ASSESSMENT OF VULNERABILITY OF WATER ASSETS TO HYDROLOGICAL CHANGE CAUSED BY COAL SEAM GAS AND LARGE COAL MINING DEVELOPMENT IN SOUTH AUSTRALIA

XX

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

ASSESSMENT OF VULNERABILITY OF WATER ASSETS TO HYDROLOGICAL CHANGE CAUSED BY COAL SEAM GAS AND LARGE COAL MINING DEVELOPMENT IN SOUTH AUSTRALIA

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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.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

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SUMMARY

In 2012, the Australian Government intervened to strengthen regulation of coal seam gas (CSG) and large coal mining (LCM) development in Australia. This intervention resulted in the National Partnership Agreement (NPA) on Coal Seam Gas and Large Coal Mining Development (Council of Australian Governments, 2012) with five jurisdictions including South Australia, amendments to the *Environment Protection and Biodiversity Conservation Act 1999*, establishment of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) and funding for a range of knowledge programs, including Bioregional Assessments, to inform the functions of the IESC.

To facilitate knowledge programs, the former Australian Government Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) Office of Water Science (OWS) provided funding to six participating South Australian Natural Resources Management (NRM) Boards to identify and attribute water assets and to assess the vulnerability of these assets to potential and existing CSG and LCM development activities. SEWPaC provided database templates for the collation of water assets and linked vulnerability assessments. The vulnerability assessment template defined vulnerabilities according to six attributes including CSG or LCM related activity, effect, impact (i.e. magnitude of effect), hazard (i.e. whether the asset is located in the zone of an existing/potential CSG/LCM development). It also included free text fields for mitigation (i.e. measures in place to reduce vulnerability) and a description of the vulnerability.

Participating NRM regions agreed to collaborate with the South Australian Department of Environment, Water and Natural Resources (DEWNR) on the SA NPA NRM Data Project to undertake water asset delineation, asset attribution and vulnerability assessments in a coordinated and scientifically rigorous manner. A series of vulnerability assessment workshops was undertaken under the auspices of this project between September and November 2012 to:

i) arrive at an agreed stance with respect to the concepts of vulnerability given the context of DEWNR's existing Risk Management Framework for Water Planning and Management (DEWNR, 2012)

ii) develop a framework and criteria for assessing vulnerabilities

iii) progress the assessment through expert elicitation.

A review of literature showed that there is a growing role for vulnerability assessments contributing to aspects of sustainability science, development and management of land use change. In these applications, vulnerability is generally defined as a function of sensitivity to a hazard, exposure and condition of the asset. It is recognised that while a vulnerability assessment may inform a risk assessment, it is not intended to provide a framework for incorporating additional context necessary for decision making regarding risks to water assets such as organisational goals, stakeholders, culture, values and other factors affecting the tolerability or acceptability of risk.

To assist with scoping the assessment, a generic water-asset risk model, based on a pressure-stressor-response (PSR) framework to environmental impacts (Marshall et al., 2006), was adopted as a guide. To address the specifications of the SEWPaC vulnerability database template, it was agreed to focus the assessment on potential hydrological changes to assets arising from CSG/LCM activities (i.e. "pressure" and "stressor" components of the PSR model). To achieve a workable outcome in the timeframes required by the SA NRM Data Project, it was agreed that "responses" representing potential changes to environmental, social/cultural and economic values should not be covered making this, in effect, a partial assessment. Furthermore, it was decided that the assessment should focus on hydrological asset classes based on the water source and water regime attributes rather than on individual assets.

To achieve a consistent and rigorous vulnerability assessment, participants in the SA NPA NRM Data Project workshopped a set of definitions and criteria to guide each stage. These became known as the SA Vulnerability Assessment Framework. Elements of this framework included lists and definitions with respect to CSG/LCM related activities, hydrological effects, and criteria for rating impact based on potential change to hydrological integrity, resilience and time to recovery. A series of expert elicitation workshops was then held to arrive at impact ratings for each combination of asset class, activity and effect defined by the framework. This process, undertaken in separate streams for surface and groundwater asset types respectively, produced a table of 8849 impact ratings for all combinations of water source and water regime identified in the water asset database produced through the SA NRM Data Project.

Analysis of the results shows a high incidence of unknown ratings due to asset classes having water source or water regime attributes assigned as unknown, unset, or various combinations of options. After accounting for these issues, there was found to be significantly more uncertainty regarding vulnerability to in-situ gasification, managed aquifer recharge and overburden management compared to other activities. Similarly, there was most uncertainty about effects regarding functional connectivity of surface water and surface water/groundwater connectivity. Comparison of weighted aggregate vulnerability shows considerable variance between CSG/LCM activities regarding impact ratings. On average, surface water diversion, in-situ gasification and discharge to surface water attracted higher vulnerability ratings, while there was least vulnerability to well drilling, overburden management and evaporation ponds and tailings dams. A similar comparison carried out for the hydrological effects showed that changes to water quantity and quality attracted higher vulnerability ratings on average, with aquifer structural integrity, groundwater pressure and groundwater flow patterns attracting the lowest ratings.

The output of the assessment was applied to the water asset database to create a table of vulnerabilities keyed to assets as required by the SEWPaC vulnerability assessment template. Combining a large number of assets (96 024) and vulnerabilities generated over 9 million rows of data in this format. This was found to be impractical leading to slow database queries and difficulty in importing data into desktop applications. Further normalisation of the database schema was required to eliminate redundant, repeated vulnerability information shared between assets, which greatly reduced data storage requirements and improved responsiveness of queries.

Workshops and discussions held following the completion of the assessment have identified potential for the vulnerability assessment to be of utility in the NRM domains in South Australia, both at regional and state level. It was recognised that this work is foundational activity contributing to the building of a knowledge and information platform supporting improved management of water resources in South Australia. It was agreed that the approach could inform the context setting, risk identification and risk analysis stages of DEWNR's Risk Management Framework for Water Planning and Management.

By adopting consistent frameworks and definitions (i.e. DEWNR's Risk Management Framework for Water Planning and Management and the PSR model for water asset risk), the vulnerability assessment framework described within this report lends itself to further development to (i) broaden the scope of decision support issues that can be tackled and (ii) increase the realism (i.e. accuracy) of assessments. Development opportunities canvassed by stakeholders include:

i) consideration of vulnerability of water assets to other types of development pressures, including those not related to minerals and petroleum

ii) consideration of the vulnerabilities of water asset values such as environmental values

iii) improving realism of assessments through consideration of gaps, improved impact criteria, more detailed asset typologies and hydrological stressors

iv) implementing a more transparent approach to representing uncertainty through adoption of a probabilistic approach to reporting impact

Further to these specific opportunities, an important general finding from this assessment is that a large component of hydrological vulnerability is relevant for surface water asset classes. This finding is significant because much of the attention regarding the risks of CSG and LCM development in Australia has been largely focussed on potential groundwater impacts. It can be recommended that, while potential groundwater impacts should not be downplayed, an understanding of the surface water stressors arising from CSG and LCM activities and the potential habitat and ecological responses is likely to be a key priority in improving the capacity to manage risk.

1.INTRODUCTION

1.1. NATIONAL PARTNERSHIP AGREEMENT ON COAL SEAM GAS AND LARGE COAL MINING DEVELOPMENT

The National Partnership Agreement (NPA) on Coal Seam Gas (CSG) and Large Coal Mining (LCM) Development was established in 2012 to strengthen the regulation of CSG and LCM and provide for transparent decision making (Council of Australian Governments, 2012). This agreement between the Australian Government and the signatory state governments aims to ensure that future decisions regarding CSG and LCM development in Australia are informed by the best available science and independent expert advice. The agreement commits signatories to considering the advice of the Independent Expert Scientific Committee (IESC) on proposed CSG and LCM development, whose function has been formalised under amendments to the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Commonwealth of Australia).

The Australian Government has commissioned *Bioregional Assessments* to be conducted in key resource provinces with existing or potential CSG and LCM development. The Bioregional Assessment program aims to analyse the risks to water dependent assets arising from the most likely CSG and LCM development scenario. These assessments will draw on a number of *Research Projects*, *Knowledge Projects* and *Data Gathering Projects*. Within South Australia funding has been allocated under the auspices of the NPA to support a number of these projects to underpin the information needs of the IESC and the Bioregional Assessment Program.

A key data gathering activity supported by Australian Government funding within South Australia is the Water Asset Database and Vulnerability Assessment Project and the SA Natural Resources Management (NRM) Data Project. Australian Government funding was provided to six participating South Australian NRM Boards to

- identify and delineate water assets and populate database templates,
- assess the vulnerability of the identified assets to potential CSG and LCM development activities,
- ground truth or validate existing knowledge of water resources in potential CSG/LCM regions.

The Science, Monitoring and Knowledge (SMK) Branch of DEWNR was engaged by participating NRM regions to assist in delivering against their agreed Australian Government milestones. This led to the commissioning of the SA NRM Data Project, which encapsulated the lead role played by SMK in coordinating regional and central expertise in the development of a database management framework, a database structure and a vulnerability assessment framework. A key objective of the SA NRM Data Project was the achievement of a robust, consistent and accessible data product for the NRM regions' future use whilst achieving the primary objectives of the Australian Government funding.

This present document describes the aims, methodology and outcomes of the vulnerability assessment component of the SA NRM Data project.

1.2. WATER ASSET AND VULNERABILITY ASSESSMENT DATABASE

The main deliverable of the SA NRM Data Project is a database of water assets known as the Water Asset and Vulnerability Assessment Database. The design of this database has drawn on the specifications provided by the Australian Government as a starting point. It is a deliverable arising from the suite of projects occurring under the auspices of the NPA that is intended to be a key input to the Bioregional Assessment program. It is also a resource that could support regional NRM boards and DEWNR in the future.

A key principle governing data collation work sponsored by the Australian Government Department of the Environment (formerly Department of Sustainability, Environment, Water, Population and Communities (SEWPaC)) was to capture the priorities and values of the local communities with respect to water assets. To achieve this aim, the participating NRM regions were directly funded by the Australian Government to develop the asset databases relevant for their regions in accordance with the templates and schema provided. SEWPaC provided a data entry tool and underlying database schema that outlines the required data attributes for water assets and their vulnerabilities to CSG and LCM development.

The SA NRM Data project was instituted because it was recognised by the participating regions that there was an opportunity to enhance the value of the water asset database for Australian Government and state/regional users through further development of the underpinning data model and the data entry tools. Key benefits sought by the SA NRM Data project included

- a consistent approach to defining and identifying water assets,
- a spatial database enabling spatial querying and analysis,
- greater richness in terms of the consistent water asset data that are available within and across regions,
- efficient methodologies and tools for collation of data sources and data entry,
- a structured assessment of water asset vulnerability to CSG and LCM, consistent with DEWNR's risk management framework for water planning and management,
- improved data availability for regional and state natural resource management and statutory processes,
- capacity building at both the regional and state levels.

To achieve these outcomes, DEWNR hosted a number of workshops to engage with a range of expertise and stakeholder groups including natural resource managers, scientists (i.e. hydrologists, hydrogeologists, ecologists), social scientists, economists, water planning advisors, policy advisors and database managers. Also state and Australian Government entities external to DEWNR were engaged, including DMITRE, EPA, DPC and SEWPaC Office of Water Science (OWS).

1.2.1. WATER ASSET DELINEATION AND ATTRIBUTION

An initial outcome of this engagement was agreement on a framework for delineating water assets, as presented in Table 1. This framework provides a definition for what a water asset is, the scales over which assets may be defined and the rules governing how multiple spatial features can be aggregated to define single assets. This approach was intended to provide a high level of flexibility with respect to asset delineation and attribution. Examples of assets that could be defined using this framework includes streams, wetlands, aquifers, springs, bores, monitoring well networks, rockholes, catchments, groundwater basins, management units such as prescribed wells areas, floodplains, drains, town water supplies, industry water supplies and areas of indigenous and cultural value.

Table 1: Water asset definition determined by SA NPA NRM Data project (DEWNR 2013)

Definition	A physical feature or region (natural or non-natural) of environmental, social, economic or cultural value that contains water permanently or periodically
Scale of delineation	Assets can be defined at multiple scales, from local, landscape to regional scale, based on relevant groupings of environmental, social, economic or cultural values
Rules for aggregating features into an asset	They have hydrological and/or biological and/or cultural and/or economic connectivity (e.g. wetland complex)
	They fall within a common management area (e.g. a prescribed water resources area under the *South Australian Natural Resources Management Act 2004*)
	They fall within a common area (e.g. a catchment)

The SA NRM Data Project identified existing data sources from which assets could be identified. These included state corporate and regional datasets such as surface water layers (including wetlands, watercourses, catchments, surface water basins, water storages, mound springs and water points), groundwater datasets (including drillholes, aquifers and groundwater basins) and state administrative boundaries such as NRM regions, prescribed areas, groundwater networks, water protection areas, and surface and groundwater management areas. A flowchart and user guide were developed to promote a consistent process for asset identification and spatial definition using these existing datasets.

1.2.2. DATABASE DESIGN

Stakeholders, domain experts and database professionals were engaged to undertake further development of the data model and data entry tools. The outcomes of this work were two-fold. Firstly, SEWPaC's template was translated into a spatial relational database schema, as illustrated in Figure 1. According to this schema there are separate tables storing information on the spatial extent of assets (i.e. points, lines or polygons), the attributes of the assets (e.g. asset name, hydrology, values, pressures), links to published or grey-literature references describing the assets and links to the outcomes of the vulnerability assessment.

The database design is relational in nature, meaning that the completed delineation, attribution and vulnerability of a single asset are recorded in a number of tables joined by keys. The entity relationship model illustrated by Figure 1 shows that the assets table containing the attribute information is joined to the references and vulnerabilities table by means of *many to many* relationships achieved through the intervening link tables. This means that a single asset may have multiple vulnerabilities or references, and that a single vulnerability or reference may link to multiple assets.

The second outcome of the stakeholder engagement process was the development of a so-called "controlled language" for the attributes fields. This involved agreement on a standard set of definitions for all attributes. The data entry and database tables were altered to reflect this controlled language, where appropriate, by replacing free text fields with "dropdown" menus with pre-configured options to promote consistency.

