria to be shared between assets of a similar type. It also enables assessments for assets where there are few site-specific data.

To support risk analysis at the asset scale, the classification system would provide an index for relevant conceptual and/or numerical model templates for assets deemed to be within the zone of influence of a development. In addition to supporting detailed assessments, the classification system will provide for reporting of generic vulnerabilities of assets which could, for example, inform approval processes of the overall profile of risk that would need to be addressed by a proposed development. The ISMF guides and directs the collation of information, model development and assessments for both assets and overarching asset types.

Assessments for networks of connected assets may require individual models to be created for each network to define the interactions across assets within those networks. The LEBRM approach, however, will focus on site-scale asset and asset typologies rather than complex networks of assets. These networks and their interactions will be addressed either through BAs or by mining proponents as part of the approvals process requirements to analyse specific vulnerability. To provide guidance to the spatial and temporal interactions across asset types, however, conceptual models will be developed to describe the relative connectedness and isolation of asset types under different hydro-climatic phases (e.g. boom *versus* bust periods).

It is intended that the asset and asset type lists will be dynamic, allowing new assets and new asset types (such as assets or asset types not present in the LEB or newly-defined sub-types that sit within an existing class) to be entered at any time. New types need to be attributed with component and process lists, conceptual, ecological and PSR models, indicators, TPCs and values, consistent with those developed within the LEBRM Framework.

2.5. Attributes, Components and Processes

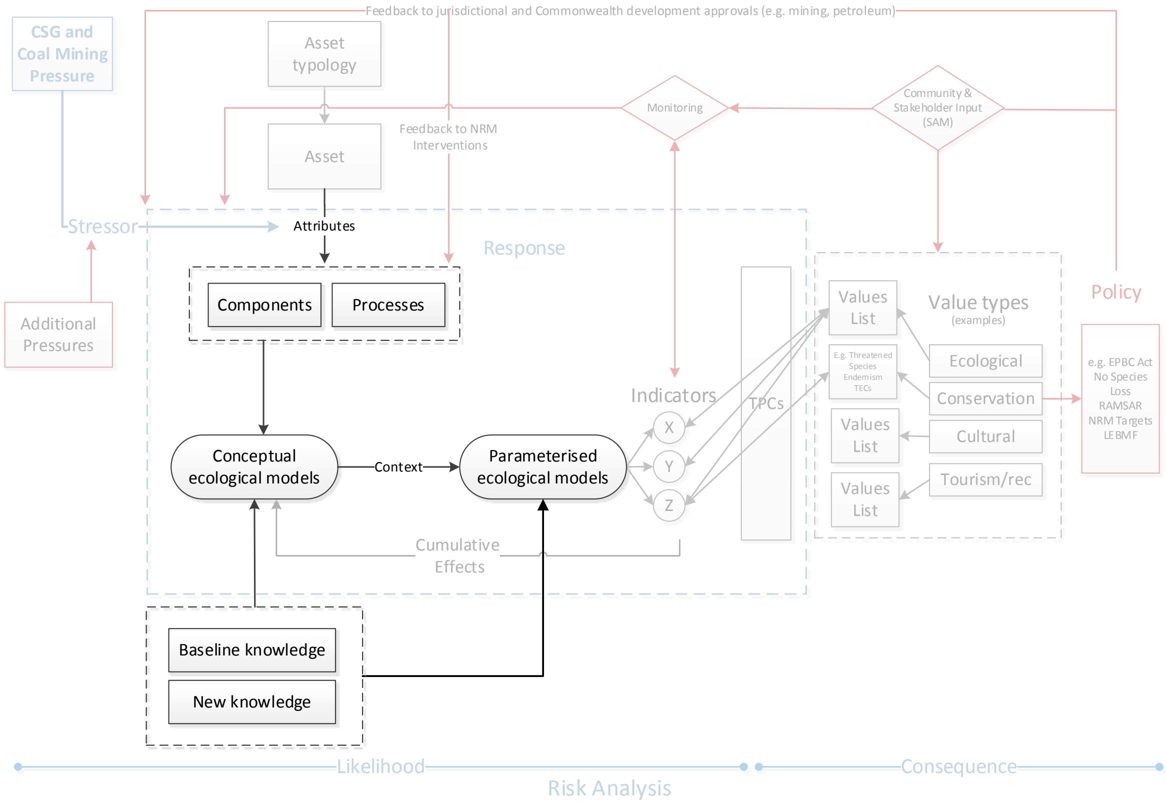

Figure 7. ISMF model highlighting attributes, conceptual models, response models and knowledge

The attributes of a given asset (or asset type) provide a direct link to the *response* component of the PSR framework and provide the ecological detail that link potential impacts to human values (Figure 7). Whilst PSR models serve to capture the impacts and responses, attribution of the asset can provide the scientific detail that can help verify or inform the expert opinion or conceptual model basis upon which PSR models are frequently constructed. It is important to note that the framework does not suggest that detailed ecological models be developed before a PSR model can be developed; rather, the opportunity to collect detailed scientific knowledge about each ecosystem or type will enhance the utility of PSR models and improve the confidence of risk assessments.

Understanding the attributes that characterise individual assets or asset types is critical for understanding how aquatic ecosystems might respond to impacts, and critical also for understanding the values attached to an asset or asset type.

In accordance with the Ramsar framework (DSE 2005), attributes fall into the following broad categories:

- Components are physical descriptors relevant to the asset, such as depth, riparian structure, substrates, water quality and biota
- Processes define the interactions between components of the asset as a functional unit that give rise to benefits valued by people
- Services (or ecosystem services) are the benefits that people obtain from assets or asset types. These are often thought of as values, and will be dealt with through the vulnerability and risk assessment component of the framework, rather than attributes.

Furthermore, asset *receptors* (measureable, responsive components of ecosystem assets; Barrett et al., 2013) can be identified from among the components and processes representing a given asset type. Within the framework, receptors may be identified at two points:

- Stressors, or attributes, used to represent the hydrological impact on an asset caused by CSG or coal mining activity or other pressures

- Ecological responses, which include indicators of impacts on an asset, linked in some way to asset values.

It is anticipated that identification of stressors and receptors for an asset type will be based on an understanding of components, processes, potential development pressures and the values likely to be placed on that asset type by the community. Examples of processes to be considered include cycling of nutrients, transfers of energy and, at a community level, rates of recruitment or dispersal.

According to the BRAM, receptors may be defined for multiple points in the causal chain linking CSG and coal mining developments to asset-scale impacts represented by conceptual or numerical response models (Barrett et al., 2013). Receptors may equally be the hydrological drivers of ecosystem response (*stressor*) or may be changed ecological processes that are consequences of an ecological response (*response*). Attributes representing *stressors* for a given asset type will form the inputs or independent variables of conceptual or numerical response models defined for that type. Similarly, attributes representing asset *responses* will likely form outputs or dependent variables of models.

Attributes will be linked to key constants or parameters in a response model to represent the state of key ecological components or processes, providing asset-specific context. Given this generic model configuration, it is anticipated that receptors indicating impact may be linked to stressor or response attributes – that is, the inputs or outputs of response models.

The BRAM acknowledges the need to identify receptors relevant at the stressor and ecological response levels. Stressor receptors relate to factors driving response which are most likely to be addressed through preventative management measures. Ecological response receptors link strongly to values and are the point at which ecological context and scientific knowledge about impacts can be captured to provide certainty and confidence to support risk assessment.

Risk analysis considers an understanding of the attributes and their vulnerability to change, which may be formalised through conceptual or numerical models. Similarly risk evaluation criteria may be linked to attributes indicating ecological response to pressures and stressors. Ideally, these indicators will inform on the severity of consequences in terms of degraded values that are relevant to community objectives with respect to the asset or asset class.

Whilst the components and processes present at each individual asset may vary, asset types are defined largely by similarities in physical and hydro-geomorphic structure and function, and asset types therefore will group assets with similar components and processes. For example, an individual wetland asset may or may not possess aquatic macrophytes, but macrophytes as a generalised asset type might confidently be included in a list of wetland components. By collating attribute lists outlining components and processes under each asset type, conceptual models and representative ecological response models can be developed to represent assets that fall within each type.

Once individual assets are considered, the components and processes present should be represented within the asset type components and process lists. Ideally, asset types, component and process lists categorised under the LEBRM project should form a comprehensive ecosystem knowledge base that can be made available to other ecological or management projects in the LEB (e.g. LEBRA, State of the Environment reporting).

The clear identification of asset attributes (components and processes) is central to the LEBRM ISMF, and provides the units of ecological response that inform conceptual and empirical model development, PSR models and the assessment of risk. Importantly, asset component and process lists will contain the indicators that can be measured to inform modelling and monitoring of ecological response. It is from these lists that measurable receptors could be identified to inform the BA methodology. It is also important to note that the values associated with assets and asset types (discussed below) will be based on component and process attributes.

Table 1 shows an example of the attribute list structure including definitions and a worked example using a native fish attribute.

It should be noted that information captured in attribute tables are nested under each of the components and processes for a particular asset and therefore the information in the table will expand significantly for columns towards the right hand side of the tables. For example a single component will support a number of processes, each with a number of models, indicators and TPCs. As a legacy output, attribute tables should be updated and maintained continually to capture, protect and utilise the continually expanding information base that they represent.

This step requires detailed scientific knowledge of how the components and processes that characterise assets are linked ecologically, to determine what responses might be anticipated given the suite of interconnecting ecological factors through which aquatic ecosystems function. It is therefore in the realm of ecological function and response that detailed knowledge and understanding of the hydro-ecology of aquatic assets is integrated into the framework. The LEBRM project is addressing this through identification and collation of baseline knowledge, literature and datasets relevant to the hydro-ecology and management of LEB (Miles and McNeil, 2015). Conceptual modelling frameworks can be utilised at this point to represent the nature and function of various assets and asset types.

