Australian Government

BIOREGIONAL ASSESSMENTS

PROVIDING SCIENTIFIC WATER RESOURCE INFORMATION ASSOCIATED WITH COAL SEAM GAS AND LARGE COAL MINES

Assigning receptors to water-dependent assets

Submethodology M03 from the Bioregional Assessment Technical Programme

1 November 2016

A scientific collaboration between the Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia

The Bioregional Assessment Programme

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

The Programme is funded by the Australian Government Department of the Environment and Energy. The Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment and Energy

The Office of Water Science, within the Australian Government Department of the Environment and Energy, is strengthening the regulation of coal seam gas and large coal mining development by ensuring that future decisions are informed by substantially improved science and independent expert advice about the potential water related impacts of those developments. For more information, visit https://www.environment.gov.au/water/coal-and-coal-seam-gas/office-of-water-science.

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The Bureau of Meteorology is Australia's national weather, climate and water agency. Under the *Water Act 2007*, the Bureau is responsible for compiling and disseminating Australia's water information. The Bureau is committed to increasing access to water information to support informed decision making about the management of water resources. For more information, visit http://www.bom.gov.au/water/.

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Geoscience Australia

Geoscience Australia is Australia's national geoscience agency and exists to apply geoscience to Australia's most important challenges. Geoscience Australia provides geoscientific advice and information to the Australian Government to support current priorities. These include contributing to responsible resource development; cleaner and low emission energy technologies; community safety; and improving marine planning and protection. The outcome of Geoscience Australia's work is an enhanced potential for the Australian community to obtain economic, social and environmental benefits through the application of first class research and information. For more information, visit http://www.ga.gov.au.

ISBN-PDF 978-1-925315-41-7

Citation

O'Grady AP, Mount R, Holland K, Sparrow A, Crosbie R, Marston F, Dambacher J, Hayes K, Henderson B, Pollino C and Macfarlane C (2016) Assigning receptors to water-dependent assets. Submethodology M03 from the Bioregional Assessment Technical Programme. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Authorship is listed in relative order of contribution.

Cover photograph

Wards River, NSW, 10 December 2013

Credit: Heinz Buettikofer, CSIRO

Australian Government
Department of the Environment and Energy
Bureau of Meteorology
Geoscience Australia

CSIRO

v20161201

Executive summary

> ***Caveat***
>
> A large part of this submethodology is superseded by advances in methods for the bioregional assessments (BAs). Specifically, there is now no need to either generate receptors as spatial points across the landscape or to collate them into a receptor register. Instead, receptors are addressed spatially by the asset and landscape class spatial features (polygons, lines and points) and covered conceptually through the development of the landscape classes (product 2.3 (conceptual modelling)), the causal pathways (product 2.3 (conceptual modelling)) and the receptor impact modelling (product 2.7). They are then assessed spatially during the impact analysis using a regular grid of assessment units. Potential impacts on receptors are reported in aggregate via landscape class and asset profiles in product 3-4 (risk and impact analysis) and delivered as spatial datasets at data.gov.au.
>
> As a consequence there is no requirement for a BA to produce a point-based receptor dataset or a receptor register. However, Chapter 3 of this submethodology is still relevant to conducting a BA as it refers to the conceptual basis and criteria for assigning receptors, which informs the relationship between receptors and other parts of the BA process. Chapter 3.2 provides the basis and approach to BA landscape classification, which is then applied to produce the landscape classes in product 2.3 (conceptual modelling).

This submethodology provides a framework for assigning receptors in a subregion or bioregion for each bioregional assessment (BA) in a complete, efficient and representative manner that is fit for purpose and in accord with high standards of professional scientific practice. It defines receptors; outlines the role that receptors play in the broad context of a BA; and describes the documentation and development of the receptor register required for each BA.

A *receptor* is a point in the landscape where water-related impacts on assets are assessed.

The process of assigning the location of receptors is the primary mechanism for focusing a BA on the location of potential water-related impacts associated with coal resource development and for addressing risks to ecological, economic and sociocultural water-dependent assets within the subregion or bioregion. While the process is highly interdependent with other BA activities, it is important to note that this submethodology initially focuses on the preliminary placement of the receptors across the subregion or bioregion. The receptors will be subsequently updated with further information produced by other BA activities. For example, identification and refinement of critical relationships and impacts for each receptor will occur during the conceptual modelling and receptor impact modelling in Component 2: Model-data analysis.