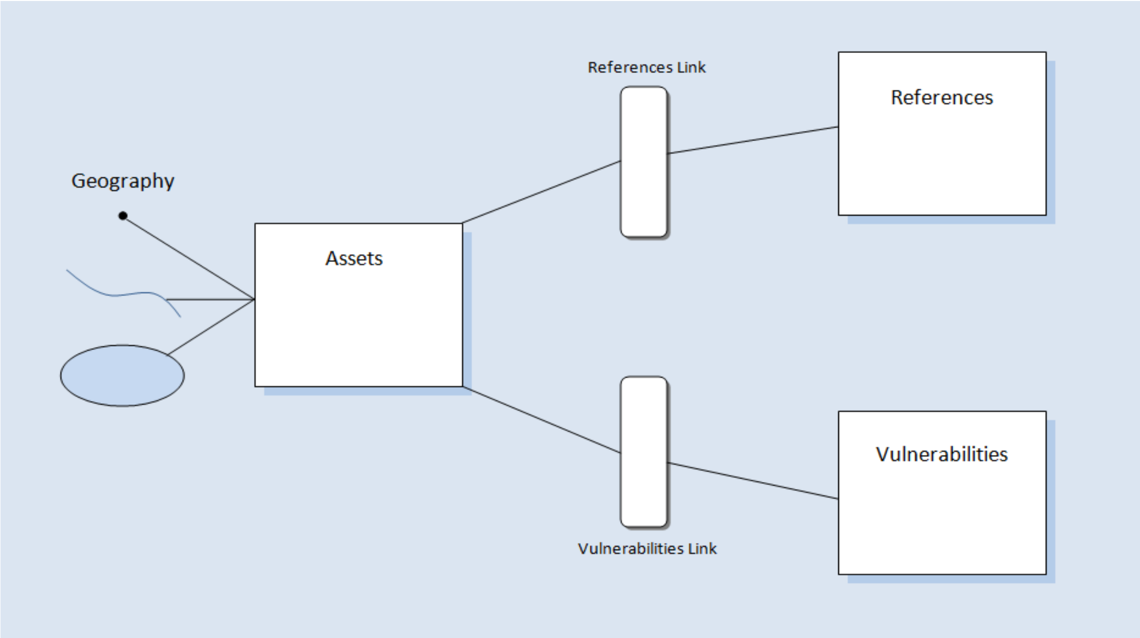


Figure 1: Water Asset and Vulnerability Assessment Database schema

1.3. SCOPE OF THIS REPORT

This report is concerned with the vulnerability assessment component of the SA NRM Data Project. As with the asset delineation and attribution task, the participating NRM regions and DEWNR agreed to undertake coordinated approach to the assessment of the vulnerabilities of water assets to CSG and LCM activities. Accordingly, this report outlines the framework that was developed collaboratively by the project participants (Section 3), and explains how this was used to guide a consistent and scientifically valid approach to documenting the vulnerabilities of water assets to CSG and LCM related activities (Section 4.1). It presents the results of the vulnerability assessment (Section 4.2), and describes how asset class vulnerabilities are linked to assets (Section 4.3). Finally it provides discussion on potential use cases, implications from the outcomes for the management of water asset risk caused by development and approaches to either expanding the scope of the assessment or improving its realism (Section 5).

2. BACKGROUND – RISK AND VULNERABILITY

2.1. THE AS/NZS ISO 31000:2009 RISK MANAGEMENT GUIDELINES

The AS/NZS ISO 31000:2009 guidelines (Joint Technical Committee OB-007, Risk Management, 2009) define risk as the "effect of uncertainty on objectives". Risk management is defined as directing and controlling an organisation with respect to risk.

Figure 2 presents the key features of risk management as promoted by the ISO guidelines. It shows that risk management activities should be consistent with a set of principles (in blue) such that it provides an overall benefit to an organisation. The risk management framework (in green) outlines the organisational arrangements for designing, implementing, monitoring, reviewing and continuously improving risk management throughout an enterprise.

The suggested risk management process promoted by the ISO guidelines (yellow in Figure 2) consists of five steps informed by appropriate communication and consultation and subject to monitoring and evaluation. These steps (in order) are as follows:

1. Establishing context, whereby the risk management scope, objectives, stakeholders, and parameters affecting risk are determined. These inform the setting of appropriate risk criteria to inform the risk assessment.
2. Risk identification, which is concerned with finding, recognising and describing risks.
3. Risk analysis aims to achieve comprehension of the nature of risk to determine the risk level. Risk level is a function of the likelihood and consequences of an event.
4. Risk evaluation compares the results of the risk analysis (i.e. the risk level) with risk criteria to determine the acceptability or tolerability of risk given the context of the overall risk management task.
5. Risk treatment is the process of modifying intolerable risks so that they become acceptable given the risk management context. Examples of risk treatment options include avoiding risk, taking increased risk to pursue an opportunity, removal of the source of risk, modifying risk likelihood through preventative or preparatory controls, modifying consequence through response and recovery controls, sharing risk with other parties or retaining risk through informed decision.

According to the ISO guidelines, the term "risk assessment" refers to the second, third and fourth steps outlined above (i.e. risk identification, analysis and evaluation).

2.2. DEWNR'S RISK MANAGEMENT FRAMEWORK FOR WATER PLANNING AND MANAGEMENT

In 2012, the DEWNR executive endorsed the Risk Management Framework for Water Planning and Management (DEWNR 2012a) and the Risk Management Policy and Guidelines for Water Planning and Management (DEWNR 2012b). These documents together outline the risk management definitions, concepts and processes for water resource planning and management in South Australia.

2. BACKGROUND – RISK AND VULNERABILITY

The Risk Management Framework for Water Planning and Management (the framework) is a high-level document setting out the general context and process for risk assessments in the area of water planning and management in South Australia. It is intended to address risk assessments at all planning scales and for water resources that are both "prescribed" and "non-prescribed" in accordance with the South Australian *Natural Resources Management Act 2004* (NRM Act) (Government of South Australia, 2004).

This framework utilises the AS/NZS ISO 31000:2009 risk management guidelines as a backbone, endorsing and building on the ISO risk management definitions and processes. It establishes three categories of risk to be addressed by water planning and management activities:

1. Risks to the resource (e.g. the potential for adverse changes impacting water quantity, water quality or the health of water dependent ecosystems)
2. Risks to community values (e.g. the potential for changes in the condition of the water resource to cause impacts on economic development, water for human consumption, community amenity, and recreational, spiritual or cultural use)
3. Risks to the effective operation of a plan (e.g. a Water Allocation Plan in accordance with the NRM Act). Examples include the potential for outcomes of a plan not being achieved due to difficulties in implementing policies, legal challenges, lack of public support, non-compliance, extreme climatic events etc.

The risk management framework provides general guidelines for all stages of the ISO risk management process outlined in Figure 2 and provides a summary of risk assessment and treatment selection tools. It also promotes carefully constructed risk statements that identify both sources of risk and consequences to aid transparent assessment of risk. The following generic form is suggested:

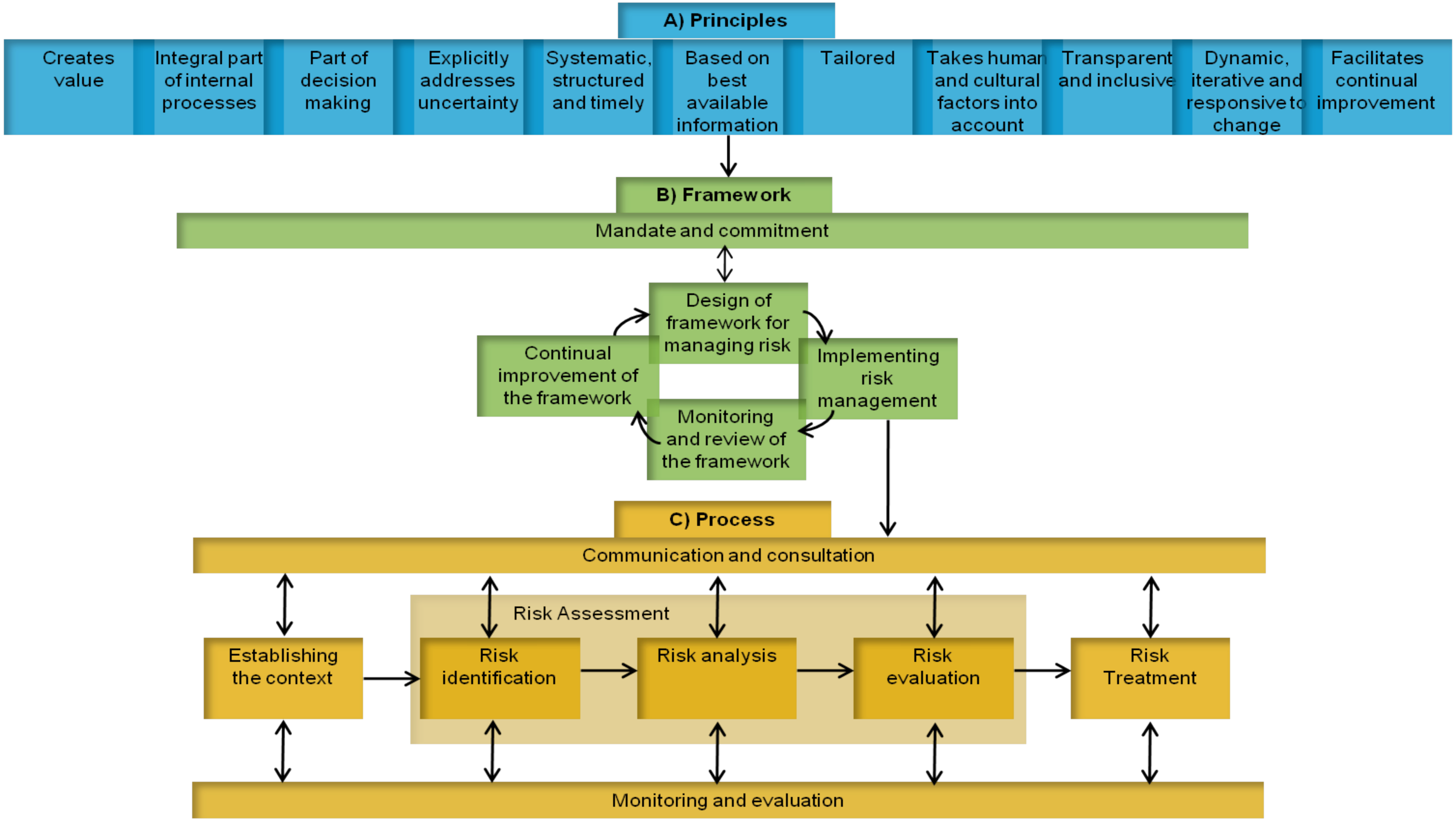
> There is the potential that [*risk source*] leading to [*event*] in turn leads to [*consequence*].

It also promotes determination of the level of confidence in the outcomes of a risk assessment process to support transparency, inform risk evaluation criteria and provide for gap analysis and prioritisation of further investigations where needed.

The Risk Management Policy and Guidelines for Water Allocation Plans (DEWNR 2012b) describe how the principles and processes of the risk management framework are implemented during the development of water allocation plans (WAPs) for prescribed water resource areas (i.e. in accordance with the NRM Act).

The policy and guidelines document suggest that water allocation plans be informed by assessments of the three categories of risk identified by the Risk Management Framework (i.e. risks to the resource, risks to community values and risks to the effective operation of the plan). They outline how these risk assessments address specific requirements of the NRM Act, and provide guidelines and minimum standards for each step of the risk assessment process. They also provide tools and templates such as generic context, example likelihood and consequence tables, assessment methods, criteria for evaluating risk tolerability and generic treatment recommendations for each category of risk tolerability.

Figure 2: AS/NZS ISO 31000:2009 risk management principles, framework and process



Source: AS/NZS IS031000: 2009

2.3. VULNERABILITY CONCEPTS

2.3.1. BACKGROUND AND DEFINITIONS

Vulnerability assessment as a process or discipline originates from the social science domain, but has recently found utility in the fields on geography, natural hazards and disaster management, ecology, sustainability science, land use change, climate change impacts, public health, poverty and development (De Lange et al. 2010). By contrast, applications relating specifically to CSG or LCM development are relatively uncommon in the literature, but examples include Liao et al. (2013), Saedi et al. (2009) and Worley Parsons 2013).

According to the AS/NZS ISO 31000:2009 risk management guidelines, vulnerability relates to the intrinsic properties of something resulting in susceptibility to a risk source that in turn can lead to an event with a consequence. For ecological and sustainability applications, there has been a trend towards integrating multiple components or factors when analysing vulnerability (Turner II et al., 2003), with attributes such as resilience, marginality, susceptibility, adaptability, fragility and risk now being considered (Fussel 2007). The exact definition and use of the term varies between disciplines and between applications within a discipline (Kasperson et al. 2005). However, there have been efforts to derive more generic conceptual frameworks, such as those of Fussel (2007) and De Lange et al. (2010).

For ecological and sustainability applications, vulnerability is generally considered to be a function of

- exposure to a stressor,
- sensitivity or potential impact or effect on the unit exposed,
- resilience or potential for recovery (De Lange et al. 2010, Turner II et al. 2003).

This definition has been used for applications at different hierarchical levels (e.g. organism, species, community, population, ecosystem, landscape etc.) and varying scope, with some methods incorporating differing elements of likelihood, risk, consequence and mitigation. With respect to species, vulnerability assessment frameworks are moving to a definition whereby vulnerability is defined as a function of sensitivity and exposure, where sensitivity relates to factors intrinsic to the species and exposure relates to factors extrinsic to the species (Williams et al., 2008).

2.3.2. APPROACHES TO VULNERABILITY ASSESSMENT

Vulnerability is inherently difficult to measure and quantify as it is not generally a clearly observable entity depending on how it has been defined. This means that quantification is often a subjective process (Villa and McLeod 2002), that is attempted relatively infrequently (see for example Metzger and Schröter 2006; Neukam and Azzam 2009). When quantification is attempted the results are generally spatially modelled and integrated over large spatial areas.

De Lange et al. (2010) observed that common aspects of published vulnerability assessment methods include use of expert judgement, input from stakeholders and qualitative ranking of impact. However, some vulnerability assessments do incorporate and/or integrate objective, quantitative data with qualitative, subjective information. Similarly, Hinkel (2011) outlined both qualitative and quantitative approaches to determining vulnerability including

- participatory (e.g. expert judgement and stakeholder driven approaches),
- simulation and model based approaches,
- indicator based approaches.

Fussel (2007) identified a number of conceptual frameworks for undertaking vulnerability assessments, including:

- Risk-hazard approach: assesses the risk to a given unit (e.g. ecosystem) arising from exposure to hazards of a particular type and magnitude.
- Political economy approach: focused on people, communities and social vulnerability.
- Pressure-and-release model: similar to the risk-hazard approach but presents an explanatory model with root causes, regional pressures and local vulnerable conditions. This approach is similar to the pressure-stressor-response model often used in environmental science (see Section 3.1.2.)
- Resilience approach: focused on the capacity of an ecosystem to bounce back, incorporating the dynamic temporal aspects of vulnerability.
- Integrated approach: combining two or more of the above.

To achieve the most effective outcomes from an assessment process based on expert judgement and stakeholder input, consistent terminology along with clearly articulated questions are essential (Fussel 2007).