2.6. Conceptual models

The development of conceptual models is a significant component of the BA methodology (Barrett et al., 2013) and it is anticipated that clear, comprehensive and detailed conceptual model outputs consistent with this framework of the LEBRM project will be valuable to the LEB Bioregional Assessment programme.

Conceptual models in this context are defined as qualitative, non-mathematical representations of how an ecosystem works. They represent working hypotheses about system form and function that document key assumptions (Wilkinson et al. 2007). They may be presented in many forms such as diagrams, tables and flow charges, and may have accompanying narratives or contextual information (Hierl et al. 2007). Where necessary, they may be used as the basis of more realistic mathematical representations such as analytic or simulation models that are parameterised and validated through use of data.

Conceptual models have great value as communication tools to facilitate stakeholder understanding of what makes up an asset, how that asset works and how its components and processes might change under different conditions. It is intended they be used to identify potential indicators or *receptors* of change, which in turn provides direction for monitoring. Conceptual models should be continually questioned and, where necessary, updated as new information and knowledge is developed. They should provide a key interface to an iterative, long-term repository for knowledge and management tools.

The establishment of generalised Attribute lists for each of the asset types will facilitate development of qualitative conceptual models representing the often complex interactions between components and processes that drive ecosystem function. A detailed report has been developed to outline the LEBRM Conceptual Modelling Framework (see Imgraben and McNeil, 2015).

Table 1. Attribute table outlining structure, with example for native fishes (a component) in the Neales River

Attribute classes	Component	Sub-component	Processes	Critical process statements	Information, modelling and criteria	Indicator rules	Thresholds of potential concern
The features and physical characteristics of an asset: - **Hydrology** - **Aquatic biota** - **Terrestrial biota** - **Physical habitat and geomorphology** - **Water quality**	What are the physical components that make up each attribute?	Are components logically sub-divided, e.g. fish are a component whilst individual species or guilds are also important scales at which fish should be considered.	Processes that occur between organisms and within and between populations and communities, including interactions with the environment, that maintain ecosystem assets over time	The aspects of processes that need to be maintained to support the components and sub-components	What information is available and what are the modelling and data frameworks within which indicator rules can be made for each component/process?	Utilising the context set by modelling and criteria for an asset or asset type, what statements can be made about measureable ecosystem indicators?	What are clear, potentially data driven thresholds that can be identified in support of the indicator rules? TPCs should represent tipping points beyond which ecosystem function resilience or viability are threatened in response to disturbance.
Example: Aquatic biota	Native fishes	Golden perch Barcoo grunter Welch's grunter Spangled perch Barred grunter Bony herring Silver tandan Hyrtl's tandan Desert goby Desert rainbowfish Lake Eyre hardyhead	For each species:- - Spawning - Recruitment - Recolonisation potential - Trophic interactions - Competition - Refuge use - Tolerance (resistance) to disturbance - Maintaining resilience	For each process - e.g. for Refuge use: - Persistence of permanent Ark refugia, to be protected - Persistence of non-permanent Disco refuges protected during recovery periods to support resilience building - with only localised losses during wet phases - Permanent saline Polo Club refugia protected during dry phase	- Refuge typology (after Robson et al. 2008). - Species Trait Models (e.g. Pusey et al. 2004, -McNeil et al. 2011a). - Salinity tolerance models (McNeil et al. 2011a). - Neales River Refuge Model (McNeil 2011a). - LEB Fish Trajectory Model (Humphries et al. 2007, McNeil et al. 2008, Balcombe and McNeil 2008, Balcombe & Kerezsy 2009,). - Expert opinion.	- All catchment species must be present within Ark and Polo Club refugia during dry phase - Salinity level in Polo Club refugia maintained for tolerant species only during dry phase - Populations of saline tolerant species maintained across catchments during resilience and wet phase - Natural maximum cease to flow requirements protected for Ark refugia	- All Neales River species present within Algebuckina waterhole during Bust, Recovery and Collapse phases. - Cease to flow period of X at Algebuckina waterhole not exceeded. - All species present within at least one refuge waterhole during dry phase. - Abundances of barred grunter in Ark refugia maintained within recorded ranges during dry phase.

2.7. Ecological Response-Indicators/Receptors and Thresholds of Potential Concern

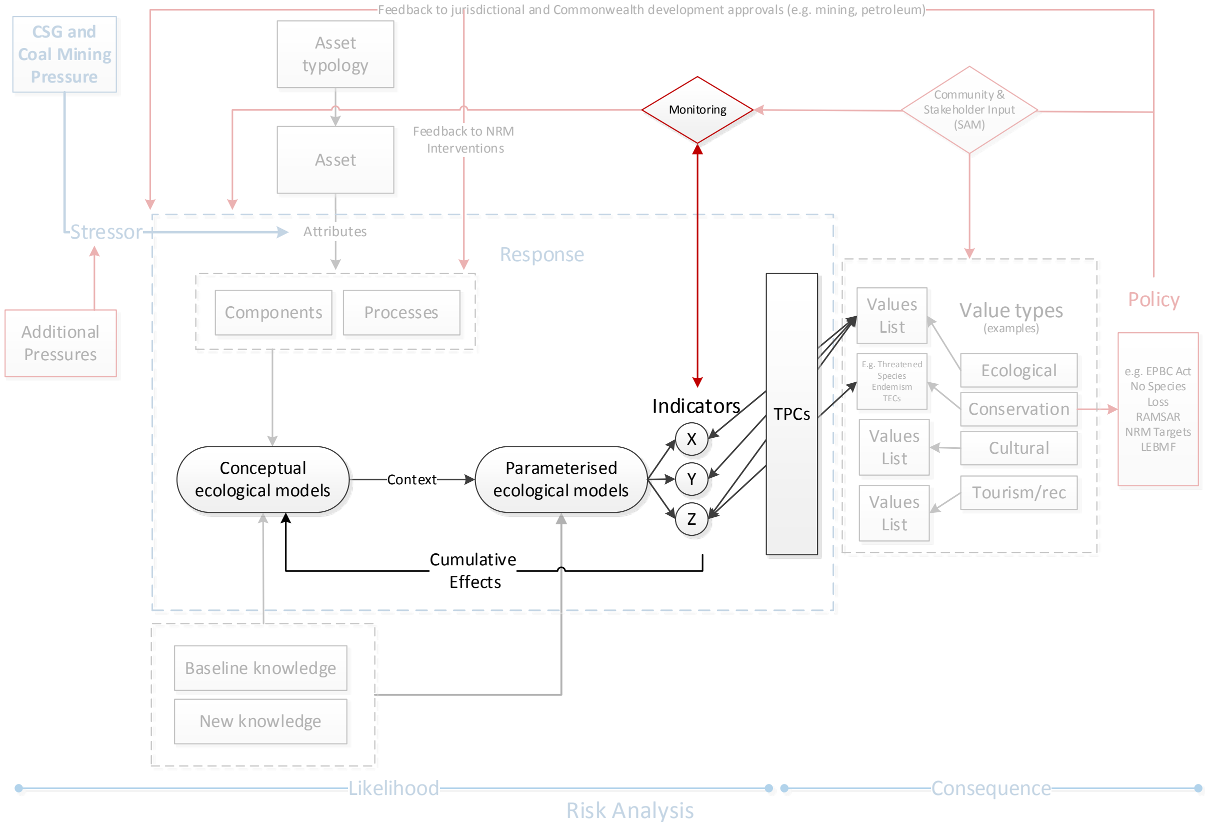

Figure 8. ISMF model highlighting response models, indicators, TPCs and monitoring

Measurable indicator rules and/or TPCs are a key element facilitating SAM (Kingsford and Biggs, 2012) (see example in Table 1). TPCs are criteria for determining the point at which a stressor causes the ecological functions of an asset to be altered such that there is a high likelihood that environmental value is lost. TPCs can inform risk management decisions affecting NRM (planning, project delivery, monitoring etc.), development proposals (process design, environmental assessments, etc.), development approvals and knowledge projects. Indicator rules, which represent the low risk conditions, are more general in nature and may be used in place of TPCs for situations where a higher level of uncertainty is acceptable.

In the context of the ISMF, ecological response models are a key mechanism by which TCPs and indicator rules are identified and configured (Figure 8). Development of ecological response models involves the following steps:

- Identification and characterisation of the ecological functions of the ecosystem (e.g. how do the components and processes interact ecologically?) (*model development*)
- Rendering the ecosystem response to scenarios (pressures and stressors) according to relevant indicators (*model runtime*)
- Determination of indicator rules and/or thresholds of potential concern informing the low and high risk states regarding ecosystem integrity and function (*analysis of model outputs*).

Scoping and development of ecological response models is dependent on the other elements of the ISMF. Assuming the elements of the ISMF are operationalized in a knowledge management system, the asset typology indexes relevant components, processes and conceptual response models for a specific asset. Similarly, the objectives of policy, planning and legislation and relevant community and stakeholder input provide the goal function in terms of values to be protected. Together this informs both the scope of response model development (i.e. dependent and independent variables, response functions etc.) and the level of scientific certainty that is fit for purpose.

A requirement for ecological response model development in the context of the ISMF is it should incorporate some mechanism for quantifying the uncertainty underpinning the model outputs. This allows for a transparent analysis of risk that considers uncertainty alongside other factors in accordance with AS/NZS ISO 31000:2009 risk management standard and the BRAM. This requirement may favour the use of probabilistic over deterministic modelling approaches

The level of model realism required is context specific. It may depend on multiple factors including:

- The scope and importance of asset values at risk
- The community's attitude to risk with respect to these values (as determined from policy drivers and relevant community engagement)
- The types of development pressures and stressors
- The economic and social values of developments that potentially represent environmental pressures
- The types of environmental risk management decision the response model is intended to inform.

Consideration of these factors allows determination of the costs versus benefits of improved model realism. In general it can be anticipated that greater model realism will be justifiable in situations where the risks and benefits from development are high.