Each receptor is a unique entity. It has coordinate attributes in two dimensions, latitude and longitude. Information and data can be recorded at a receptor including depth-related information. The coordinate attributes are recorded in the *receptor register*. The receptor register is a simple and authoritative list of receptors in a specific bioregional assessment. The list includes a unique identifier, the location of each receptor and the relevant landscape class. For BA purposes, a *landscape class* is an ecosystem with characteristics that are expected to respond similarly to changes in the groundwater and/or surface water due to coal resource development. Note that there is expected to be less heterogeneity in the response within a landscape class than between landscape classes. They are present on the landscape across the entire BA subregion or bioregion and their spatial coverage is exhaustive and non-overlapping. Conceptually landscape classes can be considered as types of ecosystem assets, which are ecosystems that may provide benefits to humanity and are spatial areas comprising a combination of biotic and abiotic components and other elements which function together. The receptor register, when finalised, is stored as a spatial dataset in the Bioregional Assessment Repository and a snapshot extract may be obtained at any particular point in time in spreadsheet format – for example, for publication purposes.

The process for compiling the receptor register is described in this submethodology (broadly illustrated in Figure 7). In broad terms, receptors are selected to be representative of, and linked to, assets in the water-dependent asset register and the potential impacts upon them. A number of methods can be employed to achieve this end and they are described in this submethodology. To ensure that the distribution of receptors across the landscape captures the impacts of potential coal resource development within the subregion or bioregion, receptors also need to be defined with reference to the coal resource development pathway (CRDP) and hazard analysis. Where there is limited or no additional coal resource development in the CRDP, receptors are generally only required to be allocated for defined landscape classes (described in Section 3.2). In other cases, receptors may already be available from pre-existing work.

Given the potential for very large numbers of assets within a subregion or bioregion, a *landscape classification* approach is used to reduce the complexity of the task of assigning receptors across the landscape while retaining the information necessary for the assessment. The rule set for defining the landscape classes is underpinned by an understanding of the geology, geography, ecology and hydrology (surface water and groundwater) of the subregion or bioregion. Different subregions and bioregions might use different landscape classes. The landscape classification improves the efficiency in defining the required conceptual models for multiple assets and in the subsequent assignment of:

- *hydrological response variables*, the hydrological characteristics of the system that potentially change due to coal resource development (for example, drawdown or the annual streamflow volume)
- *receptor impact variables*, the characteristics of the system that, according to the conceptual modelling, potentially change due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums).

Once the preliminary distribution of receptors within the subregion or bioregion has been determined, receptors are linked to the assets and landscape classes via causal pathways defined by the conceptual modelling and the receptor impact modelling activities of Component 2: Model-data analysis. This is to ensure that the distribution of receptors is complete and representative of the subregion or bioregion’s assets. Each receptor may be associated with more than one asset and, as some assets are very large, each asset may be associated with more than one receptor. At this stage, gaps or biases in the distribution of receptors across assets can be assessed. If needed, additional receptors can be assigned to address these gaps or receptors removed where redundancies exist.

The process of assignment and distribution of receptors within a subregion or bioregion must be conducted in consultation with ecology, hydrology, hydrogeology and risk discipline experts working on the BA. They also must be assigned according to the guiding principles outlined in this submethodology (Section 3.1), which require that the placement of receptors is representative, efficient and complete.

Product 1.4 (description of the receptor register) summarises the landscape classification and point to the reasoning and evidence used to select the location of the receptors given the relevant knowledge available about the subregion or bioregion (noting that the conceptual models that underpin this reasoning are documented in product 2.3 (conceptual modelling) and product 2.7 (receptor impact modelling), whereas the landscape classification is presented in full in product 2.3 (conceptual modelling)). The preliminary receptor register should be reviewed by relevant domain expertise and those with local knowledge to enable feedback and clarification on the receptor placement, landscape classification, conceptual models and, when known, hydrological response variables and receptor impact variables. After this, any changes, such as additional receptors, can be incorporated into the preliminary receptor register and an updated receptor register produced.