In a review of studies using the participatory approach, De Lange et al. (2010) found that advantages included the ability to incorporate unpublished scientific knowledge, the ability to provide a qualified assessment for data poor areas, and the ability to easily adapt and update the assessment when new knowledge becomes available. However, major disadvantages are that it can be subjective and may lack transparency with respect to expert judgements.

2.3.3. EXAMPLES OF VULNERABILITY ASSESSMENTS

There are examples of simulation and model based approaches for vulnerability assessments in the socio-economic, climate change and groundwater vulnerability domains. Dwyer et al. (2004) used modelling to assess social vulnerability to natural hazard impacts. Metzger and Schröter (2006) present a method for quantitative spatial analyses of the vulnerability of the human-environment system to climate change in Europe by integrating spatially modelled results over large spatial scales. In both of these cases it was found that the approach used is suitable only for very broad scales.

Neukam and Azzam (2009) used groundwater simulations of water flow and solute transport to assess the vulnerability of groundwater to contamination. Whilst they were able to provide an approach for quantifying vulnerability, they also caution that such simulations tend to be restricted spatially and have to be run separately for each test site with unique hydrological and hydrogeological characteristics.

There are examples in the literature where indicators of vulnerability have been applied for policy and planning purposes. Hinkell (2011) identified that vulnerability indicators are particularly useful for the identification of vulnerable entities (e.g. people, communities, regions etc.) but may not be suited for some of the other issues that policy often requires, such as identification and prioritisation of mitigation targets, allocation of funds and evaluation of monitoring outcomes. Hinkell (2011) identifies four main types of indicators used in vulnerability assessment including

- deductive indicators, based on existing theory,
- inductive indicators, based on indicating variables and observed harm,
- normative indicators, based on value judgements,
- non-substantial indicators, based only on indicators without regard for knowledge about vulnerability.

2.4. THE SEWPAC VULNERABILITY DATABASE ENTRY FORM

As discussed in Section 1.2, a key deliverable of the SA NRM Data Project is a database of water assets and vulnerabilities structured according to the specifications of the Australian Government. To facilitate compilation of this database, SEWPaC provided a Microsoft Access vulnerability assessment data entry form as illustrated in Figure 3. The fields and options of this form represent the key attributes of vulnerability of water assets to CSG and LCM development to be considered by this assessment.

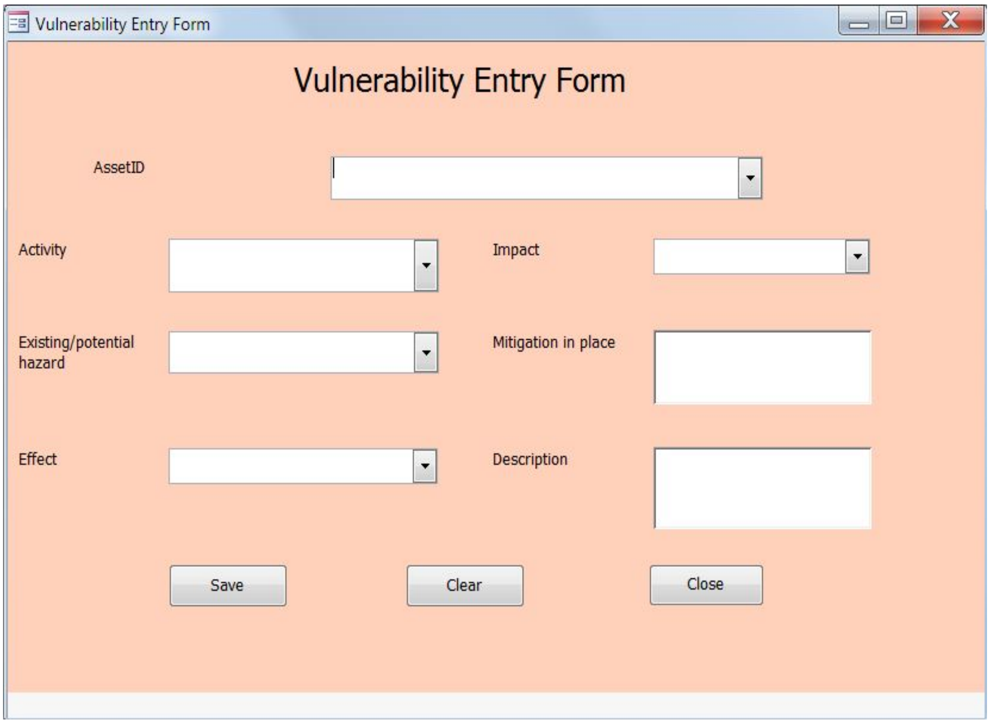


Figure 3: SEWPaC vulnerability assessment Microsoft Access data entry template

Table 2 provides a description of the fields in the data entry form. This template is designed to support a database structure whereby each water asset record may be linked to one or more vulnerability records.

Table 2: Description of the SEWPaC vulnerability assessment template

Attribute	Description	Allowed values
Asset ID	Foreign key for records in asset table	Not unique – multiple vulnerabilities per asset permitted.
Activity	CSG or LCM related development activity potentially impacting water assets	11 options (see Table 3 below)
Existing or potential hazard	Is the asset likely to be in the zone of influence for an existing or planned CSG or LCM development?	"Existing", "Potential", "None"
Effect	Component of the asset being impacted by the activity	"Flow pattern", "Habitat", "Water quality", "Water quantity"
Impact	Magnitude of effect	"Low", "Medium", "High"
Mitigation	Relevant mitigations in place to deal with risks caused by activity.	Free text
Description	Additional information regarding the vulnerability of the asset – e.g. specific community concerns	Free text

Table 3 lists the options for the 'activity' field of the SEWPaC vulnerability database template.

Table 3: SEWPaC vulnerability template. Options for 'activity' field

Activity
Coal mining
Coal seam gas
Ecosystem/community stresses
Human intrusions and disturbance
Invasive and problem species
Natural system modifications
Pollution
Residential and commercial development
Species stresses
Transportation and service corridors
Uncategorised

2.5. DISCUSSION AND CONCLUSIONS

It can be concluded from the review presented in this section that the concepts of risk and vulnerability commonly serve similar, but distinct purposes:

- Vulnerability is concerned with characterising and describing the potential for degradation or injury, which is generally interpreted as being a function of sensitivity and exposure to a hazard.
- Risk is concerned with applying an understanding of vulnerability and associated uncertainties for the purposes of decision making in a management context.

Given this distinction, it can be reasoned that assessing vulnerability is primarily a technical or scientific undertaking, while risk assessments must also factor in a risk management context including organisational goals, stakeholders, culture, uncertainty and other factors likely to affect the tolerability or acceptability of risk. Thus, in the language of risk, vulnerability assessments may be a component of a risk assessment that mostly contributes to the context setting, risk identification and risk analysis stages (see Section 2.1, Figure 2).

The review also shows that, like risk assessments, vulnerability assessments can be wide ranging, complex and context dependent because:

- They may integrate multiple sources and types of evidence.
- Inputs and the outputs of vulnerability assessment may be quantitative or qualitative in nature.
- Determination of vulnerability may be based on either deductive reasoning (i.e. application of existing theory), or inductive analysis (i.e. application of rules determined from examples).

Also, it is stressed by a number of sources that success for vulnerability assessments depends on having an agreed framework with consistent terminology and clearly articulated questions.

The specifications provided by the SEWPaC database template (Figure 3) provide the dependent and independent variables to be considered in a vulnerability assessment. Of particular note is that the only options provided for “effect” are hydrological in nature.

It also facilitates the collation of contextual information useful for a risk assessment, such as the potential for the asset in question to be affected by a CSG or LCM development and free text fields regarding risk mitigation factors and additional context.

However, the SEWPaC database template is not prescriptive on whether the impacts are intended direct impacts (i.e. the extent of hydrological change as defined by the “effect” field), or whether they can also apply to consequences or responses arising from the effect, such as the social, economic and environmental impacts of the effect. It is presumed this is intended as a decision to be left to the discretion of the user.

3. THE SA VULNERABILTY ASSESSMENT FRAMEWORK

This section describes the process for developing the SA vulnerability assessment framework and the rationale for decisions made during this process. It also presents the framework components that were developed through this collaborative effort. The assessment process to generate asset vulnerabilities, applying definitions and components described in this section, is presented in Section 4.

3.1. DEVELOPING THE SA VULNERABLITY ASSESSMENT FRAMEWORK

3.1.1. PROCESS FOR DEVELOPING A VULNERABILITY ASSESSMENT FRAMEWORK FOR SOUTH AUSTRALIA

As outlined in Section 1.2.1, the SA NRM data project was initiated as a collaborative approach to assembling water asset data with the aim of achieving a consistent and technically rigorous product. It was decided to undertake a similarly coordinated approach for the vulnerability assessment, with the assessment process to run in parallel with the water asset delineation and attribution process.

A series of workshops with relevant stakeholders was held to scope and develop the vulnerability assessment for SA water assets. A chronology of major events scheduled for this process is presented in Table 4, with the first workshop being held on 4 September 2012. There was also considerable informal consultation out of session.

Participants in the development of the vulnerability framework and assessment process included representation from organisations including

- DEWNR's Science, Monitoring and Knowledge Branch,
- Six participating South Australian NRM regions (Alinytjara Wilurara, Eyre Peninsula, Northern and Yorke, South Australian Murray-Darling Basin, South East, and South Australian Arid Lands),
- DEWNR's Information, Communications and Technology Branch.

There was also periodic communication and consultation with SEWPaC.

At the first workshop, it was decided that stakeholders would collaboratively refine and develop SEWPaC's vulnerability assessment concept in order to achieve a scientifically valid product that addressed the Australian Government's requirements in the timeframe of the project. It was also agreed that there was an opportunity to develop a product that could be used to inform water resource planning and management in South Australia into the future.

Table 4: Process for development and population of the SA Vulnerability Assessment

Date	Workshop purpose	Outcomes
4 September 2012	Scoping of SA Vulnerability Assessment Framework	- Introduced vulnerability assessment - Agreed methodology for undertaking a coordinated and consistent assessment - Defined scope of assessment - List of draft activities and effects
4 October 2012	Development of SA Vulnerability Assessment Framework	- Agreed principles for defining asset classes - Further developed and defined list of activities and effects - Discussed an approach to defining impact level - Discussed an approach to applying confidence ratings
25 October 2012	Expert panel rating of vulnerabilities – surface water assets	- Discussed asset classes - Discussed activities and effects - Preliminary population of vulnerability model for surface water asset classes
26 October 2012	Expert panel vulnerability rating – groundwater assets	- Discussed asset classes - Discussed activities and effects - Population of vulnerability model for groundwater asset classes
30 October 2012	Expert panel vulnerability rating – surface water assets	- Further population of model for surface water asset classes
1 November 2012	Expert panel vulnerability rating – surface water assets	- Further population of model for surface water asset classes
11 February 2013	Review of vulnerability assessment framework – all stakeholders	- Presented vulnerability framework as undertaken for delivery to the Commonwealth - Discussed strengths and weaknesses of, and potential improvements to, the framework

3.1.2. ADOPTING A PRESSURE-STRESSOR-RESPONSE MODEL FOR WATER ASSET RISK

At the initial scoping workshop (see Table 4), participants agreed that the vulnerability assessment methodology should be conceptually simple so that it is practicable in the context of the large number of water assets and the timeframes of the project. It was therefore agreed that the vulnerability assessment should draw as much as possible on established frameworks and concepts such as the DEWNR Risk Management Framework for Water Planning and Management (DEWNR, 2012a) and existing models for water asset risk.

It was determined that the 'Pressure-Stressor-Response' (PSR) approach (Marshall et al. 2006) provides a useful conceptual model for water asset risk that would

- facilitate communication of key components of the vulnerability assessment data model underpinning the SEWPaC data entry form (described in Section 2.4 above),
- achieve consistency across the attributes of the vulnerability assessment data model promoted by SEWPaC's data entry template (Figure 3).

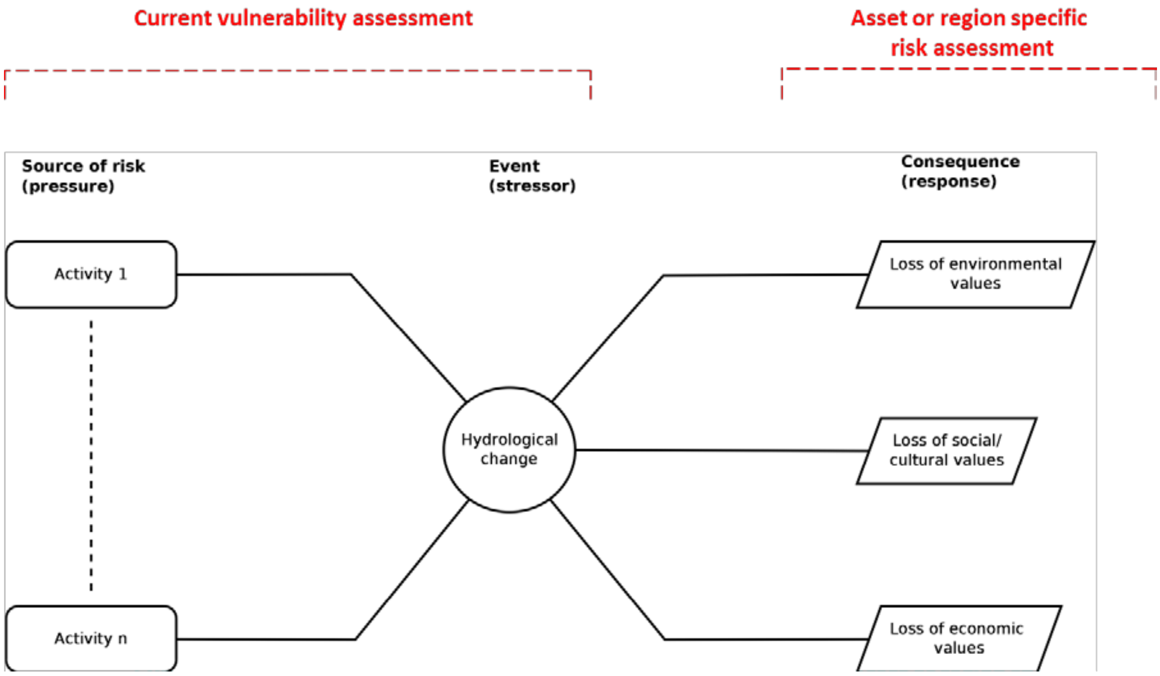


Figure 4: Generic "bow-tie" model of water asset risk

Figure 4 presents a "bow-tie" conceptual model of water asset risk, agreed to by stakeholders, showing how elements of risk align with the PSR framework. Tracing a line from left to right through this model (i.e. through pressure, stressor and response) provides a description of an occurrence or change in circumstances caused by development that is consistent with the structure of a generic risk statement as proposed by DEWNR's Risk Management Framework for Water Planning and Management (see Section 2.2).