Through the LEBRM project, PSR models have been developed for all asset types based on all of the information (and models) in the attribute tables. The attribute tables link assets or asset types through their ecosystem attributes and relevant models to key response indicators and clearly-stated TPCs. As such, they are able to support a wide range of activities under the BA and mining approvals process, especially the development of PSR models and risk analysis to determine the vulnerability of assets to water related mining impacts. To provide optimal support to the risk analysis process, however, the indicators and thresholds from the attribute tables must be linked to some level of consequence. They must, therefore, be linked to the values and services associated with each asset or asset type.

2.8. Values and Value Classes

The determination of values is necessary for linking assets with the concerns and cares of communities, stakeholders, management agencies and governments. Values represent the reasons why the community cares about any given asset or asset type. They can be aligned to individual attributes of a specific asset or more generically to an asset type. There may also be value in the sum or accumulation of all the individual values apparent at a site-specific scale. It is important that assessments of values apply both at scales of individual assets and for asset types. A transparent approach to establishing asset value is a key requirement for risk analysis, particularly with respect to determination of the consequence component of risk.

The range of values for aquatic assets may be inconsistent and diverse in nature. Recent programs have attempted to capture the values around water resources in the LEB (MacDonald et al. 2012), and have developed a set of value classes to accommodate values having similar characteristics (Table 2). The ISMF utilises these value classes as a mechanism for collating and organising a broader collection of individual values, beneath which a range of ecological indicators can be identified (Figure 9).

Prioritising or ranking values can be achieved via input from stakeholders and community groups (McNeil et al. 2011b). The LEBRM project, with LEBRA and the Goyder Institute, aims to build and rank lists of values for water-dependent assets in the LEB by undertaking stakeholder and community consultation. Highly-ranked values will be linked to value indicators, supporting risk analyses within the LEBRM project and, potentially, the LEB Bioregional Assessment.

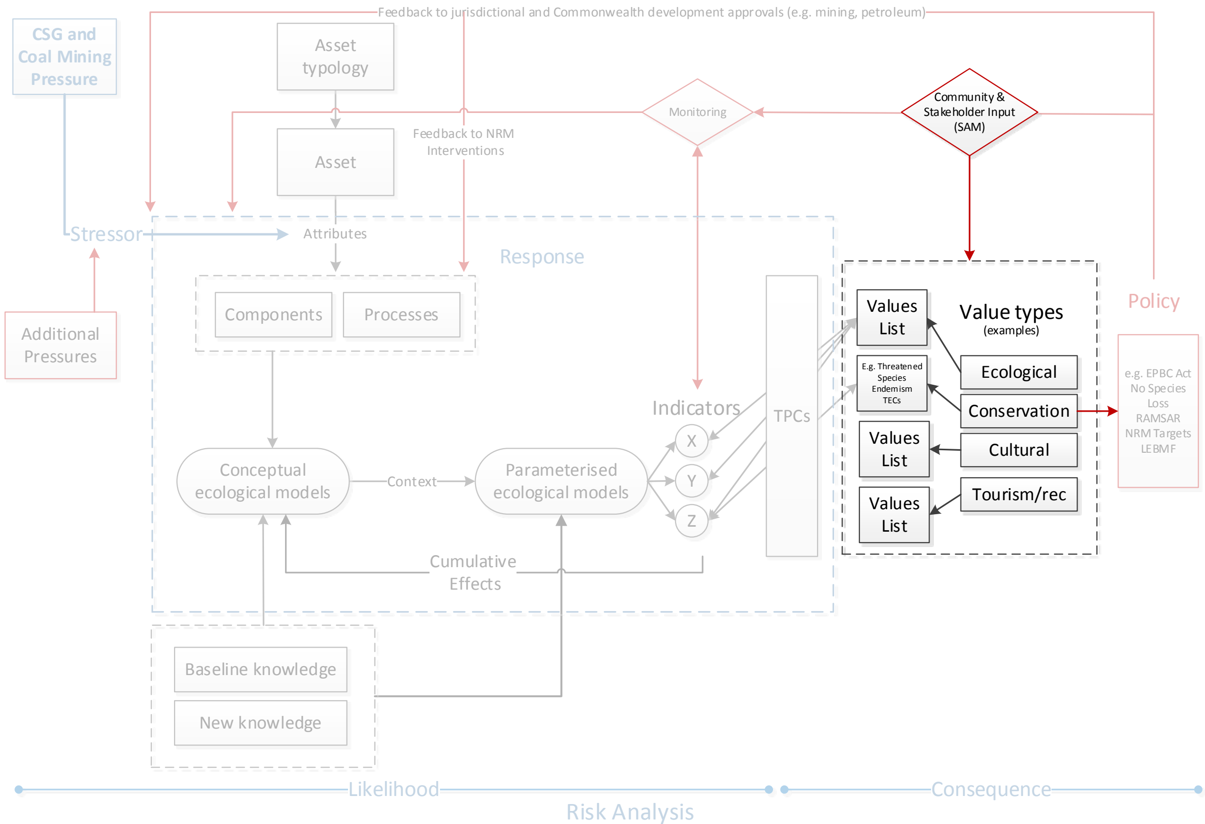

Figure 9. ISMF model highlighting the requirement for capturing community and stakeholder values to drive policy and management response linking to science

Table 2. Values and sub-value classes identified by Macdonald and McNeil (2012)

VALUE	SUB VALUES	VALUE	SUB VALUES
Aesthetic	Artistic	**Ecosystem**	Physical
	Personal		Biological
	Intangible		Ecological
Amenity/Consumptive			Conservation
Cultural	Historic	**Recreational**	Tourism
	Heritage		Local use
	Social	**Educational**	
	Spiritual	**Knowledge**	
Economic	Agriculture	**Legal**	
	Mining	**Ownership**	
	Commercial fishing	**Recreational**	Tourism
	Science		Local use
	Tourism	**Political**	

Figure 10 shows how policy links with management and science. Policy in the context of the ISMF describes any principles adopted to guide decisions contributing to the outcomes of stakeholder and community objectives in the LEB. Policy drivers exist at multiple levels including:

- Legislation affecting the environmental management or management of environmental risks in the LEB
- NRM plans and policy created under legislation; such as the SAAL NRM regional plan or water allocation planning
- Principles within NRM plans such as those governing water affecting activity permits or water allocations
- Programs and strategies, such as No Species Loss – a nature conservation strategy for South Australia 2007-17 and threatened species recover plans.

Policy provides the mechanism by which stakeholder objectives for LEB assets are achieved. Figure 10 illustrates this connection with the red arrows indicating feedback to management approvals (e.g. for proposed developments such as CSG and large coal mining, or for water allocations or water affecting activity permits) and feedback to NRM interventions such as those programs and projects concerned with protecting and enhancing environmental values.

Under the SAM model, policy development involves multi-stakeholder engagement to:

- Identify community values with regards to environmental assets
- Determine environmental objectives
- Map out pathways to achieve objectives in the context of potentially conflicting social and economic goals.

A key feature of the ISMF is that policy development is informed by science, and more specifically by knowledge of how environmental values can be impacted under anthropogenic and natural pressures and stressors. This function is represented in Figure 10 by the connection of policy with the process for determination of values, which in turn informs the development of TPCs.

Figure 10 shows that policy is also a driver for the management of existing knowledge and development of new knowledge critical to support science-based management of environmental values. In the LEB, the LEBRM and Goyder Institute LEB projects are examples of how existing knowledge can be enhanced and utilised, and new scientific knowledge projects developed in response to identified policy needs.

Finally, Figure 10 illustrates community engagement and participation in monitoring, evaluation, reporting and improvement processes to enhance accountability of policy for achieving outcomes consistent with stakeholders and community values and objectives.