Once the receptor register is compiled, the BA progresses to assess potential impacts of coal resource development on receptors found within water-dependent assets.

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Acknowledgements

This technical product was reviewed by several groups:

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- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment and Energy), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments
- Additional reviewers: Alexander Herr.

Valuable comments were also provided by Phillippa Higgins.

Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments (IESC, 2015).

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made available to the public, providing the opportunity for all other interested parties, including government regulators, industry, community and the general public, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential impacts of CSG and coal mining development on water resources.

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA will be different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment and Energy, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions (see http://www.bioregionalassessments.gov.au/assessments for a map and further information):

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion

- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in a later section) will progressively be delivered throughout the Programme.

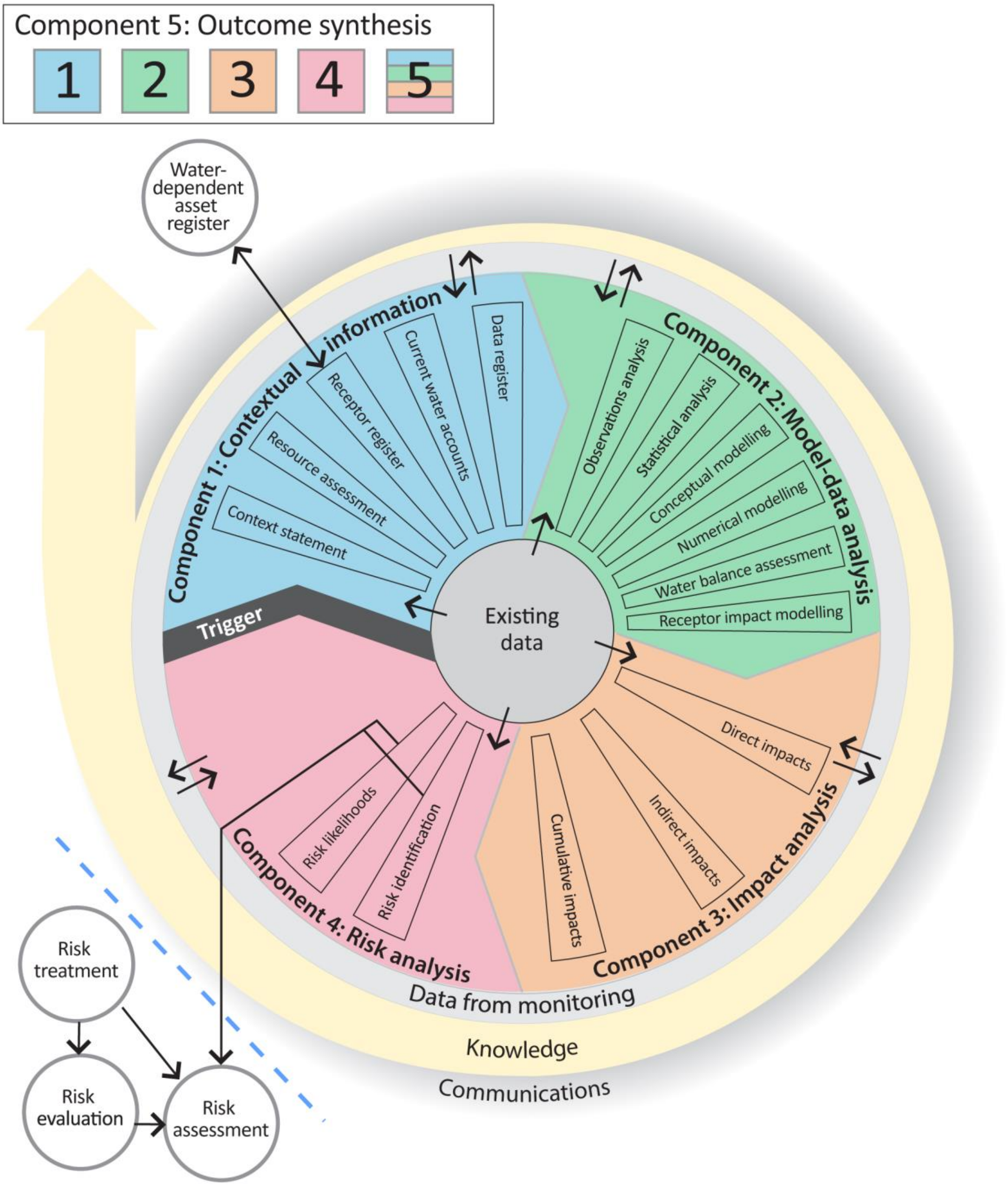

Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute to activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

The overall scientific and intellectual basis of the BAs is provided in the BA methodology (Barrett et al., 2013). Additional guidance is required, however, about how to apply the BA methodology to a range of subregions and bioregions. To this end, the teams undertaking the BAs have developed and documented detailed scientific submethodologies (Table 1) to, in the first instance, support the consistency of their work across the BAs and, secondly, to open the approach to scrutiny, criticism and improvement through review and publication. In some instances, methodologies applied in a particular BA may differ from what is documented in the submethodologies – in this case an explanation will be supplied in the technical products of that BA. Ultimately the Programme anticipates publishing a consolidated 'operational BA methodology' with fully worked examples based on the experience and lessons learned through applying the methods to 13 bioregions and subregions.

The relationship of the submethodologies to BA components and technical products is illustrated in Figure 2. While much scientific attention is given to assembling and transforming information, particularly through the development of the numerical, conceptual and receptor impact models, integration of the overall assessment is critical to achieving the aim of the BAs. To this end, each submethodology explains how it is related to other submethodologies and what inputs and outputs are required. They also define the technical products and provide guidance on the content to be included. When this full suite of submethodologies is implemented, a BA will result in a substantial body of collated and integrated information for a subregion or bioregion, including new information about the potential impacts of coal resource development on water and water-dependent assets.