Table 5: Alignment of a Pressure-Stressor-Response model with vulnerability and risk concepts (after McNeil and Wilson, 2013)

PSR model Component	Vulnerability Component	Risk Component	Definition from AS.NZS ISO 3100:2009
Pressure	CSG or LCM activity	Risk source or hazard	Element which alone or in combination has the intrinsic potential to give rise to risk
Stressor	Potential hydrological change caused by pressure. Expressed as effect and impact according to the SEWPaC data model (Figure 3).	Event	Occurrence or change of a particular set of circumstances
Response	Changes of environmental, social or economic values (beyond the scope of this assessment)	Consequence	Outcome of an event affecting objectives

This model was also adopted by McNeil and Wilson (2013) as an organising principle for data and models supporting the Bioregional Assessment process for the Lake Eyre Basin, contributing to a strategic adaptive management framework (Kingsford and Biggs, 2012).

Table 5 provides more description on how the concepts of the PSR model and elements of risk and vulnerability align. This table also includes relevant definitions of the risk components from the AS/NZS ISO 31000:2009 risk management guidelines (Joint Technical Committee OB-007, 2009).

3.1.3. OBJECT OF THE ASSESSMENT – ASSETS VS ASSET CLASSES

A key realisation made early in the framework development process was that the most feasible approach to achieving a comprehensive vulnerability assessment for all assets delineated through the SA NRM data project was to focus the assessment on asset classes rather than individual assets. Thus, it was elected to define an asset typology, undertake vulnerability assessments for the categories or classes of assets defined by this typology and then generalise the results of the assessments to all assets in the asset database.

In addition to concerns regarding practicality and consistency, stakeholders identified the following advantages of this generic approach:

- Focussing on a generic approach tends to promote a more transparent basis for assessments.
- Uncertainty regarding potential CSG and LCM development and the location of coal deposits has no bearing on the outcomes of the assessment (although this type of uncertainty may be relevant for an overarching risk assessment).
- Vulnerabilities can be generalised to other development pressures involving similar activities to those typical of CSG and LCM projects.

Over the first two workshops (4 September and 4 October 2012), it was recognised that the hydrologically focussed definition of a water asset adopted by the SA NRM Data project (see Table 1) would fundamentally affect the scope of vulnerabilities that could reasonably be assessed. Therefore, the following decisions were made regarding the scope of the vulnerability assessment framework:

- Asset classes, on which vulnerability is to be assessed, should be based on those attributes that describe the hydrology of the asset and the potential for hydrological change.
- Vulnerabilities should characterise and rank hydrological changes that could affect an asset's value as indicated by receptors (see discussion on the PSR model of water asset risk in Section 3.1.2).
- Activities should focus on those CSG and LCM operations that could contribute to risk of hydrological change, defined according to the scope of vulnerabilities to be considered.

On this basis, it was decided to define asset classes according to the "water source" and "water regime" attributes of the water asset database.

3.1.4. ALIGNING THE SEWPAC VULNERABILITY DATABASE SCHEMA WITH THE PRESSURE-STRESSOR-RESPONSE MODEL

To achieve consistency with the agreed definition of a water asset and the PSR model of water asset risk adopted at the outset of the project (see Section 3.1.2), a series of conclusions was drawn by stakeholders regarding the “activity”, “effect” and “impact” fields of the SEWPaC vulnerability assessment template (Section 2.4).

With respect to the activities field, there was concern that the options provided by the Microsoft Access database form (Figure 1) cut across all elements of the PSR water asset risk model, including pressures, stressors and responses. It was anticipated this could affect both the consistency of the information and ratings captured by the assessment and its future applicability in supporting risk assessments. To address this issue, it was agreed by stakeholders to review these options in line with the following principles:

- Activities should only be related to pressures – those deemed to be stressors and responses should not be considered by the assessment.
- Activities should be limited to those that arise directly from CSG and LCM developments. Activities that are secondary pressures (i.e. additional pressures caused as a result of a coal related development such as urban development) or have no relation to CSG and LCM developments should not be considered.
- There should be a more comprehensive coverage of direct CSG and LCM related pressures than is provided in the original data entry template.

With respect to the effects field, it was concluded that the options provided by the Microsoft Access database entry form were too general to be useful in supporting more focussed risk assessments in future. Therefore, it was elected to revise and expand the list of potential effects to provide more comprehensive coverage of the types of hydrological changes potentially caused by the types of CSG and LCM activities considered in the assessment. Furthermore, it was agreed that the effects field should describe stressors in the context of a PSR model for water asset risk (as foreshadowed in Section 3.1.3).

Finally, it was agreed that options for the “impacts” field should cover negligible and unknown impacts as well as low, moderate and high impacts, and that assignment of impact should be guided by a framework of agreed criteria and assumptions to provide a meaningful and consistent basis for each of the ratings.

3.1.5. DISCUSSION – CONTRASTING VULNERABILITY AND RISK ASSESSMENT FRAMEWORKS

The agreed scope for water asset vulnerabilities is expressed in the top left of the PSR water asset risk model illustrated in Figure 4 (in red). This shows that the vulnerability assessment deals with the potential transformation of pressures caused by CSG and LCM to hydrological stressors. In the language of risk, this can be described as the potential for risk sources, or hazards, to cause events of a hydrological nature.

However, it was agreed that the vulnerability assessment should not, in this instance, deal with how stressors are related to responses (i.e. events to consequences). Thus, determination of consequences that may arise from hydrological changes, such as impacts on social, economic or environmental values, are specifically excluded from this assessment, although they would need to be picked up by a more comprehensive risk assessment process.

These decisions regarding the scope of the SA Vulnerability Assessment Framework mean that while it is intended to address a component of the information needed to support a full risk assessment, it does not in itself represent a risk assessment in accordance with DEWNR's risk management frameworks. For example, it does not consider

- likelihood of CSG and coal mining activities,
- social, economic and environment values attached to water assets by the community,
- evaluation of the acceptability or tolerability of vulnerabilities.

However, it is anticipated that the vulnerability assessment, as scoped, will provide a useful information resource and framework for supporting future risk assessments because it informs the following steps of the risk assessment process (Figure 2):

- Establishing context, including identification of the parameters affecting risk and determination of risk criteria.
- Risk identification, involving finding, recognising and describing risks.
- Risk analysis, where the nature of the risk is comprehended and the risk level is determined.

As the vulnerability assessment is intended to be linked to the asset database, assessments will apply for assets identified at a range of scales from local to regional.

3.1.6. CONCLUSIONS – SUMMARY OF AGREED OUTPUTS FOR THE VULNERABILITY ASSESSMENT FRAMEWORK

Having reached agreement on the purpose and scope of the vulnerability assessment, the project embarked on developing a framework to enable a consistent vulnerability assessment across all the water assets delineated through the NPA NRM data project. This framework comprises the following elements:

- An asset typology driving the vulnerability assessment (Section 3.2.1).
- A refined list of options for:
  - CSG and LCM activities,
  - effects.
- An agreed methodology for deriving impact including
  - criteria for impact ratings,
  - assumptions governing impact rating criteria,
  - criteria for confidence in ratings.
- A populated vulnerability model.

It should also be noted that, in the language of DEWNR's Risk Management Framework for water planning and management, the agreed vulnerability assessment approach is primarily intended to document properties of different types of water asset that relate to risks to the resource. Thus, following the discussion in Section 2.5, the impact rating required by the SEWPaC database template is interpreted as relating only to vulnerabilities leading to potential hydrological changes, not to other types of social, economic or environmental changes.

3.2. COMPONENTS OF THE SA VULNERABILITY ASSESSMENT FRAMEWORK

3.2.1. ASSET CLASSES TO BE ASSESSED

As discussed in Section 3.1.3, it was decided that the object of the vulnerability assessment would be asset classes identified according to the water source and water regime attributes of the asset database. Table 6 and Table 7 list the possible values for water source and water regime. It should be noted that these attribute definitions were determined through the SA NRM Data Project. The scope of these definitions provides an upper limit to the detail of information about an asset (e.g. temporal context of changes) that can be considered when determining vulnerabilities. The vulnerability assessment framework addresses the likely combinations of these two fields following population of the water asset database.

Water source (Table 6) for an asset may be a combination of one or more sources including rainfall, runoff from land, overflow from rivers or streams and groundwater where the dominant water source is defined as having a greater than 70% contribution of water to the asset. Only one selection is permitted per asset, although it is possible to define an asset with a combination of water sources through the 'combined' options.

Table 6: Water asset database: Options for water source

Water source
Surface: In-stream
Surface: Rainfall
Surface: Overbank
Groundwater
Combined: groundwater dominant
Combined: surface water dominant
Combined: unknown
Unknown

The water regime of an asset (Table 7) is the prevailing pattern of water flow. It may refer to the duration, magnitude, frequency and seasonality of flows resulting from the water sources. Unlike water source, multiple water regime selections were allowed for each asset. Note that it is possible to delineate and attribute assets where either or the both water source or water regime are unknown. Table 8 lists components of water regime relevant for surface water systems.

Table 7: Water asset database: Options for water regime

Surface water assets	
Permanent	May be static or flowing, with varying levels, however is predictably filled.
Seasonal	Covers intermittent with wet and dry periods on a regular basis according to season
Episodic	Dry most of the time with irregular wet phases that may persist for months. Annual inflow is less than minimum annual loss in 90% of years
Ephemeral	Only filled after unpredictable rainfall and runoff. Surface water dries within days/weeks of filling, and drying time may impact certain short-lived macroscopic aquatic life
Waterlogged	Areas that are wet but generally not inundated. No pooled water at surface.
Surface: Combined	Combination of the above water regimes
Surface: Unknown	Surface water asset, unknown water regime
Groundwater assets	
Confined artesian	An artesian aquifer is a confined aquifer containing pressurised groundwater. A confined aquifer is overlain by a low permeability layer, so it does not receive direct recharge and is less responsive to surface conditions. Water in a confined aquifer is under pressure
Confined non-artesian	A confined aquifer is overlain by a low permeability layer, so it does not receive direct recharge and is less responsive to surface conditions. Water in a confined aquifer may be under pressure, but the pressure head is not above ground level.
Unconfined	An unconfined aquifer, or water-table aquifer, receives recharge from the land surface directly above. Ecological conditions in unconfined aquifers are responsive to rainfall and land use.
Surface and groundwater assets	
Combined	Combination of water regimes
Unknown	Surface or groundwater asset, unknown water regime

Table 8: Components of water regime for surface water systems (after Boulton and Brock, 1999)

Features	Definition
Timing	When water is present. Within-year patterns are most important in seasonal wetlands whereas among-year patterns and variability in timing are relevant to temporary wetlands.
Frequency	How often filling and drying occur. Ranges from zero (permanent waters) to filling and drying in shallow wetlands many times a year.
Duration	Period of inundation. Days to years, varying within and among wetlands. Rates of rise and fall may be important
Extent and depth	The area of inundation and depth of water (influenced by volume and landscape)

3.2.2. ACTIVITIES

An extended list of CSG and LCM related activities was agreed during the initial two workshops of the vulnerability assessment framework development process presented in Table 4. As explained in Section 3.1.4, the aim for the revised list of activities was

- to promote a vulnerability assessment consistent with the hydrological focus of the water asset definition agreed through the NPA NRM data project (see Table 1),
- to provide for a comprehensive coverage of the hydrological pressures that may be caused by CSG and LCM,
- to focus the vulnerability assessment on the contribution of CSG and LCM pressures to hydrological stressors (see Figure 4).

Table 9 presents a list of activities to be considered by the vulnerability assessment, as agreed in the first two workshops outlined in Table 4. This table also presents definitions and any key assumptions or exceptions regarding each activity. Note that the table on provides definitions for activity and is not intended to communicate vulnerabilities specific to these activities – this is expressed through the assessment of effects and impacts.

3.2.3. EFFECTS

The 'effect' field is intended to indicate a hydrological component or feature of the asset being impacted by one of the activities listed in Table 9. As discussed in Section 3.1.4, it was agreed that the original options provided by SEWPaC should be revised and expanded so as to provide a more comprehensive coverage of the potential hydrological changes to water assets caused by CSG and LCM activities. This revised list of effects to be used for the current assessment, along with accompanying descriptions, is presented in Table 10.

Table 9: SA vulnerability assessment framework – agreed CSG and LCM activities

Activity	Definition	Assumptions/exceptions
Discharge to surface water	Discharge of water to any surface-water body as part of an authorised activity.	It is assumed that discharged water is treated where necessary in accordance with relevant requirements. This activity does not include disposal of tailings or other waste.
Evaporation ponds and tailings storage	Storage of mine waste water or tailings in evaporation ponds and/or tailings storage facilities. Waste water may be generated through mine dewatering or coal seam gas activities. Tailings are the materials left over after the process of separating the valuable fraction from the uneconomic fraction during the mining process	It is assumed that the ponds and storage facilities are approved and have been constructed and maintained according to the required standards.
Groundwater dewatering and extraction	Extraction or removal of groundwater from aquifers through wells (either pumped or through natural pressure). This may be for the purposes of water supply, mine slope stability and trafficability, CSG production and management of tailings storage facilities and/or evaporation ponds.	
Hydraulic fracturing ("fracking")	Pumping a fracturing fluid into a well under sufficient pressure to induce an artificial fracture network within the rock or coal seam to facilitate the flow of gas to a well. Fracturing fluid may be comprised of water, sand and chemicals.	Well drilling and waste disposal are dealt with through other activities – this activity focuses on the pressurisation process and the introduction of chemicals and sand into an aquifer.
In-situ gasification	A process by which coal is converted into gas while still in the coal seam. It involves controlled, high-pressure combustion of the coal seam and extraction of the product gas to the surface through wells. Constituents to support the desired combustion process such as air and/or oxygen and steam are fed through injection wells.	Also known as underground coal gasification (UCG).
Managed aquifer recharge	Adding a water source, such as recycled water, to aquifers under controlled conditions – for example by injection or infiltration.	
Overburden management	Overburden is the soil or rock overlying a mineral deposit that is displaced during mining without being processed. This material needs to be stored or deposited elsewhere – often in a surface facility such as a waste rock dump.	