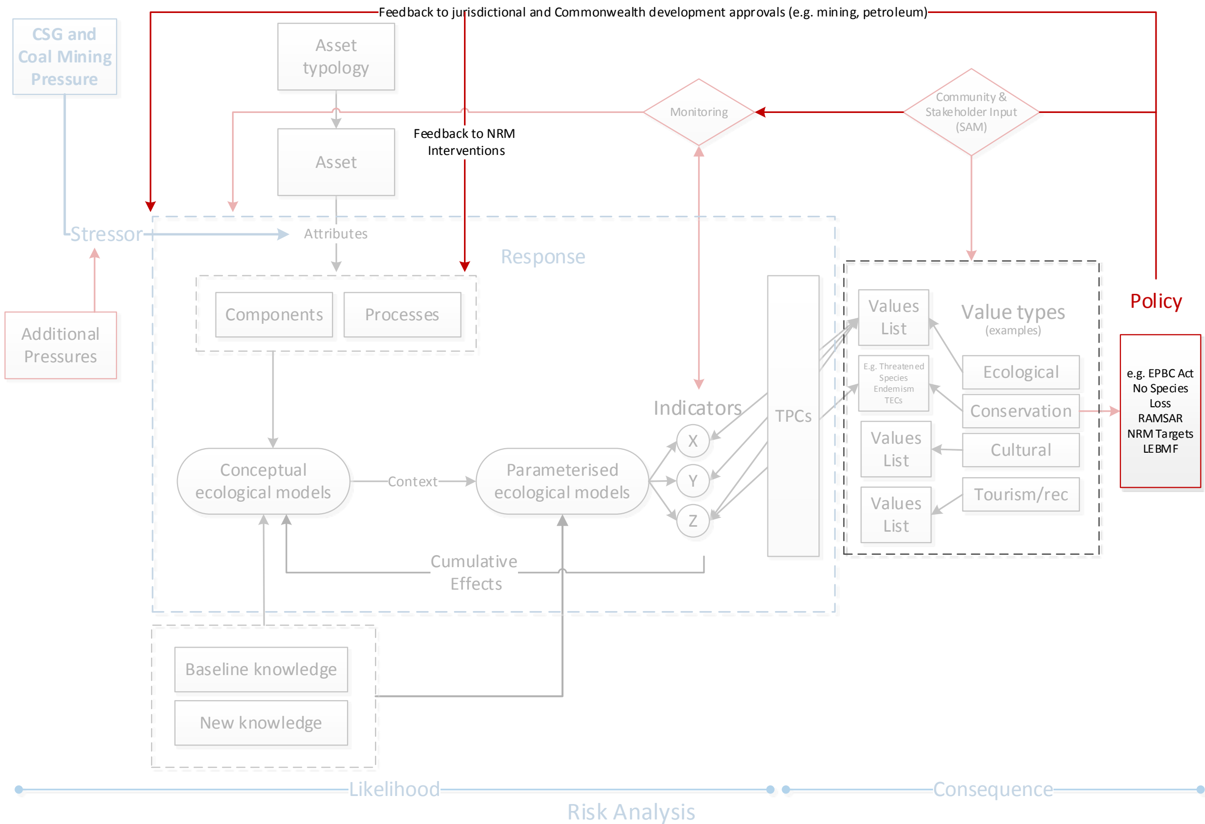

Figure 10. ISMF model highlighting policy drivers and management responses

3. Application of the framework to support risk management

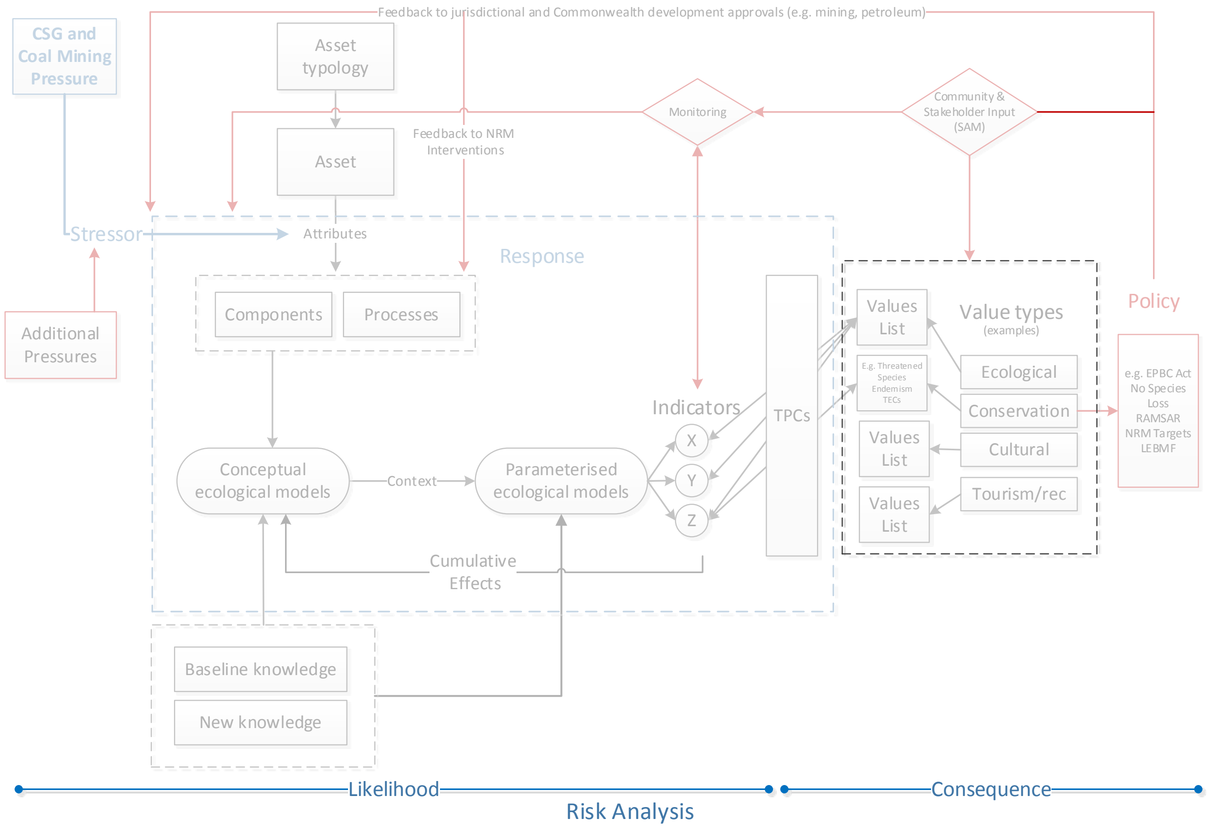

Figure 11. ISMF model highlighting risk analysis concepts

Jurisdictions are moving towards risk-based management of water resources based on the AS/NZS ISO 31000:2009 risk management guidelines in accordance with the directions of the *Intergovernmental Agreement on a National Water Initiative 2004* (the NWI). For example, in South Australia the Risk Management Framework for Water Planning and Management (DEWNR 2012) addresses risks to natural resources, risks to community values dependent on those resources and risks to the effective operation of management actions. Risk assessments in this context aim to facilitate informed decision-making for sustainable outcomes contributing to improved efficiency and effectiveness of water planning and management activities. They also provide for transparency of regulatory processes which, in turn, promotes resource development outcomes likely to be acceptable to stakeholders and the community.

This section summarises the key elements of the AS/NZS ISO 31000:2009 risk management guidelines (Joint Technical Committee OB-007, 2009). It describes how the components of the ISMF have been structured to support risk analyses that are informed by baseline scientific knowledge. It also proposes an approach intended to prioritise knowledge gaps that impede effective management of risks associated with CSG and coal mining developments.

3.1. AS/NZS ISO 31000:2009 Risk Management Guidelines

According to the AS/NZS ISO 31000:2009 Risk Management Guidelines, *risk* is the effect of uncertainty on *objectives*, where objectives may have different aspects (e.g. environmental, economic, community) and can apply at different levels (e.g. inter-jurisdictional, organisational or project/process level). This definition could refer to unexpected events that are positive as well as negative.

"Risk management" describes coordinated activities intended to direct and control an organisation with regards to risk. Figure 12 shows the principles, framework and process for risk management as described by AS/NZS ISO 31000:2009. The diagram shows that, at the highest level, risk management should be governed by a set of principles that describe the desired goals and features of the risk management process for any given context.

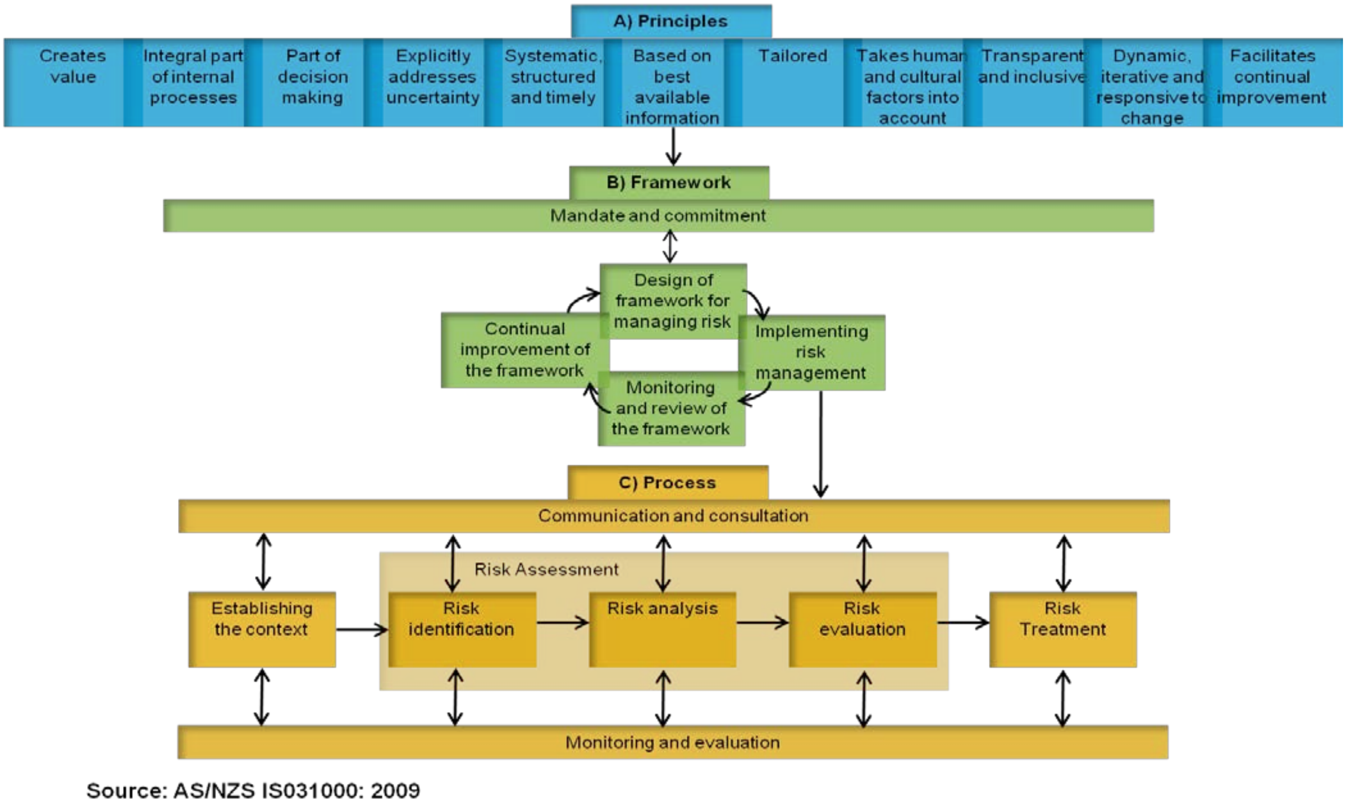

Figure 12. AS/NZS ISO 31000:2009 risk management - principles, framework and process

At the next level, the risk management framework sets up the components to provide for the organisational elements of the risk management process. Figure 12 shows that the framework should be consistent with the overarching principles, be subject to continuous monitoring, review and improvement and have the appropriate mandate and commitment within an organisation.