Activity	Definition	Assumptions/exceptions
Site establishment and traffic	Site presence, clearing, development and existence of infrastructure (structures), site traffic (both foot and vehicular), pit excavation, and any other physical disturbance associated with the establishment of a mine site. It also includes any site establishment activities and traffic associated with exploration.	Focuses on the more localised aspects of site establishment. Activities such as site runoff, water diversion, flow capture and water extraction are excluded from this definition as they are covered in other activities
Site runoff	Changes in surface runoff as a result of rainfall caused by the presence of hard surfaces, unprotected surfaces, and compaction of soil at a mine site.	
Surface water diversion and capture	Diversion of surface water, via physical structures, that result in changes to natural surface-water flow path. This may include re-routing of surface water, as well as storages that capture runoff or impede flow. It includes both diversion and on-stream and off-stream capture. Examples of this activity may include the diversion (re-routing) of a flow path for operational reasons, or an on-stream dam or farm dam.	Note that extraction or loss through increased evaporation are specifically excluded from this definition as these activities are the province of the 'surface water extraction' activity. Anything covered by this activity can be undertaken with a permit only (i.e. no license required as for extraction).
Surface water extraction	Includes the extraction or removal of surface water including water that is extracted through diversion activities. This also includes any additional losses to the system due to coal mining development, for example pumping (either on-stream or from an off stream diversion) or increased evaporation (due to capture).	This activity includes any removal of water that requires a license.
Well drilling	Physical drilling and construction of a well (excludes consideration of waste products produced as part of the drilling process, or any water extraction that may occur)	Note that the definition excludes consideration of the waste products produced as part of the drilling process, or any water extraction that may occur as part of this process as these activities are covered by other definitions.

Table 10: SA vulnerability assessment framework: Effects

Effect	Description
Surface water/ground water connectivity	Surface water-groundwater connectivity refers to the direction and extent of flow between surface water and groundwater resources, and connectivity between surface water assets. This may include, for example • groundwater contributing to the base flow in a stream, • groundwater seepage maintaining a surface water site during an extended dry period, • a surface water expression of groundwater such as a spring, • surface water recharging groundwater by seeping into the aquifer, • surface water to surface water connectivity. Assessing the degree of connectivity between surface and ground water systems is complex and includes both spatial and temporal components. It is important to consider, for example, that an impact to a surface water system may also impact the aquifer indirectly through lack of recharge, or vice versa.
Physical habitat	The disturbance of geomorphology and landform, by which the underlying geomorphic structure of an asset is changed resulting in altered hydrology and other impacts either directly or indirectly (e.g. sedimentation). It may also include the disturbance of structural organic habitat components, such as macrophyte beds and lignum stands.
Water quantity	A change in the amount of water available to an asset, outside the bounds of natural variability, and may include either an increase or decrease in water quantity. This effect is concerned with either an increase or decrease of water volume only, as other aspects of the water regime are dealt with as part of other effects (surface water regime and groundwater flow pattern).
Surface water regime	A change in the surface water regime, as summarised in Table 7.
Water quality	A change to the water quality parameters of an asset, outside the bounds of natural variability, and may affect • salinity, • sediment load, hence turbidity, • temperature, • pH, • pollutants/toxicants, • nutrients, • dissolved oxygen.
Groundwater flow pattern	A change in groundwater flow patterns, including • rate of flow, • direction of flow, • depth to aquifer, • residence time, • disruption to paleochannels,, and • spatial extent of flow.
Groundwater pressure	An increase or decrease in groundwater pressure.
Aquifer structural integrity	A change to aquifer and aquitard structural integrity, for example the fracturing of a confining layer.
Functional connectivity of surface water	The creation of barriers (physical or temporal) that inhibit the movement of flora (for example, as seeds and other propagules) and mobile organisms (for example, fish).

3.2.4. IMPACT

3.2.4.1. Categories and criteria

In accordance with the SEWPaC vulnerability assessment template (Section 2.4), the impact ratings in this assessment are intended to describe the extent of potential change in the hydrological characteristics of an asset caused by an activity. Impact is rated for each combination of asset class, activity and effect.

It was agreed by participants in the framework development process that impact criteria should consider the hydrological integrity, asset resilience, and the time to recovery of a system relative to the expected asset state, where:

- *Hydrological integrity* is the potential for the hydrological regime to be restored if the pressure is removed.
- *Resilience* is the capacity of a system to tolerate or resist change and disturbance and remain in the same 'state' (e.g. asset type), as well as its capacity to restore itself following disturbance (Carpenter and Folke 2006; Folke 2003; Holling 1973).
- *Time to recovery* incorporates the temporal scale of resilience, and indicates whether return to its previous condition is rapid, slow or whether the change to an asset is permanent.

Unlike vulnerability assessment frameworks described in the literature (Section 2.3) these criteria do not address exposure to a hazard, although this is implicitly covered through the assessment of vulnerability to CSG and LCM activities.

Loss of resilience may lead to more vulnerable systems and possible shifts to undesired 'states' that provide fewer, or different, services and values. For this assessment, resilience will be considered as the degree of recovery that may be seen in a system after a disturbance (e.g. activity and effect).

Table 11 shows the impact ratings and associated criteria related to each rating for the categories described above.

It was agreed that criteria for 'slow' versus 'rapid' time to recovery depends on the expected natural dynamics of the asset class being assessed. For example, a 'slow' time to recovery might be very different when comparing the vulnerability of a seasonal wetland with an episodic wetland, which might be wet only once in 25 years. Due to the timeframes of the project, no definitive *a-priori* rules were established regarding appropriate temporal scales for each impact category and asset class. However it was accepted during the assessment that a slow recovery might take longer than a single wetting and drying cycle expected for the asset class.

For the purposes of this vulnerability assessment the impact criteria specifically exclude the following considerations:

- Temporal nature of the onset of the impact (i.e. time to impact)
- Current asset condition (i.e. physical condition)
- Potential effects on the asset ecological or socio-economic values.

Current asset condition is excluded because it is deemed to be most relevant regarding vulnerability for ecological values as opposed to hydrological attributes, which are the focus of the current assessment.

As discussed in Section 3.1.4, 'n/a', 'negligible' and 'unknown' were added to the list of possible impact ratings provided in the SEWPaC vulnerability template.

Table 11: SA vulnerability assessment framework - criteria for rating impact

	Change to hydrological integrity	Resilience	Time to recovery
High	Change in 'state' (i.e. different asset class)	No return or transition back to previous hydrology or asset class	Permanent or non-permanent change
	Change to hydrology	No return or transition back to previous hydrology	Permanent change
Moderate	Change to hydrology	Return to expected/previous hydrology	Slow
Low	Change to hydrology	Return to expected/previous hydrology	Rapid
Negligible	No change to hydrology	Not relevant	Not relevant
N/A	Not relevant	Not relevant	Not relevant
Unknown	Unknown	Unknown	unknown

3.2.4.2. Assumptions affecting impact ratings

These assumptions outline the basis on which impact ratings have been made by this vulnerability assessment. They provide documentation on how sources of variance in data, opinion and interpretation of the vulnerability assessment framework have been considered for the purposes of achieving consistent and comparable impact ratings. The full list of assumptions is presented in Table 12.

Compilation of these assumptions has occurred through the workshop and synthesis phases of this vulnerability assessment – thus, they represent collective decisions and expert opinions regarding the implementation of the framework.

Table 12: Assumptions underpinning impact ratings for the vulnerability assessment

	Assumption
1	This assessment is concerned with the hydrological impact on water assets arising from coal development activities. It does not assess any impacts on the values attributed to water assets such as ecological degradation occurring as the result of hydrological impacts.[1]
2	Surface water is considered to be any expression of water above the surface of the ground, this may include the surface expression of groundwater and areas of waterlogging.
3	Groundwater is considered to be any water existing below ground; assets may include aquifers along with related aquitards.
4	It is assumed that due process and regulation has been followed by CSG and LCM development. The risks of pollution, changing water regimes and other effects that are considered when making vulnerability assessments therefore do not consider the possibility of illegal or unreasonably non-compliant operations.
5	It is acknowledged that many factors not explicitly considered by this vulnerability assessment may influence the effects and impacts of coal development activities on assets. Since the aim of this assessment is to establish generic vulnerabilities for asset classes where circumstances are broadly equivalent in order to establish relative sensitivity to pressures (as an input to future risk assessment processes), a 'worst case scenario' is assumed in terms of pressures, effects and impacts. For example, where the size of an asset could influence the magnitude of an impact it is assumed that the ratio of pressure (e.g. extraction, discharge) to size of the site is sufficient to have a significant impact.
6	For surface water assets, the degree of flushing that occurs could influence the effect and impact of coal development activities. For vulnerabilities where flushing could be a factor the assessment has been annotated accordingly. The following general assumptions may be made for the purposes of this assessment: • Stream systems have some degree of flushing. • Rain-fed systems have little, or no, flushing. • No assumptions can be made with respect to the degree of flushing for overbank systems or systems with combinations of water sources. In these cases the default 'worst case scenario' has been applied (i.e. little, or no, flushing).
7	While 'episodic' and 'ephemeral' are distinct water regimes, it is assumed for the purposes of the current vulnerability assessment that effects and impacts of activities are similar for each class. Therefore in the database where both options are available, the outcome of the vulnerability assessment will be the same for each.
8	A 'combined' groundwater asset is assumed to be a regional rather than a local asset as it contains both confined and unconfined regimes. Therefore highest impact (from both confined and unconfined) at a regional scale is used for the assessment.

[1] A detailed risk assessment investigating the effects of coal development on ecological objectives could consider ecological vulnerabilities and values in addition to the hydrological vulnerabilities being determined through this assessment.

3.3. SUMMARY OF CHANGES TO THE SEWPAC VULNERABILITY TEMPLATE

The changes to the SEWPaC vulnerability template along with the rationale for each change are summarised in Table 13.

In addition to the changes to the options available for the activities, effects and impacts fields, it was elected to add fields for confidence, scale and conditions. The description of these fields and the rationale for their inclusion are presented in Table 13.

Table 13: SA vulnerability assessment framework: Summary of changes to SEWPaC vulnerability template

Attribute	Change	Rationale
AssetID	No change	
Activities	Expand list of activities to more accurately reflect the potential range of CSG and LCM activities	Provide for a more comprehensive coverage of the hydrological pressures that may be caused by CSG and LCM activities.
Activities	Disregard activities not directly related to CSG and large coal mining activities	Some of the activities present in the existing list e.g. ecosystem/community stresses, species stresses etc were deleted as it was deemed they related to pressures that are either unrelated to coal development, or that they were relevant for secondary effects arising from hydrological pressures (i.e. stressors).
Hazard	No change	
Effects	Add additional effects reflective of CSG and large coal mining activities	Provide for a more comprehensive coverage of the hydrological stressors that may be directly caused by CSG and large coal mining activities.
	Disregard effects that are unrepresentative of CSG and large coal mining	Maintain focus on the potential hydrological stressors caused by CSG and large coal mining as opposed to broader environmental, social and economic impacts.
Impact	Add additional impact ratings; “Unknown”, “Negligible”, “n/a”	Provide more granularity in the assessment and enable identification of vulnerability cases where a lack of knowledge precludes a rating.
	Definitions for each of the impact ratings	Facilitate impact ratings in accordance with contemporary concepts of vulnerability. Promote consistency of assessment between asset classes, activities and effects.
	A set of assumptions or preconditions that apply with respect to all ratings	Facilitate impact ratings that are consistent across all cases and define the scope of conditions under which a vulnerability score is valid.
Mitigation	No change	
Description	No change	
Confidence	Add confidence rating for each impact rating: “low”, “medium, “high”	Facilitate uncertainty/gap analysis based on this assessment.
Scale	Add attribute describing the scale of the asset: “local”, “regional”	In some cases, the vulnerability of the asset varies depending on the geographic extent of the asset compared with the activity/pressure. This field was added to permit these differences to be recorded.
Conditions	Add free text field	This field enabling specific conditions identified by expert panels regarding an impact assessment to be recorded in the database.

4. APPLYING THE SA VULNERABILITY ASSESSMENT FRAMEWORK

This section describes how the vulnerability assessment framework presented in Section 3 was applied to i) determine the vulnerability of asset classes, and ii) generalise these vulnerabilities to the SA NRM water asset database.

4.1. ASSESSMENT METHODOLOGY

The vulnerability assessment was predominantly an expert elicitation process engaging knowledge from the fields of surface water hydrology, ecology of water dependent ecosystems and hydrogeology. The assessment process also drew on data, references and models. Four scheduled workshops were held over October and November 2012 as outlined in Table 4. These workshops were attended by DEWNR staff from the SMK Branch and by experts and stakeholders from the participating NRM regions. In addition to these scheduled workshops, there were a number of additional follow-up meetings that took place to clarify ratings or to address questions on notice.

It was found that determination of the vulnerabilities of surface water asset types was more demanding in terms of expert elicitation than for groundwater asset types. In particular, it was noted that for surface water systems there is an implicit link between hydrological change and ecological values which can be difficult to put aside when making impact ratings. These challenges are indicated by the requirement for three workshops to assign surface water asset type vulnerabilities as opposed to a single groundwater vulnerability workshop.

4.1.1. RATING IMPACT

Experts were asked to arrive at a single impact rating for each instance of water source, water regime, activity and effect. Given the project timeframes, it was elected not to compile separate scores for each attribute of the rating criteria outlined in Table 11, but to consider all of these attributes together in coming up with a rating.

When considering a rating, participants were asked to refer to the vulnerability framework discussed in Section 3.2, with particular reference to agreed definitions (i.e. water source, water regime, activity and effect) and the assumptions accompanying the impact rating criteria. For the most part, those involved in the expert elicitation process had also been engaged during the framework development process meaning that they had familiarity with the types of questions likely be put to them.

Vulnerabilities were recorded in a table that was prefilled with the following options:

- Water source (see Table 6 for a list of options)
- Water regime (see Table 7 for a list of options)
- Activity (see Table 9 – total of 12 options)
- Effect (see Table 10 – total of 9 options)

For each asset class (i.e. combination of water source and water regime) experts were asked to provide impact ratings for all combinations of activity and effect. Thus, each asset class to be assessed would be applied to 12 activities and 9 effects, making a total of 108 impact ratings.

As outlined in Section 3.3, the outputs of the expert elicitation phase included the following fields:

- Scale (local, regional)
- Conditions (free text)
- Comments (free text)
- Impact (see Table 11 – total of six options)
- Confidence

It was elected not to include the “potential/existing hazard” or the “mitigation” fields as outputs of the assessment for vulnerability of asset classes. These fields were instead addressed on a per-asset basis by the NRM region responsible for asset delineation in accordance with the agreed approach for populating the water asset database.

Due to project timeframes, the vulnerability assessment was undertaken in parallel with the water asset delineation and attribution process. As a result, the vulnerability assessment process could not proceed on the basis of a known set of water source and water regime combinations. This left two options available:

1. Undertake assessments for all possible combinations of the water source water regime outlined in Table 6 and Table 7 respectively. This would mean undertaking assessments for 96 possible asset classes.
2. Make a projection based on reasonable expectations of asset classes likely to be represented in the database to reduce the number of assessments required.