Finally, the risk management process established by the framework should be guided at every step by communication and consultation and monitoring and evaluation. This process has three components:

- Establishing context, including;
  - Articulating objectives and setting scope for risk management activities
  - Identifying stakeholders
  - Identifying parameters that affect risk
  - Determining risk criteria
- Risk assessment, in three steps:
  - Identification and description of risks
  - Analysis to comprehend the nature of risk and to determine risk level

    - Risk evaluation, whereby the results of risk analysis are compared with risk criteria to determine acceptability or tolerability
- Risk treatment, a process to modify intolerable risks to become tolerable or acceptable; for example:
    - Avoiding risk
    - Increasing risk to pursue opportunity
    - Removal of risk source
    - Modify likelihood through preventative or preparatory controls
    - Modify consequence through response or recovery controls
    - Sharing risk with other parties
    - Retaining risk through informed decision.

Initial risk analysis is undertaken using a likelihood and consequence matrix that combines qualitative or semi-quantitative ratings of consequence with probability to arrive at a risk level or rating. Depending on the context, more sophisticated approaches may be used.

The BRAM (Barrett et al, 2013) specifically focusses on the risk identification and risk analysis stages of the AS/NZS ISO 31000:2009 risk management process outlined in Figure 12. Thus it specifically focusses on determination of risk level in terms of the likelihood and consequences of events, and excludes evaluation of the tolerability or acceptability of risks or consideration of potential risk treatments.

3.2. Risk management in the context of the ISMF

In adopting AS/NZS ISO 31000:2009, it is intended that the ISMF will complement risk frameworks endorsed by regulatory agencies at state and national levels including the BRAM. It is anticipated that having a common standard will encourage cooperation and sharing of information between stakeholders across jurisdictional boundaries and between the public and private sector. In doing so, the risk management approach should contribute to more defensible and transparent development processes that engender stakeholder and public confidence.

A key outcome will be a mechanism for focussing and targeting science and data collection on the tasks that address those data and knowledge gaps likely to affect decisions made on CSG or coal mining developments. It is anticipated the risk framework will ensure development approval decisions are informed by baseline knowledge, and provide an indicator for the marginal utility of additional data collection in the context of water resources risk management in the LEB.

The ISMF describes a number of concepts and components that, working together, will likely facilitate risk analyses in accordance with AS/NZS ISO 31000:2009. A key element of the ISMF is the PSR model of environmental impact as a means to characterise environmental impacts of CSG and coal mining. The PSR model is an intuitive template for scoping the identification and description of risks, because its components are analogous to key concepts in a risk analysis, as demonstrated in Table 3.

An understanding of the pressure, stressor and response elements for a given asset allows for systematic interrogation of relevant data, knowledge and models to reveal the likelihood and consequence components of a risk assessment. The ISMF facilitates this approach by providing for attribution of assets in a manner consistent with the overall risk management context for CSG and coal mining regulation, as:

- Attributes related to pressure and stressor components of the PSR model describe the mechanisms whereby CSG and coal mining developments impact on ecological assets
- Attributes related to the response components of the PSR model indicate the environmental benefits that humans derive (and value) from ecological assets.

Table 3. Relating Pressure-Stressor-Response framework to components of a risk statement

PSR model component	Bioregional Assessment context	Component of risk	Definition from AS/NZS ISO 31000
Pressure	CSG or coal mining activity	Risk source or hazard	Elements which alone or in combination have intrinsic potential to give rise to risk
Stressor	Hydrological change leading to impact on ecological function	Event	An occurrence or change in a particular set of circumstances
Response	Ecological change indicating loss of environmental, social or economic value	Consequence	Outcome of an event that affects objectives

Linkage of response indicators to values is an important aspect of the ISMF for risk analysis as it provides an interface between ecological functions and societal goals or objectives. This helps to ensure that the output of knowledge projects identify and assess risks in a manner that is consistent with the objectives of the overall risk management task. Similarly, a feature of Strategic Adaptive Management (Kingsford et al. 2012) is development of TPCs in consultation with stakeholders. For a risk-management task, the setting of TPCs may be appropriate in the context setting and risk treatment phases.

Another relevant feature of the ISMF is that it promotes an asset-based approach wherein assets are spatially delineated and linked to values. This provides an appropriate spatial scale for risk identification and analysis and a mechanism for relating assets to contextual data (e.g. temporal variability) and knowledge that may be important in the definition of risk criteria.

The framework establishes an asset typology that classifies assets according to the observed ecological components and processes. A key objective for the typology is the generalisation of knowledge regarding the dynamic behaviour of assets for a range of potential stressors. This feature is relevant for an overarching risk management framework as it promotes consistency and scientific rigour for assessments. It also allows for generalised assessments of risks for assets with very few site-specific data, and provides a scheme to highlight knowledge gaps of highest priority with respect to management decisions.

3.3. Risk evaluation and risk treatment – prioritising knowledge gaps

For the purposes of the ISMF, the risk assessment method should explicitly address the uncertainty regarding ecological responses to pressures and stressors. In this way, risk assessments can be transparent regarding how data and knowledge gaps are likely to affect decisions regarding CSG and coal development. This in turn facilitates determination of the costs versus benefits of improvements in model realism achieved through additional analysis or data collection. This section describes the general concepts of risk evaluation and suggests how evaluation criteria can prioritise the collection and collation of data and knowledge.

The risk evaluation step (see the *Process* element of Figure 12) involves comparing risk level with predefined risk criteria in order to determine the overall significance of a risk. While there are multiple approaches to classifying risk level, one widely adopted evaluation method considers the following risk categories of risk tolerability:

- Acceptable, meaning no treatment action is necessary
- Tolerable subject to being as low as reasonably practicable (ALARP), meaning that the risk is tolerable provided that the benefits in treating it are greatly outweighed by the costs of treatment
- Intolerable, meaning the risk is unacceptable and action must be taken to reduce the level of risk.

It is proposed that as a general principle, greater uncertainty regarding potential impacts and consequences should lead to a more precautionary approach in management. On this basis, further effort to address knowledge gaps should focus on risks where the outcomes of risk evaluation would likely be different if confidence in the analysis were increased.

Table 4 and Table 5 provide an example to show how this principle may be put into practice for a simple risk analysis. The tables present risk evaluation criteria based on likelihood and consequence given high and low confidence in analysis outcomes, respectively (see Table 6 for a key to the risk tolerability categories). According to these criteria the boundaries between the tolerability categories vary according to the level of confidence in the risk analysis. It can be inferred that, where confidence is low, risk tolerability (and decisions with respect to treatment priorities) may change should confidence in the risk analysis outcomes be increased.

Table 7 presents sample confidence criteria that provide a minimum standard for representing uncertainty in the context of a non-probabilistic analysis. In addition to addressing the reliability of data and knowledge contributing to a risk analysis, confidence criteria should consider the level of agreement by participants on the risk criteria and the ways that they are applied. This approach means that, where there is significant disagreement regarding the nature of risks among stakeholders, a more precautionary approach to management is indicated.

Table 4. Example risk evaluation criteria - high confidence in the analysis and underlying data

	Consequence level				
Likelihood level	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost certain					
Likely					
Possible					
Unlikely					
Rare					

Table 5. Example risk evaluation criteria - low confidence in the analysis and underlying data

	Consequence level				
Likelihood level	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost certain					
Likely					
Possible					
Unlikely					
Rare					

Table 6. Key for risk tolerability categories

	Intolerable
	Tolerable subject to being as low as reasonably practical (ALARP)
	Acceptable

Table 7. Example confidence criteria for risk analysis (after Australian Emergency Management Committee 2010)

Criteria	**Low confidence**	**Moderate confidence**	**High confidence**
Data/information	Not location specific; anecdotal evidence only; Not tested	Location specific (regional scale); validated historical or scientific evidence	Location specific (local scale); validated historical or scientific evidence based on hypothesis testing
Team knowledge	Neither risk source, risk assessment or location specific	Risk source or process and location specific	Risk source and process and location specific
Agreement	Neither on interpretations	On interpretations or risk levels	On interpretations and risk levels

	nor risk levels		

Figure 13 shows a risk evaluation approach proposed by Green and Wilson (in prep) where the risk analysis is based on a probabilistic ecological response model. In this case the analysis has produced a probability distribution of outcomes mapped against a set of consequence severity levels. Figure 13 shows both the matrix of risk evaluation criteria (bottom right) and the output of the analysis (top left). For the model output the y-axis corresponds to the consequence severity levels while the x-axis represents the likelihood of each of these outcomes. The lines connecting the bins of the probability distribution to the risk matrix show how each combination of likelihood and consequence represented by the distribution corresponds to a risk rating. To arrive at the final risk rating the highest risk level is reported, which in this example is the intermediate risk category.

Note that this approach accounts for the uncertainty in determination of potential consequence severity. According to these criteria, complete uncertainty regarding a risk pathway may be represented as an equal chance (i.e. 20%) for all consequence severity levels. In this case it is anticipated that at least the intermediate risk category would be returned by the risk evaluation.