It was elected to rationalise the assessment according to the second of these two options. In addition, the following rules were applied as further measures for making the assessment task manageable:

- Where water source or water regime is unknown or unset, set all vulnerabilities to “unknown”.
- Where water regime is “combined”, set all vulnerabilities to “unknown”.
- Do not consider combinations of water source and water regime unlikely to be observed – e.g. some combinations of “surface” derived water source and groundwater regimes.

In total, it was found that 81 (out of a possible 96) asset classes needed to be subject to a vulnerability assessment to provide complete coverage for all the assets that were delineated and attributed by NRM regions through the SA NRM data project. These include those asset classes where all impacts were set to “unknown” through application of the above rules.

4.1.2. “SCALE” AND “CONDITIONS” FIELDS

During the framework development phase, stakeholders recognised that even with the assistance of a more strictly applied PSR model and focussed definitions for each element of the framework, there were a number of foreseeable difficulties in rating impact:

- The simplicity of the model combined with the generic nature of the framework constrains the realism of the assessments.
- Experts may be uncomfortable with the notion of making judgements in this context without the capacity to provide a set of governing assumptions or caveats regarding the judgements.

However, it was recognised that, while the vulnerability assessment model in this instance is simplistic, it is structured to facilitate further development. It was also realised that the process of undertaking this assessment provided opportunity to simultaneously collate information that may be useful for scoping more realistic analyses in future. Given these insights, the decision was made to enable participants to provide additional information regarding individual assessments in a semi-structured manner through addition of optional “scale” and “conditions” fields to the outputs of the assessment. These fields address the following:

- the “scale” field allows assignment of vulnerability given different scales of development pressure
- the “conditions” field allows the documentation of additional caveats or conditions regarding an assessment

Furthermore, it was elected to allow the creation of multiple impact ratings per instance of asset class, activity and effect. This allowed differentiation of impact either on the basis of scale or on other arbitrary conditions or assumptions, where workshop participants deemed this relevant.

4.2. OUTPUTS OF THE VULNERABILITY ASSESSMENT PROCESS

4.2.1. NUMBER OF ASSESSMENTS

The vulnerability assessment process generated a total of 8849 rows of data, where each row reports an impact assessment given the modified SEWPaC schema outlined in Table 13. It was noted during the assessment process that, for a number of cases, outputs of one set of assessments (i.e. for a given asset class/activity combination) could be largely copied to similar instances with minor modifications. Thus, it was not necessary for experts to directly consider all 8849 instances.

Out of this set of 8849 results, there are 8703 records having unique water source, water regime, activity and effect combinations. This means that, as foreshadowed in Section 4.1.2, the expert panels utilised the opportunity to provide multiple impact assessments for some scenarios, or instances of asset class, activity and effect.

Out of these 8703 unique instances, 8561 were provided with a single impact assessment, 138 had two impact assessments while four had three impact assessments. It was found that all vulnerability assessments where multiple impact assessments had been applied were for groundwater assets as indicated by water regime (see Table 14). For these instances, it was found that impact depended on the scale of impact (i.e. local versus regional) and on other specific conditions identified by the expert panels as listed in Table 15.

Table 14: Water regime values for which multiple impact assessments per asset class, activity and effect were recorded

Water regime	Number of instances with >1 impact assessment
Groundwater: Confined artesian	36
Groundwater: Confined non-artesian	27
Groundwater: Unconfined	79

Table 15: Conditions recorded for groundwater assets where multiple impacts were recorded

Conditions	Count
Activity occurs in asset	8
Activity occurs in confined aquifer beneath asset	8
Aquifer is thick fine silt or clay	4
Badly constructed/ completed wells	30
Confined aquifers in close proximity to GAB mound springs	6
CSG operation	3
Environment Protection Authority guidelines difficult to implement	3
Great Artesian Basin springs	3
High density of hydraulic fracturing (fracking) operations	8
Losing system	72
Low density of fracking operations	8
Most confined aquifers	6
Open cut mine	3
Pressure head below confining layer	2
Well is badly constructed/completed	12

4.2.2. DISTRIBUTION OF IMPACT RATINGS

Table 16 shows the distribution of impact ratings across the entire vulnerability assessment. 'Unknown' accounts for 5101 of the records in the vulnerability table, which is over 50% of the total vulnerability assessments. Also, 2232 assessments (i.e. approximately 25% of the total vulnerability assessments) received ratings of 'n/a'. In these cases it was deemed that it was impossible for the activity to lead to an effect for the asset class – for example "well drilling" could not affect "aquifer structural integrity" for a surface water asset.

Table 16: Vulnerability assessments, total counts per impact rating

Impact rating	Count	Percentage
High	232	3%
Moderate	486	6%
Low	448	5%
Negligible	350	4%
n/a	2232	25%
Unknown	5101	58%

Table 17 shows the proportion of impact ratings set to 'unknown' according to water source. This table shows that having an 'unknown' or 'unset' water source leads to nearly all vulnerability ratings being 'unknown'. Similarly, the 'Combined: Surface water/groundwater (SW/GW) unknown' water source was characterised by a higher proportion of 'unknown' impact ratings than the other less ambiguous water source options (69% compared to 40-53% for the remainder).

Table 17: Unknown impact rating by water source

Water source	Unknown
Combined: groundwater dominant	40%
Combined: surface water dominant	53%
Combined: SW/GW unknown	69%
Groundwater	40%
Surface: in-stream	53%
Surface: overbank	41%
Surface: rainfall	41%
Unknown	92%
Unset	95%

Table 18 shows the distribution of impact ratings by water source, where 'unknown' ratings have been disregarded. Note that the 'unknown' and 'unset' water source categories have not been included in this analysis. From this table it can be observed that the 'surface in-stream' and 'surface overbank' asset types had more 'high' vulnerability ratings than the other asset types, while 'surface rainfall 'had the fewest 'high' ratings.

Table 18: Known impact rating by water source

Water source	High	Mod	Low	Neg	n/a
Combined: groundwater dominant	5%	18%	15%	9%	53%
Combined: surface water dominant	7%	18%	16%	11%	49%
Combined: SW/GW unknown	7%	8%	10%	13%	62%
Groundwater	6%	16%	14%	11%	53%
Surface: in-stream	9%	7%	8%	6%	69%
Surface: overbank	9%	8%	9%	6%	68%
Surface: rainfall	2%	12%	12%	11%	64%

Similar to observations regarding the pattern of impact ratings according to water source, Table 19 shows that having a water regime set to 'unknown', 'unset' or a permutation of 'combined' leads to either all or the overwhelming majority of impact ratings being set to 'unknown'. Additionally, it appears that there was little attention or knowledge with respect to the vulnerability of assets of 'Surface: waterlogged' water regime, as nearly all ratings were set to 'unknown'. Conversely, the results show that there was much greater confidence in the rating of the groundwater confined artesian and non-artesian asset types, with only 0.83% and 0.85% 'unknown' impacts in each case. Similarly, the unconfined groundwater assets were rated with greater confidence than all the surface water asset types, with approximately 18% of ratings set to 'unknown' compared with 34-39%.

Table 19: Unknown vulnerability by water regime

Water regime	Unknown
Combined	94%
Groundwater: combined	97%
Groundwater: confined artesian	1%
Groundwater: confined non-artesian	1%
Groundwater: unconfined	18%
Surface: combined	94%
Surface: ephemeral	34%
Surface: episodic	38%
Surface: permanent	38%
Surface: seasonal	38%
Surface: unknown	100%
Surface: waterlogged	92%
Unknown	95%
Unset	72%

Table 20 shows the distribution of known impact ratings grouped by water regime, where unknown ratings have been disregarded. It can be observed that asset types where the water regime is groundwater confined (artesian and non-artesian) attracted a slightly greater number of 'high' impact ratings compared to other asset types (9% and 8% respectively, compared to between 6% and 7%). These asset types were also characterised by having the greatest number of 'negligible' and 'n/a' impacts as well. By contrast, unconfined groundwater asset types attracted the lowest number of high impact ratings.

Table 20: Known impact ratings by water regime

Water regime	High	Mod	Low	Neg	n/a
Groundwater: confined artesian	9%	6%	9%	12%	64%
Groundwater: confined non-artesian	8%	7%	9%	13%	62%
Groundwater: unconfined	6%	19%	14%	14%	48%
Surface: ephemeral	7%	15%	13%	8%	58%
Surface: episodic	6%	16%	14%	8%	56%
Surface: permanent	6%	14%	15%	10%	57%
Surface: seasonal	6%	16%	14%	8%	56%

For the analysis of impact ratings according to activity and effect, the impact ratings for water source and water regime assignments with a high proportion of unknown values as observed in Table 17 and Table 19 were disregarded. These asset types are listed in Table 21 and accounted for 4095 out of 8849 of all vulnerability assessments (i.e. 46%). The purpose of eliminating these water regimes from the analysis was to highlight cases where the source of uncertainty in the analysis is caused by activity or effect as opposed to the asset class and to emphasise patterns in the known effects.

Table 21: Water source, water regime values with high proportion of unknown and n/a impact ratings

Asset class element	Value
Water source	Unknown
	Unset
Water regime	Combined
	Groundwater: combined
	Surface: waterlogged
	Surface: unknown
	Unknown
	Unset

Comparing Table 22 with Table 16 shows that disregarding the asset classes where all or most impacts are unknown reduces the total proportion of unknown impact ratings from 58% to 28%.

Table 22: Vulnerability assessments, total by impact rating disregarding asset classes with high proportion of "unknown" ratings (i.e. as per Table 21)

Impact rating	Count	Percentage
High	232	5%
Moderate	481	10%
Low	447	9%
Negligible	343	7%
n/a	1941	41%
Unknown	1310	28%

Table 23 shows proportion of impact ratings set to unknown grouped by activity where the impact ratings for water regimes having water source and/or water regime listed in Table 21 have been disregarded. The proportion of ratings set to 'unknown' falls into three distinct groupings, with highest uncertainty observed regarding in-situ gasification, managed aquifer recharge and overburden management (42%, 40% and 41% unknown respectively). Well drilling appears to have the least uncertainty regarding its effects, with only 4% of impact ratings set to unknown. The remaining activities had proportion of unknown falling between 22% and 32%.

Table 23: Unknown impact ratings by activity

Activity	unknown
Discharge to surface water	22%
Evaporation ponds and tailings dams	29%
Groundwater dewatering, extraction	23%
Hydraulic fracturing	24%
In-situ gasification	42%
Managed aquifer recharge	40%
Overburden management	41%
Site establishment and traffic	29%
Site runoff	32%
Surface water diversion	24%
Surface water extraction	23%
Well drilling	4%

Table 24 shows the distribution of known vulnerability ratings grouped by activity. Unknown impacts have been disregarded by this analysis, as have all the vulnerability ratings for the asset types listed in Table 21. It can be observed that 'surface water diversion' attracts the most 'high' vulnerability ratings (21%), followed by in-situ gasification with 13%. Conversely, 'site runoff' attracted no high impact ratings, while 'evaporation ponds and tailings dams' had only 1% high ratings. The assessment outcome for the "evaporation ponds and tailings dams" activity is likely a result of assuming developments observe due process and regulations (see Table 12) minimise risk of failure or harmful leakage. 'Well drilling' had the highest number of 'n/a' ratings, which is to be expected given that it is unlikely to directly impact surface water asset types.

Table 24: Known impacts by activity

Activity	high	mod	low	negl	n/a
Discharge to surface water	8%	19%	22%	9%	42%
Evaporation ponds and tailings dams	1%	7%	14%	19%	59%
Groundwater dewatering, extraction	7%	23%	11%	3%	57%
Hydraulic fracturing	4%	14%	11%	16%	55%
In-situ gasification	13%	22%	15%	7%	43%
Managed aquifer recharge	4%	17%	3%	3%	74%
Overburden management	7%	5%	6%	22%	60%
Site establishment and traffic	8%	0%	18%	18%	56%
Site runoff	0%	22%	24%	2%	52%
Surface water diversion	21%	18%	12%	4%	45%
Surface water extraction	3%	23%	17%	9%	48%
Well drilling	5%	1%	4%	9%	81%

To enable an easier comparison of the vulnerabilities due to different activities, considering all impact ratings, Figure 5 presents a bar graph comparison that aggregates impacts into 'vulnerable' versus 'non-vulnerable' categories, where

- 'vulnerable' equates to the weighted sum of the 'low', 'moderate' and 'high' impact ratings,
- 'non-vulnerable' equates to the weighted sum of the 'negligible' and 'n/a' impact ratings.

Table 25 shows the weightings that applied to each of the impact ratings during the aggregation process. These weightings, while arbitrary, are designed to reflect differences in the level of vulnerability (or non-vulnerability) between the ratings. Note that it was elected to assign the 'n/a' scores a higher level of non-vulnerability than 'negligible' to account for the differences in likelihood of impact in these cases (see impact framework in Section 3.2.4 for further explanation). Also note that the analysis disregards asset classes for which vulnerability was predominantly unknown (i.e. Table 21).

Figure 5 shows that according to this analysis, which takes into account all asset classes and effects, there are considerable differences in vulnerability due to different activities. Surface water diversion, in-situ gasification and discharge to surface water activities are the causes of the highest vulnerability (i.e. between 40% and 50% weighted vulnerability), while well drilling causes the least vulnerability (i.e. less than 10% weighted vulnerability).

Table 25: Calculating 'vulnerability' vs 'non-vulnerability' - weightings

'Vulnerable' impact rating	Weighting
High	2
Moderate	1.5
Low	1
'Non-vulnerable' impact rating	
n/a	2
Negligible	1

Table 26 shows proportion of impact ratings set to "unknown" grouped by effect where the impact ratings for water regimes having water source and/or water regime listed in Table 21 have been disregarded. The highest proportion of unknown ratings is observed for surface water/groundwater connectivity (41%) followed by functional connectivity of surface water (38%). The remaining effects have between 21% and 31% unknown impacts.