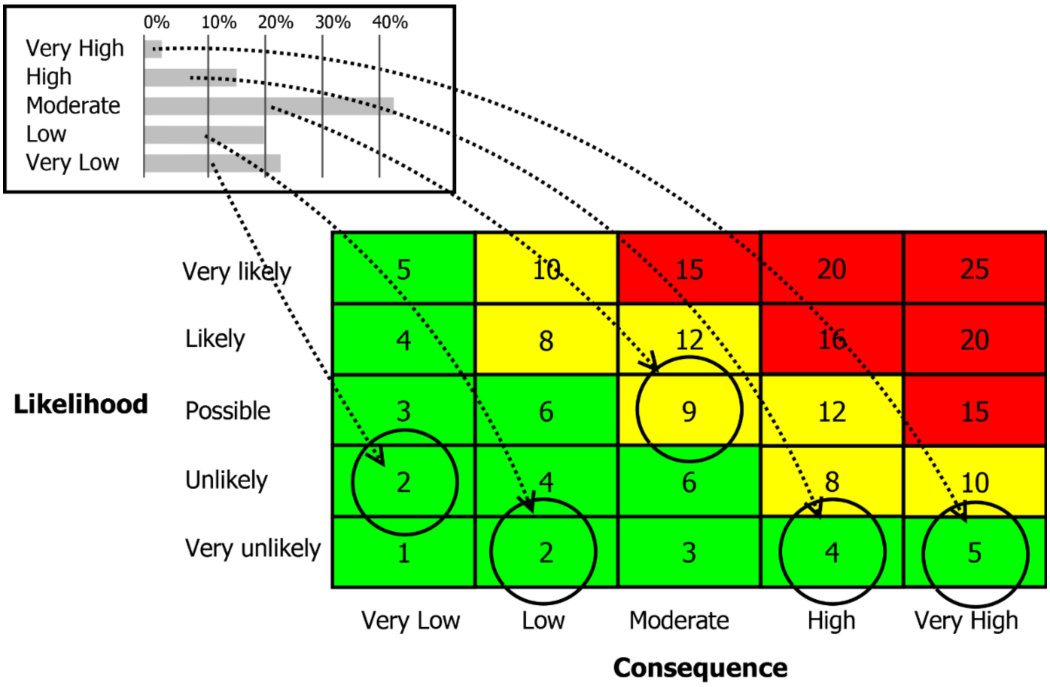

Figure 13. Risk evaluation approach for outputs from probabilistic analysis

4. Applying the framework in a highly variable ecosystem

4.1. Utilising a hydro-climatic model for the LEB

The river systems of the LEB are subject to some of the most variable climatic and hydrological conditions in the world, ranging from periods of protracted drought through to extremely wet periods when large areas of land are inundated (Puckridge et al. 1998, 2000, Costelloe et al. 2004). This variability occurs both seasonally, where dry hot seasons are interspersed with high levels of storm activity and seasonal flow and inundation, and supra-seasonally, where clusters of high rainfall years cycle into periods of extreme drought (McNeil et al. 2011a). Recent climatic and hydrographic patterns suggest that a cycle of wet-dry periodicity has occurred at roughly 10-year intervals over recent decades (linked to indicators such as operations of the Lake Hope commercial fishery). Within each supra-seasonal cycle, however, the actual pattern of wet and dry years, hence floods and drought are highly variable. There is corresponding variability in the responses of ecological systems and biotic populations (Costelloe et al. 2004; Humphries et al. 2006).

The extreme variability of drivers and responses in time and space has implications for the way that LEB ecosystems can be measured, monitored and managed. It is difficult to apply generalised models and rule sets to management issues (e.g. LEBRA Condition Report) where clear, simple metrics are needed. Even within 'wet' and 'dry' cycles, there exists no 'equilibrium state' against which the severity of a perturbation or disturbance can be measured. Ecological integrity in LEB systems relies upon a spatial mosaic of successional states in a variety of assets (Costelloe et al. 2004).

The ISMF model presented in this document provides an integrated system for collating, organising and accessing ecological information to assess the impacts and risks that mining and petroleum activities along with other development pressures might have on aquatic ecological assets. In keeping with a SAM approach, indicators and thresholds of potential concern can guide management and monitoring, and support assessments of mining developments through IESC and state approval processes.

In the LEB, objective rules and thresholds must be established within the context of the high degree of climatic and hydrological variability. For example, during wet periods water is abundant, waterholes are common and ecosystems are comparatively homogenous across connected catchment areas. In drought, highly vulnerable, isolated refuges protect assemblages of aquatic fauna and flora in a diverse, fragmented mosaic. Thresholds and indicator rules to protect refugial waterholes need to be different during wet and dry phases in order to reflect the distinct environmental vulnerabilities of those phases. Determining the level of development appropriate for a given set of hydrological conditions (or defining the risk to systems under varying hydro-climatic conditions) is a critical aspect of framework design. Management actions need to be considered within the context of antecedent hydrological conditions (Costelloe et al. 2004).

To accommodate this variability in the LEBRM framework, it is proposed that indicator rules and thresholds of potential concern for four phases of the hydro-climatic model developed by McNeil et al. (2011a – Figure 14) and the LEBRA fish trajectory model of Humphries et al. (2006) be developed. This hydro-climatic model also frames the temporal importance of various asset types, many of which are important only during wet or dry conditions, or are ecologically important for building resilience or imparting resistance to biota during interphase periods. The phases of the model are:

- **Bust**: a dry phase representing dry seasons (annual scale) or periods of extended drought (supra-seasonal). Aquatic habitats are fragmented and environmental conditions are harsh. Physiological resistance to climatic disturbance impacts drive biotic assemblage and population structure. Biota persist within suitable refugial habitats, with scant opportunity for recolonisation or large-scale reproduction. Resources are limited and competition and predation are intense (Costelloe et al. 2004). Where groundwater expression exists, groundwater-dependent ecosystem (GDE) refuges host fauna that can access and utilise these habitats. Low-flow surface water hydrology and in-channel flows drive connectivity and habitat persistence with refuge morphology, especially depth (Costelloe et al. 2007) and groundwater interactions.

- **Recovery**: wetter conditions producing widespread, persistent connectivity allowing biota to recolonise dry reaches, access new resources and undertake spawning and population building. Primary productivity increases following floodplain inundation, with emergence of animals and plants from resting stages, increasing diversity. An increasing number of habitats are filled and connected across the landscape, and assemblages become more homogenous.
- **Boom**: a wet phase where optimal environmental conditions are maintained over large areas from large floods or series of consecutive flood years. A range of asset types is inundated and hydrologically connected. Biological variables (life history traits such as reproductive strategies) become more important than localised environmental conditions in structuring assemblages. Explosive growth in numbers of some species, and waterfowl may emigrate from other regions to establish nesting colonies. Biodiversity reaches a peak, although density could be low with biotic groups spread across diverse habitat types including floodplains.
- **Collapse**: low rainfall, increasing aridity and less frequent, smaller magnitude river flows lead to broad-scale disconnection and drying of shallow habitats. Contraction of available habitats encourages species to move to permanent refugia. Density-dependent ecological processes (e.g. predation, resource limitation) intensify and physiological tolerances influence assemblage composition and distribution patterns. With persistent lack of flows, water quality and persistence decrease within and between habitats. Biota rely on smaller flow events to ameliorate local conditions or support retreat to suitable refugia. Obligate aquatic species are lost from systems that dry or where water quality deteriorates.

Aquatic ecosystems function differently during these hydro-climatic phases and management needs to make commensurate changes. This categorical approach will allow the context provided by available data and modelling to guide separate indicator rules and TPCs specific to the four phases. In some instances, rules and TPCs may not change between hydro-climatic phases, but a subset of rules and TPCs will rest on this hydro-climatic model, providing for approvals processes to protect vulnerable assets and asset types. Where resources for risk analysis and modelling are limited, it may be assumed that some phases are characterised by generally greater asset vulnerability to disturbance than others, meaning that more analysis effort might be directed to considering ecological response during those vulnerable phases.

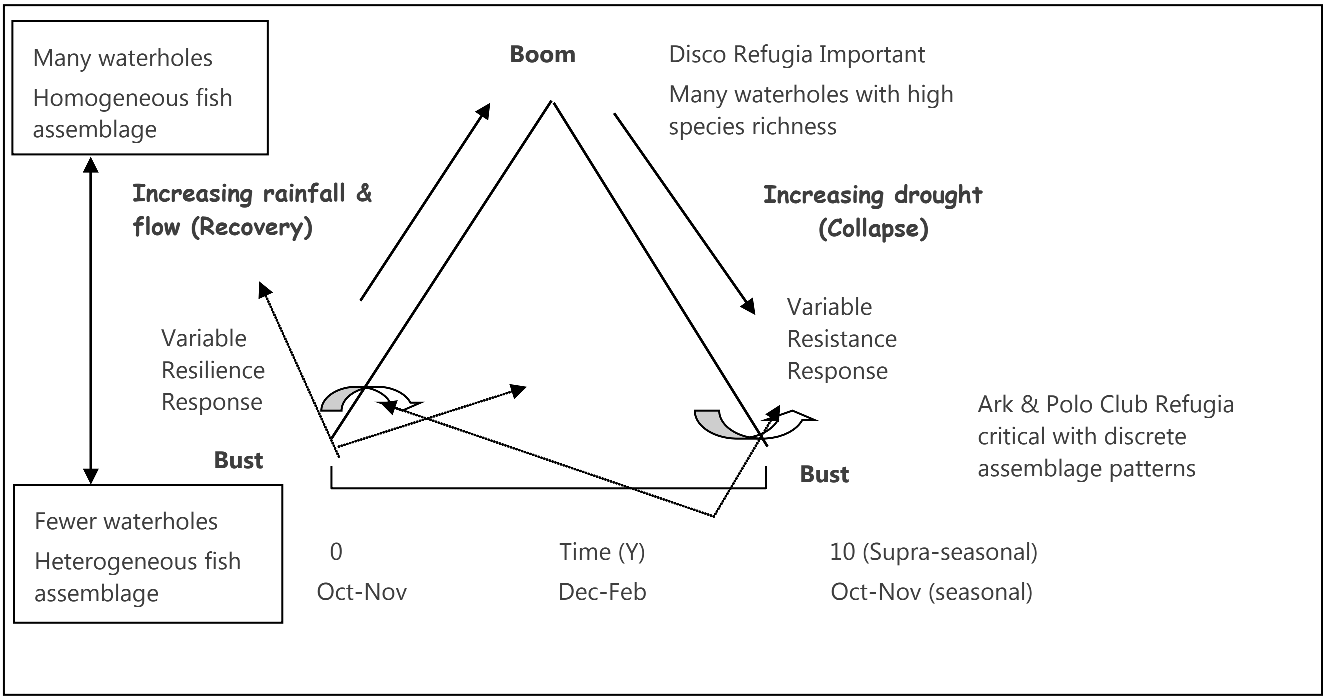

Figure 14. Conceptual hydro-climatic model developed for the Neales River (LEB) outlining interactions that can occur at annual to decadal scales between climate, hydrology and the response of aquatic ecosystems and biota adapted from McNeil et al. 2011a.

5. Applying the ISMF – an example

The preceding sections highlighted the components and functions of the ISMF. The following section provides a demonstration of how the ISMF may be applied to a management scenario in the LEB regarding a potential impact to an ecological indicator species. It also shows how the individual elements of the ISMF work together as a holistic process to drive the mechanisms of SAM in integrating science and management.

The example documented in Table 8 steps through the ISMF elements starting with the development pressure causing increased cease to flow conditions for the Algebuckina waterhole refuge, which is a key ecological asset in the Neales River. The scenario focuses on the ecological response and management of LEB Golden perch, which is a large bodied keystone aquatic species of value to a range of stakeholders and community groups in the LEB. This example demonstrates the application of state and commonwealth management context across a range of policy instruments.

For each ISMF element, Table 8 describes its purpose, a demonstration of how it is applied and links to existing resources, projects or tools that may be used to assist application of the ISMF. Note that the scenario presented in Table 8, including indicators, TPCs and other elements is intended as an example only and does not present an exhaustive application of the framework.

Table 8. ISMF example for Golden perch at Algebuckina Waterhole (Neales River)

ISMF Model element	Description and purpose	Example – LEB Golden perch, Algebuckina waterhole	Resources/ projects
CSG/LCM Pressure	Development activity modifying biophysical conditions	Mine infrastructure causing diversion of watercourse	
Stressor/vector	Change in biophysical attributes caused by pressure	Change in water regime leading to longer zero flow periods than occur in the undisturbed state	
Asset	Discrete spatially defined functional ecosystem unit	Algebuckina waterhole	Costelloe and Russel (2014) McNeil et al. (2011) NPA NRM Water Asset Database (DEWNR)
Asset type	Class for assets sharing common characteristics such as attributes	Permanent waterhole having ark refugia status	LEB ecosystem asset classification (Imgraben and McNeil, 2015) LEB HEVAE classification framework (Fee and Scholz, 2010) LEB high conservation value aquatic ecosystem pilot project (Hale et all, 2010)
Attributes – component	Biophysical ecosystem attributes	Asset components relating to golden perch ecology – physical habitat, hydrology, water quality, geomorphology, wetland biota, terrestrial biota	Attributes tables from Imgraben and McNeil (2015) (LEBRM) Costelloe 2011, Wakelin-King 2011
Attributes – processes	Interaction of ecosystem components	Asset processes relating to Golden perch ecology – hydrological processes, trophic dynamics, recruitment, assemblage structure, food webs, predation/competition, disease, habitat functionality	Attributes tables from Imgraben and McNeil (2015) (LEBRM) Costelloe 2011, Wakelin-King 2011
Models – conceptual	Qualitative description of asset components and processes showing how the asset responds to internal or external pressures and stressors	- Generic conceptual model (diagram model) for asset type (i.e. permanent waterhole) - Specific conceptual model for asset based on generic model and accompanying box and line model and attribute table - Specific hydro-ecological conceptual models relating to golden perch in Algebuckina/Neales	Pressure-stressor-response models (Imgraben and McNeil, 2015) Attribute tables (Table 1) Methods and iconography for generating conceptual models (Wiebkin, 2014) Goyder-LEB hydro-ecological conceptual models (McNeil et al., in prep.) McNeil et al. (2011), McNeil and Schmarr (2010)
Baseline and new knowledge	Identification and application of existing knowledge-base informing development of conceptual models, or new knowledge and data commissioned for purpose of addressing knowledge gaps, monitoring etc.	Process of identifying projects, published and unpublished data sources, and expert elicitation to inform model development specific for Algebuckina. Database development for purpose of informing model development	Wet/dry (Adelaide University, 1989-92) Arid flow (DLWBC, 2000-03) LEBRA (DOTE, 2010-14) SARDI (2008-14) SA Biosurvey (DENR, 2005)
Models – parameterised	Mathematical representation of asset components and processes	Data analysis and numerical models parameterised for Golden perch in Algebuckina waterhole developed using conceptual models and baseline and new knowledge	Hydro-climatic model (McNeil, 2011) Goyder-LEB parameterised hydro-ecological models for fish ecology (McNeil et al., in prep.)
Indicators	Measurable attribute of the asset providing information on status and condition relative to value-based objectives for asset	Indicators selected from models linked to Golden perch values: - Flow regime and connectivity indicators - Waterhole persistence and cease to flow - Water quality - Assemblage and abundance indicators - Disease level - LEB Golden perch recruitment o Flow response o Refuge based	Product of model outputs and definition of values
Thresholds of Potential Concern (TPCs)	Indicator conditions marking asset's transition from low to high risk of degraded values. E.g. tipping points beyond which ecosystem function, resilience or viability are threatened.	i. No LEB Golden perch observed in ark refugia during bust phase ii. No LEB Golden perch observed in disco refugia during recovery and boom phase iii. Low abundance of LEB Golden perch throughout hydro-climatic cycle iv. High percent disease occurrence for LEB Golden perch	Derived from model outputs and analyses

ISMF Model element	Description and purpose	Example – LEB Golden perch, Algebuckina waterhole	Resources/ projects
		v. Disease occurrence outside of collapse phase vi. Water quality approaching tolerance thresholds for LEB Golden perch vii. No connectivity to spawning habitats during flow periods viii. No connectivity to refugia following recovery/boom phases ix. Failure to detect significant LEB golden perch recruitment in five year period x. Failure to detect low levels of LEB Golden perch recruitment during bust phase xi. Failure to detect LEB Golden perch recruitment following seasonably appropriate flow events xii. Relative abundance of LEB Golden perch significantly decreased from baseline xiii. Detection of new pest species that threaten LEB Golden perch ecology	
Values	Importance, worth or usefulness of asset or attribute to individuals or the community.	i. Presence of fish species in numbers sufficient to support sustainable LEB recreational fishery. ii. Presence of fish species in natural condition to support cultural activities by Aboriginal communities. iii. Abundance of Golden perch to support commercial fishery in LEB iv. Golden perch as an iconic fish in LEB v. Presence of Golden perch as a keystone predator for ecosystem integrity vi. Natural fish assemblage unimpacted by human activities vii. Resilient native fish assemblage resistant to invasive pest species viii. Food resource for terrestrial and avian predators ix. Potential source of nutrients post-flooding to support floodplain and terrestrial ecosystem processes	McNeil et al. 2011b, White 2014, LEBCAC outputs, Workshop outputs Port Augusta LEB conference 2013, Morton et al. 1995 (world heritage values)
Value types	Classes of values sharing common characteristics	- Aesthetic - Amenity/consumptive - Cultural - Economic - Ecosystem	MacDonald and McNeil, 2012 Example for refuge management
Policy	Principles to guide decisions to achieve outcomes consistent with objectives (in context of environmental management for Lake Eyre Basin)	Policies and plans for water resource management, habitat and ecosystem protection, biodiversity, conservation and development reflecting values of native fish and refuge habitat and knowledge of their vulnerabilities. The ISMF outlines a mechanism by which scientific understanding can be linked to policy. It guides the following interactions between policy, science and management objectives: - Policy encapsulates objectives for LEB Golden perch informed by values determined through stakeholder engagement as required by the SAM process (e.g. expressed in targets, policies and objectives of documents such as the Plan for the Management of LEB Fisheries 2013, SAAL NRM Plan, Far North Prescribed Wells Area Water Allocation Plan) - Models, indicators, TPCs and Values inform policy development and implementation through the appropriate governance process of respective policy (i.e. monitoring, evaluation, reporting and improvement processes)	Relevant legislation includes: - Natural Resources Management Act 2004 - Mining Act 1971 - Petroleum and Geothermal Energy Act 2000 - Environmental Protection and Biodiversity Conservation Act 1999 (Commonwealth) - Environmental Protection Act 1993 Specific policy drivers includes: - Management Plan for the Lake Eyre Basin Fisheries, 2013 - SAALNRM Plan - Far North Prescribed Wells Area Water Allocation Plan - Lake Eyre intergovernmental Agreement Policies: - Principles regarding water affecting activity permits in SAAL region NRM Plan - Principles regarding water allocations under Far North PWA WAP - Requirement for Plan for Environmental Protection and Rehabilitation (PEPR) under Mining Act 1971 - Requirements for Statement of Environmental Objectives under Petroleum and Geothermal Energy Act 2000

ISMF Model element	Description and purpose	Example – LEB Golden perch, Algebuckina waterhole	Resources/ projects
			- No species loss – a nature conservation strategy for South Australia 2007-17 - Threatened species recovery plan
Feedback to management approvals	Application of policy to guide decisions regarding development activities potentially having environmental impacts	Hydro-ecological models, indicators, and TPCs informing technical review of proposed developments (e.g. CSG, mining) to ensure consistency with objectives of policy. Conditions on approvals regarding i) mitigation of unacceptable risks to values, ii) identifying and addressing knowledge gaps affecting management of environmental risk ii) appropriate monitoring to inform compliance and adaptive management where required. Specific technical reviews informing approval of the following: - Exploration licence application (Mining Act 1971) - Program for Environmental Protection and Rehabilitation (Mining Act 1971), - Permits for dam construction (water affecting activity permit) and water well construction (NRM Act 2004, SAAL NRM Plan) - Permits required under the Environmental Protection Act 1993 (e.g. release of water potentially impacting water quality of asset) - Water allocation licence (Far North Prescribed Wells Area Water Allocation Plan)	- Environmental risk management frameworks such as AS/NZS ISO 31000:2009, DEWNR Risk Management Framework for Water Planning and Management - Interdepartmental and inter-jurisdictional agreements (e.g. PACE mining, National Partnership Agreement for CSG and Large Coal Mining) - Tools developed to facilitate technical assessments and approvals (e.g. processes, databases, templates)
Feedback to NRM interventions	Application of policy to guide decisions regarding NRM activities designed to protect or enhance environmental values	The ISMF guides terms of reference for technical review of NRM interventions (strategies, plans, projects) informed by scientific understanding including conceptual and numerical models, indicators, values and TPCs. Technical review of NRM interventions (including strategies, plans, projects) to x. Ensure consistency with values and objectives relevant for Algebuckina waterhole, Golden perch and refuge protection in NRM plans and targets or other relevant management plans or programs xi. Highlighted opportunities for investments that optimise outcomes for Golden perch and refuge waterholes (e.g. riparian restoration prioritisation) xii. Highlight opportunities for regarding monitoring, evaluation, reporting and improvement activities that contribute to management objectives for Golden perch and refuge waterholes	- NRM project plans - Investment strategies - Best practice monitoring, evaluation, reporting and improvement frameworks (Australian Government NRM MERI framework, DEWNR Science Guide for Water Allocation Plans) - Environmental risk management frameworks such as AS/NZS ISO 31000:2009, DEWNR Risk Management Framework for Water Planning and Management