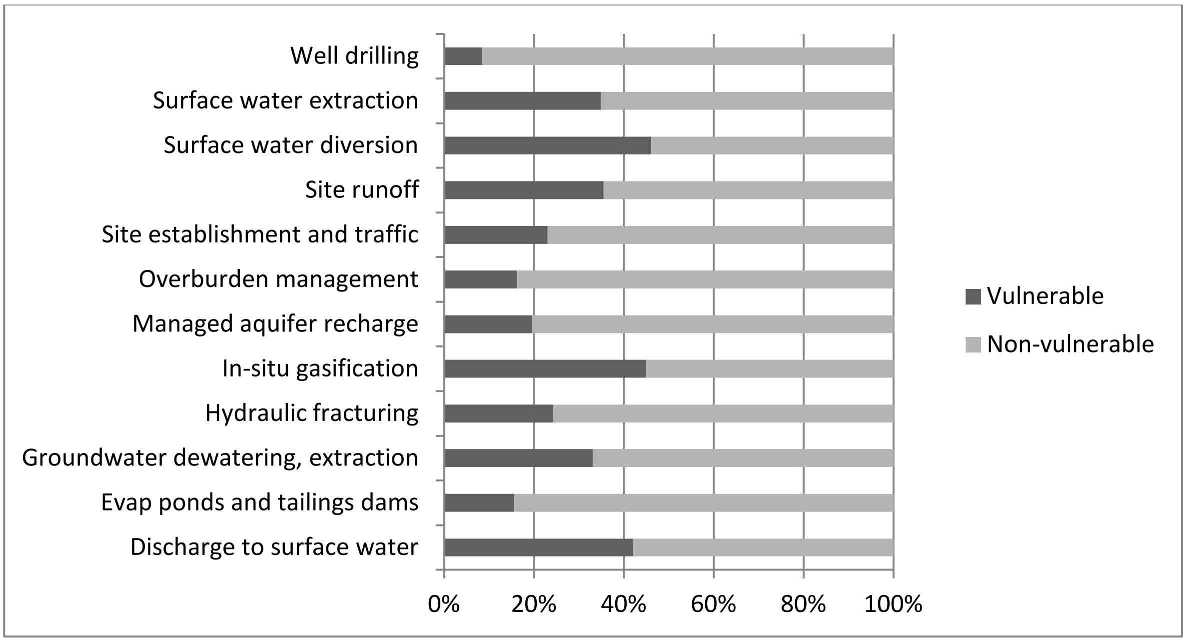


Figure 5: Aggregate 'vulnerability' vs 'non-vulnerability' grouped by activity

Table 26: Unknown impacts by effect

Effect	Unknown
Aquifer structural integrity	21%
Functional connectivity of surface water	38%
Groundwater flow pattern	21%
Groundwater pressure	21%
Physical habitat	31%
Surface water regime	26%
Surface water/groundwater connectivity	41%
Water quality	27%
Water quantity	23%

Table 27 shows the distribution of known vulnerability ratings grouped by effect. Unknown impacts have been disregarded in this analysis, as have all the vulnerability ratings for the asset types listed in Table 21. The 'physical habitat' effect attracted the biggest proportion of 'high' vulnerability ratings (21%), followed by aquifer structural integrity and water quality (10% each). The remaining effects had between 2% and 5% 'high' impact ratings.

It is noteworthy that aquifer structural integrity has a high proportion of 'n/a' ratings, meaning that, if observed, it is less likely to be reversible than other effects according to the impact rating criteria outlined in Section 3.2.4. This observation contrasts with the 'groundwater pressure' effect which, while also having a high proportion of 'n/a' impact ratings, is more likely to be reversible where observed as indicated by the higher proportion of negligible, low and moderate impact ratings compared to high.

Table 27: Known impacts by effect

Effect	High	Mod	Low	Negl	n/a
Aquifer structural integrity	10%	0%	0%	8%	82%
Functional connectivity of surface water	5%	10%	20%	9%	56%
Groundwater flow pattern	2%	7%	8%	7%	76%
Groundwater pressure	2%	4%	4%	3%	86%
Physical habitat	21%	16%	7%	5%	51%
Surface water regime	5%	19%	22%	7%	48%
Surface water/groundwater connectivity	3%	12%	26%	12%	47%
Water quality	10%	28%	20%	13%	29%
Water quantity	3%	30%	15%	24%	28%

Figure 6 is a bar graph comparing aggregate 'vulnerable' versus 'non-vulnerable' impact according to effect taking into account all asset classes and activities. This analysis employs the same aggregation and weighting approach as described previously for Table 25 and Figure 5. According to this analysis, the effects having most aggregate vulnerability are 'water quantity' and 'water quality'. This means that CSG and LCM vulnerability is more likely to be expressed as these effects than other effects considered by the assessment. 'Physical habitat' has the next highest weighted vulnerability score. The effects having least vulnerability are 'groundwater pressure', 'groundwater flow pattern' and 'aquifer structural integrity'.

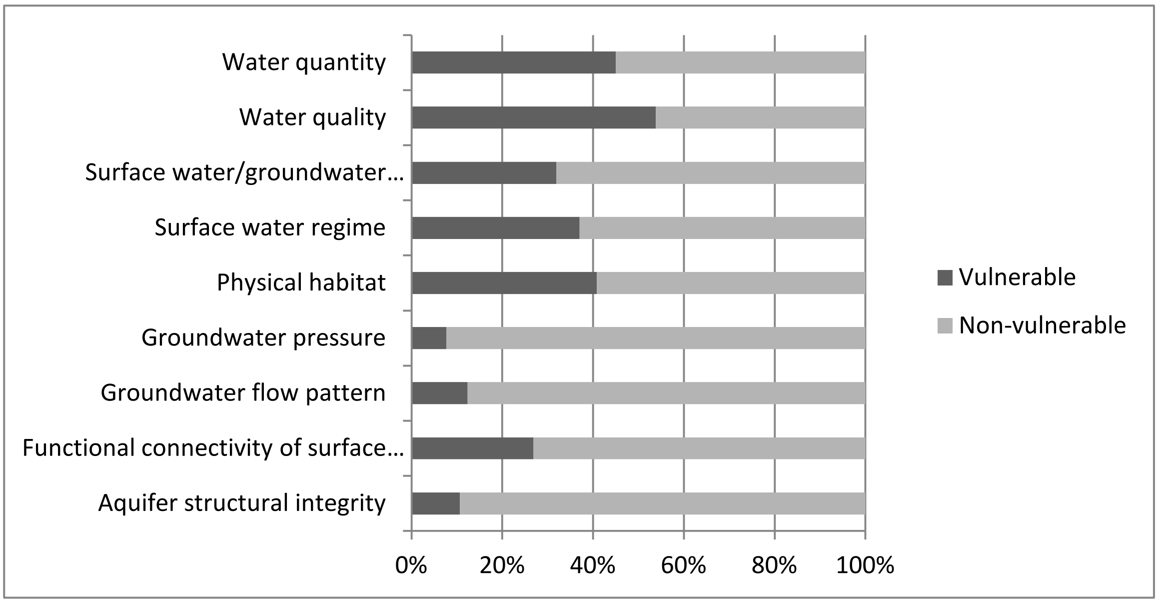


Figure 6: Aggregate 'vulnerability' vs 'non-vulnerability' grouped by effect

4.2.3. SUMMARY OF FINDINGS

With respect to the assessment process:

- Assessment of surface water asset types (i.e. those having surface water regimes) was deemed more demanding for experts than assessment of groundwater asset types
- The assessment of groundwater asset types was more likely to be qualified by factors not considered in the assessment framework, as indicated by the presence of multiple impact ratings per vulnerability proposition according to scale or other criteria.

Overall there are a high number of 'unknown' impacts with over 57% of all vulnerability propositions leading to this rating. The following conclusions can be drawn from the results regarding the distribution of 'unknown' impact ratings:

- Where water source or water regime is unknown, unset or "combined", most ratings are set to 'unknown'.
- By comparison, where the water source or water regime is not unknown, unset or combined the proportion of impact ratings set to 'unknown' is much lower.
- There was either no knowledge regarding, or no attention paid to the 'surface: waterlogged' asset type for which all impact ratings were set to unknown.
- Where vulnerabilities for asset classes having water source or water regime set to unknown, unset or combined are filtered out:
    - With respect to activities, there was most uncertainty regarding the impacts of in-situ gasification, managed aquifer recharge and overburden management.
    - With respect to effects, there was most uncertainty regarding functional connectivity of surface water and surface water/groundwater connectivity.
    - Compared to other activities, there was substantially lower uncertainty regarding the effects of well drilling.

The following broad conclusions can be drawn about the patterns of vulnerability where vulnerability is known:

- In general, both surface and groundwater asset classes (as identified by water regime) were determined to be vulnerable to hydrological effects caused by CSG and LCM activities.
- There are fewer high vulnerability impact ratings for asset classes having water sources of 'surface: rainfall' than for asset types with other water sources.
- The 'surface water diversion' and 'in-situ gasification' activities attract a higher number of 'high' impact ratings compared to other activities.
- The 'physical habitat' effect has the most 'high' impact ratings.
- Where 'vulnerable' and 'non-vulnerable' impact ratings are aggregated:
    - 'Surface water diversion', 'in-situ gasification' and 'discharge to surface water' activities cause most vulnerability, while 'well drilling', 'evaporation ponds and tailings dams' and 'overburden management' cause least vulnerability.

- ‘Water quality’ and ‘water quantity’ account for a higher proportion of impact than other effects, while ‘groundwater pressure’, ‘groundwater flow pattern’ and ‘aquifer structural integrity’ account for the least impact.

4.3. THE WATER ASSET DATABASE

4.3.1. SUMMARY OF DELINEATED ASSETS

A total of 96 024 assets was delineated by participating NRM regions. Table 28 lists the number of assets delineated according to NRM region. The South Australian Arid Lands delineated the most assets, with 49.4% of the total, while the SA Murray-Darling Basin delineated the least, with 1.9% of the total.

Some assets were assigned values for the NRM region field that did not correspond to a participating NRM region (i.e. non-participating region or state or territory). The cause of these assignments was determined to be either

- an artefact of the spatial asset delineation process. In these cases the spatial extent of the asset in question overlapped a jurisdictional boundary and the centroid of the asset lay outside the boundaries of the delineating region, and/or
- assets that are located in a neighbouring region, state or territory, but are managed by the NRM Board that delineated the asset.

Table 28: Count of assets per region

Region	Number of assets	Percentage
Adelaide and Mt Lofty Ranges	261	0.3%
Alinytjara Wilurara	2097	2.2%
Eyre Peninsula	16986	17.7%
New South Wales	2	0.0%
Northern and Yorke	9305	9.7%
Northern Territory	19	0.0%
Queensland	51	0.1%
South Australian Arid Lands	47389	49.4%
South Australian Murray-Darling Basin	1865	1.9%
South East	18000	18.7%
Victoria	47	0.0%
Western Australia	2	0.0%
Total	96024	100.%

With respect to the attribution the water source and water regime fields, the following observations were made:

- A total of 115 unique combinations of water source and water regime (i.e. asset classes) were represented.
- For 58 out of the 115 unique asset classes, multiple water regimes were selected and represented in the database as a comma delimited list, while the remaining 57 combinations had a single water regime selected.

- In total, 24 423 assets were attributed with multiple water regimes.
- The remaining 71 601 assets had a single water regime selected.

A total of 38693 assets (i.e. 40%) were attributed with water source or water regime options listed in Table 21 likely to have a high number of vulnerability assessment ratings set to 'unknown'.

4.3.2. METHOD FOR POPULATING THE SEWPAC DATABASE TABLE

As discussed in Section 1.1, a deliverable for the SA NRM Data project was a table of vulnerabilities for all assets identified by the NRM regions. This was accomplished by generalising the outputs of the vulnerability assessment of asset classes described in Section 4.2 to the assets. Conceptually, this generalisation task (to populate the SEWPaC vulnerability table described in Section 2.4) is a relatively simple procedure, as outlined in Table 29.

Table 29: Procedure for populating vulnerability table - key concepts

Step	Process iterated for each asset in asset table
1	Select asset ID, asset class (water source, water regime) and vulnerability fields ("hazard", "comments", "mitigation") for current asset record
2	Select all vulnerabilities for asset class selected at Step 1 from the vulnerabilities table (i.e. activity, effect, impact records)
3	Combine all vulnerabilities selected at Step 2 with asset data selected at Step 1 to form complete vulnerability records (i.e. asset id, hazard, mitigation, comments, activity, effect, impact)
4	Insert vulnerabilities records created at Step 3 into SEWPaC vulnerabilities table (i.e. "activity", "effect", "impact", "comments", "hazard", "mitigation")

To create the 'description' field for the SEWPaC vulnerability template, it was elected to concatenate a number of fields from the asset and vulnerability table together to provide a record of contextual information that is both asset- and vulnerability-focussed. The following fields were included in the concatenation:

- Assets table:
  - Pressures
  - Stressors
- Vulnerability table:
  - Conditions
  - Comments

For the purposes of reporting, data from these fields were pipe delimited (i.e. '|'), and where the respective fields were not set, a message of the form, "No <field> recorded" was inserted into the text.

While the procedure outlined in Table 29 is straightforward, there are two features of the asset and vulnerability data requiring decisions or rules to support a consistent and conceptually valid output for the SEWPaC vulnerabilities table. These features are:

- Approximately 25% of the assets identified were attributed with multiple water regimes (as described in Section 4.3.1).
- For some vulnerability propositions, more than one assessment was recorded, (as described in Section 4.1.2).

Addressing assets with multiple water regimes

To address the first of these issues, it was decided that where multiple water regimes were assigned to an asset, the impact ratings for all combinations of the water source and water regime options recorded for the asset are compared and the highest impact rating returned for the asset. The rationale for this approach is that it is likely that assets with multiple water regimes have been delineated at a larger scale, and it is therefore appropriate to report vulnerability for the element of that asset that could be deemed most at risk.

Table 30 shows the scoring system that was used to rank the impact ratings applied by the vulnerability assessment for the purposes of this comparison task. It was decided that the priority of impact is 'unknown' is second to 'high', because of the possibility that an unknown vulnerability could be high. This approach was deemed to be consistent with the Precautionary Principle, and in line with DEWNR convention for addressing uncertainty regarding water resource risk (i.e. DEWNR 2012a).

Table 30: Ranking priority of impact scores

Impact rating	Priority score
High	5
Unknown	4
Moderate	3
Low	2
Negligible	1
n/a	0

Selecting the appropriate vulnerability record required that an additional step be added between Steps 1 and 2 outlined in Table 29 to split the comma delimited list of water regimes in the asset table so as all combinations of water source and water regime are considered at Step 2, and a step between Steps 2 and 3 to determine which combination of water source and water regime returned the highest impact rating for a given activity and effect proposition.

Addressing asset class/activity/effect propositions with multiple impact scores

Where multiple vulnerability assessments were recorded per vulnerability proposition (i.e. asset class, activity and effect), it was elected to return the lowest impact score. This was because the high scores were contingent on conditions that were additional to the list of assumptions presented in Table 12. Thus, it was deemed that returning the minimum impact would be most consistent with the framework agreed by stakeholders. Implementing this process involved selecting the minimum impacts according to the impact priority outlined in Table 30 at Step 2 of the process outlined by Table 29.

4.3.3. REPRESENTATION OF VULNERABILITIES APPLIED TO ASSETS

Generalising the outcomes of the vulnerability assessment by applying the process described in Section 4.3.2 to populate the SEWPaC template (described in Section 2.4) created a table of asset vulnerabilities linked to the asset table by the asset ID foreign key. In practical terms, this allows the vulnerabilities of a given asset record to be queried using an SQL join within a relational database management system (RDBMS).

Due to the approach whereby vulnerability ratings were applied to all combinations of asset class, activity and effect, and given database schema which required a link between each assets and its corresponding vulnerabilities, generalising the vulnerability assessment to assets caused the populated SEWPaC template to receive over 9 million rows of data. This was found to be an impracticably large volume of data leading to slow database queries and difficulties in importing the data into commonly used desktop applications such as Microsoft Access or a Geographic Information System.

The high volume of data in this table was caused by having a large amount of redundant vulnerability information, since the same vulnerabilities are copied for assets having the same asset class. It was recognised that a number of options existed to represent data in a more efficient manner that would support a more responsive and usable information resource. Two options were considered:

1. Create an asset class ID to link the assets and vulnerabilities table on the basis of water source and water regime.
2. Query vulnerabilities directly using the water source and water regime attributes of the assets table as keys for vulnerability records in the vulnerabilities table.

The former of these options was implemented to address the limitations of typical GIS software with respect to joining tables. Also this approach allowed implementation of the rules presented in Section 4.3.2 for assigning impact ratings given multiple water regimes or vulnerability records. Implementing this option involved creating asset class IDs for all the unique combinations of water source and water regime for the vulnerabilities table, and creating an additional link table that linked asset ids to asset class ids on the basis of the rules outlined in Section 4.3.2.

4.4. DISCUSSION – VULNERABILITY ASSESSMENT USE-CASES

At the vulnerability assessment review workshop held on 12 February 2013 (see Table 4) it was noted that most value when querying the database is achieved where “questions” to be addressed are specific and structured. This is because, given the generic and comprehensive nature of the vulnerability assessment, queries that do not place conditions on attributes of assets or vulnerabilities will always return ‘high’ impacts, as all asset classes with known vulnerabilities will likely have at least one ‘high’ impact recorded over the range of activity/effect scenarios.

While the assessment enables a range of possible use-cases, the basic process for determining vulnerabilities of assets to CSG and LCM development outlined in Table 31 is an effective starting point. The outputs of the SA NRM water asset database and vulnerability assessment provide data, spatial analysis tools and vulnerability assessments to facilitate such a process. It can be anticipated this would provide a useful context setting and risk identification tool for a more comprehensive assessment of water related risks caused by CSG and LCM development.

Furthermore, as canvassed by stakeholders during the framework development process, the results of such a query can be filtered by placing further conditions on fields of either the vulnerability or asset tables. For example, it is possible to filter the results to return only those assets with certain ecological or social values, on the basis of water body type or on the basis of impact, effect or activity. It is also possible to reverse the approach – for example, assets could be identified within a given geographical zone on the basis of the existence of certain types of vulnerability.

Table 31: Use-case - vulnerability of assets to CSG/LCM development

Step	Process
1	Determine likely activities for CSG/LCM development
2	Select assets in zone of impact
3	Select vulnerabilities for each asset to likely activities

5. CONCLUDING REMARKS AND FUTURE DIRECTIONS

This report documents an approach to addressing the deliverables of the SA NRM data project that aims to satisfy stakeholder requirements for practicality, consistency and scientific veracity. The outcome of this approach is an information resource that supports the interactive querying of hydrological vulnerabilities of assets to CSG and LCM activities.

The rationale, benefits, and limitations of the elements of the framework have been discussed in the relevant sections of the report. General conclusions regarding both the level of certainty in the assessment and the patterns in water asset vulnerability to CSG and LCM activities are summarised in Section 0.

The text in this section presents a high level discussion and summary remarks regarding the benefits, limitations and potential for development offered by this assessment framework.

5.1. RELEVANCE OF SURFACE WATER ASSET VULNERABILITY

There has been considerable public and scientific attention on the groundwater related impacts of CSG in Australia. This is hardly surprising as it is well known that exploiting this natural gas resource involves activities such as extraction of groundwater and the stimulation of production wells through hydraulic fracturing of CSG bearing aquifers. Both of these activities can be reasonably expected to have direct impacts on underground water in some way.

Given this background, a key finding from the present study is that surface water vulnerability to CSG and LCM activities remains an important and possibly overlooked issue because

- NRM regions delineated a large number of surface water assets that have potential to be impacted by LCM and CSG development,
- the vulnerability assessment framework, which was collaboratively developed by experts and regional stakeholders, identified many CSG/LCM activities and hydrological effects that are relevant for surface water asset classes.
- the assessment process determined that a significant component of the overall hydrological vulnerability was applied to surface water asset classes.

The observation of significant surface water impacts arising from CSG and LCM is particularly relevant for the assessment of risks to environmental values because ecosystem components and processes can be particularly sensitive to the types of changes in water regime that are considered by this vulnerability assessment.

Furthermore, there was found to be a high level of uncertainty regarding a number of the surface water effects considered by this assessment. Therefore research and knowledge into understanding the hydrological stressors and the habitat and ecological responses are likely to be a key priority in improving capacity to manage risks regarding CSG and LCM development. This significant finding underscores the importance of using detailed and accurate scientific information on surface water hydrology and ecology as a part of the Bioregional Assessment process.

Note that this conclusion is not intended to downplay groundwater asset vulnerability to CSG and LCM development.

5.2. SUPPORT FOR RISK BASED WATER PLANNING AND MANAGEMENT

In its current form, it is proposed that the vulnerability assessment framework and the assessments made according to this framework provide a tool informing the context setting and risk identification steps of an assessment of risks caused by potential CSG and LCM development. For example, it may be used for

- identifying the types of risks needing further investigation.
- providing some insight into the level of risk.
- providing a credible rationalisation of why certain types of risks may be excluded from analysis.

Given these applications, this work can be thought of as a foundational activity contributing to the building of a knowledge and information platform supporting improved management of water resources in South Australia, in line with DEWNR’s risk management framework for water planning and management.

It is important to note that, as discussed in Section 2.5, the information resource represented by the vulnerability assessment framework and the assessments themselves do not represent completed risk assessments. At the very least, a risk assessment process would additionally be informed by

- potential social, economic or environmental consequences arising from hydrological change (i.e. the “response” component of the PSR asset risk model), and
- evaluation criteria regarding tolerability or acceptability of different levels of risk.

Thus in terms of the “bow-tie” model for water asset risk (Figure 4), the current vulnerability assessment provides information on how CSG and LCM as a source of risk potentially lead to an event defined as a hydrological effect. A completed risk assessment would need to consider how the events lead to impacts that affect environmental, social/cultural and economic objectives, and the extent to which the probability and severity of these impacts is acceptable or unacceptable given existing policy and legislative drivers and community values and aspirations.

5.3. VULNERABILITY ASSESSMENT REALISM

The vulnerability assessment presented in this report is intended to be generic in nature. This means it covers what could happen, in hydrological terms, given a general understanding of the asset type and the CSG/LCM activity, but it does not take into account local or case-specific circumstances affecting vulnerability, such as asset specific attributes, geographic features or risk control measures that may already be in place. The level of realism supported by the framework produces an information resource that should be thought of as a starting point on which a more comprehensive analysis can be built.

The analysis of the vulnerabilities presented in Section 4.2.2 demonstrates that, as in any model, the accuracy of the output is dependent on the quality of the input data. Thus, where there is lack of confidence regarding the determination of relevant attributes of an asset (in this case, water source and regime), or about effects and impacts of development pressures, there will be uncertainty regarding outputs of the assessment.

Similarly, the outputs of an application of the vulnerability assessment to an asset are likely to be dependent on the scale at which the asset is delineated. Thus, where assets are defined at a scale likely to cover multiple water regimes, the impact rating returned for a given activity/effect combination is more likely to be high or unknown (as explained in Section 4.3.2). A useful (and intended) feature of the vulnerability framework is that it provides a mechanism for reporting uncertainties so that they can be factored into further risk assessment work.

5.4. POTENTIAL FOR FUTURE DEVELOPMENT OF THE VULNERABILITY ASSESSMENT FRAMEWORK

A key feature of this vulnerability assessment framework is that it aims for consistency with the pressure-stressor-response model being used to conceptualise water asset risk in South Australia (as described in Section 3.1.2). Apart from promoting broad consistency of meaning with respect to the inputs and outputs of the assessment, it elucidates a framework on which the vulnerability model can be developed further.

It was concluded at the framework review workshop (see Table 4) there are two broad objectives for further work on the vulnerability assessment concept:

(i) improving the realism of the existing vulnerability assessment

(ii) broadening the scope of the assessment to consider different types of pressures, stressors and responses. Proposals for each of these objectives canvassed by participants in the framework development process are summarised in Table 32.

Table 32: Options for further development of the SA vulnerability assessment framework

Options for addressing assessment realism
• Address gaps in both asset attribution and vulnerability assessment (i.e. “unknown” water source, water regime, impact ratings, ratings made with low confidence). • Apply a more robust and transparent process for rating impact – e.g. record ratings for all attributes contributing to impact (i.e. hydrological integrity, resilience and recovery). • Develop impact criteria to provide a more quantitative basis for vulnerabilities (e.g. probabilities of hydrological change, defined time periods for recovery etc.). • Develop the asset typology to better represent hydrological characteristics or vulnerabilities (e.g. by considering other attributes in the water asset table such as waterbody type, existing pressures etc.). • Add attributes to the asset database to provide a richer level of information about assets (such as flowing vs static water, terminal system vs flow through). • Add elements to the vulnerability framework that take into account issues identified in the “comments”, “scale” and “conditions” fields during the vulnerability assessment.
Options for broadening the vulnerability assessment framework scope
• Addressing a broader range of pressures (e.g. other non-CSG/LCM development pressures, climate change, pastoralism etc.) by defining new activities. • Considering different hydrological stressors by defining new effects. • Adding a “stressor to response” module to consider consequences of hydrological impacts (e.g. by adding a response field and rating impacts according to each of the hydrological effects). • More transparent consideration of uncertainty by adopting a probabilistic framework to expressing the effects of assessment confidence (e.g. as adopted by IPCC, 2013)

GLOSSARY

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supersedes the *Water Resources (SA) Act 1997*

Aquatic ecosystem — The stream channel, lake or estuary bed, water and/or biotic communities and the habitat features that occur therein

Aquatic habitat — Environments characterised by the presence of standing or flowing water

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquatard — A layer in the geological profile that separates two aquifers and restricts the flow between them

Arid lands — In South Australia, arid lands are usually considered to be areas with an average annual rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping

Artesian — An aquifer in which the water surface is bounded by an impervious rock formation; the water surface is at greater than atmospheric pressure, and hence rises in any well which penetrates the overlying confining aquifer

Basin — The area drained by a major river and its tributaries

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

Bore — See 'well'

Bow-tie analysis — A commonly used approach to diagrammatically represent risk facilitating communication and identification of risk controls. The centre or knot of the bow-tie represents the event, which according to AS/NZS ISO 31000:2009 risk management guidelines is a change in circumstances. Risk sources or hazards contributing to the event are depicted on the left hand side of the event, while consequences or impacts which result from the event are represented on the right hand side.

Catchment — That area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

Coal Seam Gas (CSG) development — According to the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999, CSG development means any activity involving coal seam gas extraction that has, or is likely to have, a significant impact on water resources (including any impacts of associated salt production and/or salinity) (a) in its own right; or (b) when considered with other developments, whether past, present or reasonably foreseeable developments.

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

CSIRO — Commonwealth Scientific and Industrial Research Organisation

Dams, off-stream dam — A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted or pumped from a watercourse, a drainage path, an aquifer or from another source; may capture a limited volume of surface water from the catchment above the dam

Dams, on-stream dam — A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water

Dams, turkey nest dam — An off-stream dam that does not capture any surface water from the catchment above the dam

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

DMITRE — Department for Manufacturing, Innovation, Trade, Resources and Energy (Government of South Australia)

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement of total dissolved solids (TDS)

Ecological values — The habitats, natural ecological processes and biodiversity of ecosystems

Ecology — The study of the relationships between living organisms and their environment

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Environmental values — The uses of the environment that are recognised as being of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions — That part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

EP — Eyre Peninsula

EPA — Environment Protection Authority (Government of South Australia)

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Exposure assessment — Determination of the magnitude, frequency and duration of exposure to an agent along with the size and characteristics of the population exposed taking into account sources, pathways, routes and uncertainties.

Floodplain — Of a watercourse means: (1) floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under the Act; or (2) where (1) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development (SA) Act 1993*; or (3) where neither (1) nor (2) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse

Flow regime — The character of the timing and amount of flow in a stream

GAB — Great Artesian Basin

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Habitat — The natural place or type of site in which an animal or plant, or communities of plants and animals, live

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers; see also 'hydrology'

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

Impact — (general) A change in the chemical, physical, or biological quality or condition of a water body caused by external sources, (the SA vulnerability assessment framework) The quantum or extent of the hydrological effect caused by a CSG or LCM activity.

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

Injection well — An artificial recharge well through which water is pumped or gravity-fed into the ground

Lake — A natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

Large Coal Mining (LCM) development — According to the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999, large coal mining development means any coal mining activity that has, or is likely to have, a significant impact on water resources (including any impacts of associated salt production and/or salinity) (a) in its own right; or (b) when considered with other developments, whether past, present or reasonably foreseeable developments.

Managed aquifer recharge — Adding a water source, such as recycled water, to aquifers under controlled conditions – for example by injection or infiltration

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals and other living things

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Precautionary principle — Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation

Prescribed area, surface water — Part of the state declared to be a surface water prescribed area under the Act

Prescribed lake — A lake declared to be a prescribed lake under the Act

Prescribed watercourse — A watercourse declared to be a prescribed watercourse under the Act

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

Proponent — The person or persons (who may be a body corporate) seeking approval to take water from prescribed water

PWA — Prescribed Wells Area

PWCA — Prescribed Watercourse Area

PWRA — Prescribed Water Resources Area

Resilience — (ecology) Capacity of an ecosystem to respond to perturbation or disturbance by resisting damage and recovering quickly

Risk — Effect of uncertainty on objectives (Joint Technical Committee OB-007, Risk Management, 2009)

Seasonal watercourses or wetlands — Those watercourses or wetlands that contain water on a seasonal basis, usually over the winter–spring period, although there may be some flow or standing water at other times

SQL — Structured Query Language. A special-purpose programming language designed for managing data held in a relational database management system (RDBMS)

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Vulnerability — (AS/NZS ISO 31000:2009 risk management guidelines) Intrinsic properties of something resulting in susceptibility to a risk source that in turn can lead to an event with consequences. (Ecological and sustainability applications) Vulnerability is generally a function of exposure to a stressor, potential impact or effect on the unit exposed, current condition and resilience or potential for recovery.

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

Water allocation, area based — An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water–use year

WAP, Water Allocation Plan — a plan prepared by a water resources planning committee and adopted by the Minister in accordance with the Act

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water dependent ecosystems — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems**Well** — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance (Ramsar Secretariat, 2005). This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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