Community and Stakeholder input (SAM)	Multi-stakeholder engagement to determine community values, set strategic social, environmental and economic objectives and plan out the most effective way to achieve these objectives.	The ISMF informs community and stakeholder partnerships with relevant science.
		- Stakeholders education with respect to the vulnerabilities of values related to Golden perch and refuge protection
		- Stakeholders engaged to determine and priorities values with respect to Golden perch and waterway management
		- Stakeholders agreement regarding indicators and TPCs
		- Stakeholder participation in design and delivery of relevant NRM programs to achieve outcomes with respect to Golden perch and waterhole values
		- Stakeholder participation in monitoring, evaluation, reporting and improvement processes in accordance with NRM MERI frameworks
			- SAAL NRM Board
			- Lake Eyre Basin Ministerial Forum
			  o LEBCAC
			  o LEBSAP
			- Indigenous community partnerships
			- Steering committees
			  o LEBRM
			  o GLEB
			  o NPA for CSG and LCM (SA)
			- Communication strategies (NRM, Relevant programs including BA, other NPA programs)

Monitoring	Routine collection of quantitative or qualitative information for the purpose of reporting and/or evaluation. Includes all monitoring programs.	The ISMF is a mechanism to ensure monitoring is linked to a clear purpose. Under the framework, monitoring should inform the management of risks to community values in the LEB. In doing this, it is informed by relevant science regarding ecological responses and TPCs. A key element of the framework is identification of appropriate indicators for monitoring to achieve its objectives. The ISMF also promotes community participation and engagement in monitoring.
		For this example:
		- Multiple stakeholders articulate objectives for monitoring of indicators relevant for Golden Perch and refuge waterholes informed by hydro-ecological response models and TPCs. For example:
		  o MERI for Management Plan for LEB Fisheries 2013 (recreation, commercial and indigenous fishing indicators)
		  o Assessment of risks to Golden perch and refuge waterholes undertaken by proponents of specific
			- LEBRA
			- SAAL NRM Water Projects
			- Bioregional Assessment monitoring
			- GLEB
			- LEBRM

ISMF Model element	Description and purpose	Example – LEB Golden perch, Algebuckina waterhole	Resources/ projects
		CSG or mining developments o Required under conditions of approvals for CSG and mining developments o Bioregional assessment monitoring to inform assessment of environmental risks caused by CSG and large coal mining o LEBRA monitoring refuge waterholes and fish populations to inform stakeholders and government regarding ecological condition of LEB o MERI for relevant NRM programs and projects in LEB - Stakeholders review existing monitoring programs relating to Golden perch in the Neales River and LEB to evaluate the extent to which they address relevant indicators and TPCs - Mandate and commitment for monitoring to address key knowledge gaps or reporting requirements to address relevant indicators and TPCS.	
Risk assessments	The process of risk identification, risk analysis and risk evaluation to determine the level and acceptability or tolerability of risks in response to a management context.	The purpose of the ISMF is to map out how science informs management of environmental risks in the LEB. Under the ISMF, TPCs are the key mechanism for this to occur, as they represent: - scientific understanding of the assets and their responses to stressors, and - stakeholder objectives and attitude to risk. For this example, risk assessments informing environmental management (i.e. preparation and technical assessment of development applications for CSG and mining, water allocation plans, NRM plans, fisheries management plans) are informed by TPCs relevant for Golden perch and refuge waterholes	- AS/NZS ISO 31000:2009 risk management standard - DEWNR Risk management framework for water planning and management - Wilson et al., 2014

6. Summary and conclusions

The LEBRM ISMF represents an asset-based, multi-scale approach to identifying, assessing and managing risks caused by CSG and large coal mining. It implements a number of environmental assessment approaches (Pressure-Stressor-Response modelling, Ecological Risk Assessment), with an ecological asset-based model for classifying and attributing aquatic habitats and ecosystems. The framework extends the ecological asset information component to connect with human values associated with aquatic assets, using indicators and Thresholds of Potential Concern (TPC) that are consistent with SAM (Kingsford and Biggs 2012). The framework is a means to connect jurisdictional policy and planning frameworks with the scientific knowledge base to optimise interventions including natural resource management programs, development approval processes, and environmental assessments and reporting processes.

The framework provides for adaptive management and risk assessment processes which can be continually updated with contemporary ecological knowledge and community values. Such a system forms the basis for continual improvement of both the realism and utility of the tools underpinning SAM including models, indicator rules and TPCs. Thus operationalising the framework is a means of providing ongoing guidance for long-term management programs such as LEBRA. As such, it provides a mechanism for delivering NRM within the SAM framework that is to be developed for the protection and management of the LEB under the LEBMF.

The ISMF also provides a framework suitable for catchment management more generally. Broader application of the ISMF simply requires population with appropriate typologies, conceptual models and other framework features appropriate for the region. The focus on attributes means that the framework is also flexible in terms of application to pressures other than CSG and coal mining activities. Many of the stressor pathways and ecological responses will not differ greatly from those identified in the existing framework. The framework could therefore be useful for Regional Management Groups such as NRM groups, boards and catchment management authorities in assessing the impacts of pressures from pastoral, tourism and fisheries industries as well as the impacts of climate change or increasing urbanisation and population pressure.

One of the principal benefits of the framework is in guiding the targeting of environmental monitoring programs to ensure that programs are strategically designed to address management priorities and make the most of available scientific knowledge whilst identifying areas of uncertainty. Equally, data produced through existing monitoring programs in the LEB are likely to inform identification of indicators, TPCs and/or indicator rules. LEB projects under the Goyder Institute for Water Research assessing existing datasets to ascertain their suitability for informing indicators and thresholds. This takes advantage of existing data and ensures a baseline dataset that is as long as possible - important in an inherently variable environment to help capture the range of natural variability. The framework also helps to identify measurable indicators and thresholds to guide the way management responses are linked to monitoring programs. The framework could provide a consistent guide to monitoring ecological condition in the LEB which incorporates the outputs of programs such as LEBRA and Bioregional Assessments, State of the Environment reporting and other monitoring activities for state and regional agencies. This would create monitoring efficiencies through targeting key knowledge gaps and monitoring needs and reducing overlap between monitoring programs.

The ISMF has been used as a means of organising the collection, collation and assessment baseline knowledge and datasets relevant to the management and ecology of aquatic assets for the LEBRM project. A conceptual modelling framework has been established which integrates attribute tables capturing the components and processes of the various asset types identified in the LEB. The framework can be used to explore and, where appropriate, develop indicator rules and TPCs. It can also be used to undertake a value classification and attribution process that will link to ecological models through common ecological indicators. These outputs can then be utilised to develop Pressure-Stressor-Response models and undertake a risk analysis of a selection of assets within three focus regions in the LEB (in the Arckaringa, Pedirka and Galilee Basins) guided by the collection of hydro-ecological and related data from key assets within those regions.

A number of spatial database and mapping outputs have been produced to enhance the uptake and adoption of the project outputs. The framework presented in this document is intended to have a long-term legacy in supporting ecological and environmental management projects in the Lake Eyre Basin through a Strategic Adaptive Management approach as advocated by the LEB ministerial forum.

Finally, the framework provides a means to encourage and guide mining and petroleum proponents in implementing best-practice approaches to environmental impact assessment. It can guide infrastructure planning, research and monitoring approaches that will optimise project design to reduce environmental risks and to better inform regulators of the potential risks and ameliorative actions incorporated into mining development applications. By also providing a common system to inform both proponents and regulatory agencies, the framework may enhance the communication of potential environmental impacts and requirements and thereby improve the efficiency of mining approvals processes and help to support the sustainable development of the coal mining industry into the future.

In Summary, the key features and benefits of the ISMF model include:

- Integration of a range of contemporary ecological classification, assessment and management approaches which provides a practical way to comprehensively address factors affecting the resilience of environmental assets within a highly dynamic and variable hydro-climatic context
- An asset-based approach for characterising and classifying ecosystems and building robust and adaptable ecological knowledge systems
- Consistency with established risk management standards (i.e. AS/NZS ISO 31000:2009) underpinning contemporary jurisdictional approaches to managing natural resources. This consistency:
- Supports collection and ordering of data and knowledge in a manner facilitating identification, description and analysis of risks
- Ultimately promotes a consistent and transparent basis for decisions regarding trade-offs between environmental risks and development opportunities
- Incorporation of the principles of Strategic Adaptive Management (Kingsford et al. 2012) such as Thresholds of Potential Concern to draw linkages between scientific understanding of ecosystem function and stakeholder values in a risk management context
- The establishment of a modelling framework and process which will underpin transparent and consistent risk assessment outcomes. This, in turn, engenders stakeholder confidence in decisions regarding developments
- A requirement that risk evaluation approaches is explicit regarding uncertainty in the knowledge and data underpinning risk analysis. This provides a mechanism for risk management decisions that transparently account for uncertainty consistent with risk management best practice. It also promotes science and monitoring having optimal benefits relative to costs.
- Adoption of the PSR model as a template for understanding environmental impacts promotes a generic and flexible system that is readily adapted to a range of asset scales and development pressures.

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