About this submethodology

The following notes are relevant only for this submethodology.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of the BAs for inclusion in this document used the Albers equal area with a central meridian of 140.0° East for the Lake Eyre Basin bioregion and its subregions, and 151.0° East for all other bioregions and subregions. The two standard parallels for all bioregions and subregions are –18.0° and –36.0°.
- Visit http://bioregionalassessments.gov.au to access metadata (including copyright, attribution and licensing information) for datasets cited or used to make figures in this product.
- In addition, the datasets are published online if they are unencumbered (able to be published according to conditions in the licence or any applicable legislation). The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.

- The citation details of datasets are correct to the best of the knowledge of the Bioregional Assessment Programme at the publication date of this submethodology. Readers should use the hyperlinks provided to access the most up-to-date information about these data; where there are discrepancies, the information provided online should be considered correct. The dates used to identify Bioregional Assessment Source Datasets are the dataset's created date. Where a created date is not available, the publication date or last updated date is used.

Table 1 Methodologies

Each submethodology is available online at http://data.bioregionalassessments.gov.au/submethodology/XXX, where 'XXX' is replaced by the code in the first column. For example, the BA methodology is available at http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology and submethodology M02 is available at http://data.bioregionalassessments.gov.au/submethodology/M02. Submethodologies might be added in the future.

Code	Proposed title	Summary of content
bioregional-assessment-methodology	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets
M03	*Assigning receptors to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported about known coal and coal seam gas resources as well as current and potential resource developments
M05	*Developing the conceptual model of causal pathways*	Describes the development of the conceptual model of causal pathways, which summarises how the 'system' operates and articulates the potential links between coal resource development and changes to surface water or groundwater
M06	*Surface water modelling*	Describes the approach taken for surface water modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling
M08	*Receptor impact modelling*	Describes how to develop receptor impact models for assessing potential impact to assets due to hydrological changes that might arise from coal resource development
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantification of uncertainty in the modelled hydrological changes that might occur in response to coal resource development
M10	*Impacts and risks*	Describes the logical basis for analysing impact and risk
M11	*Systematic analysis of water-related hazards associated with coal resource development*	Describes the process to identify potential water-related hazards from coal resource development

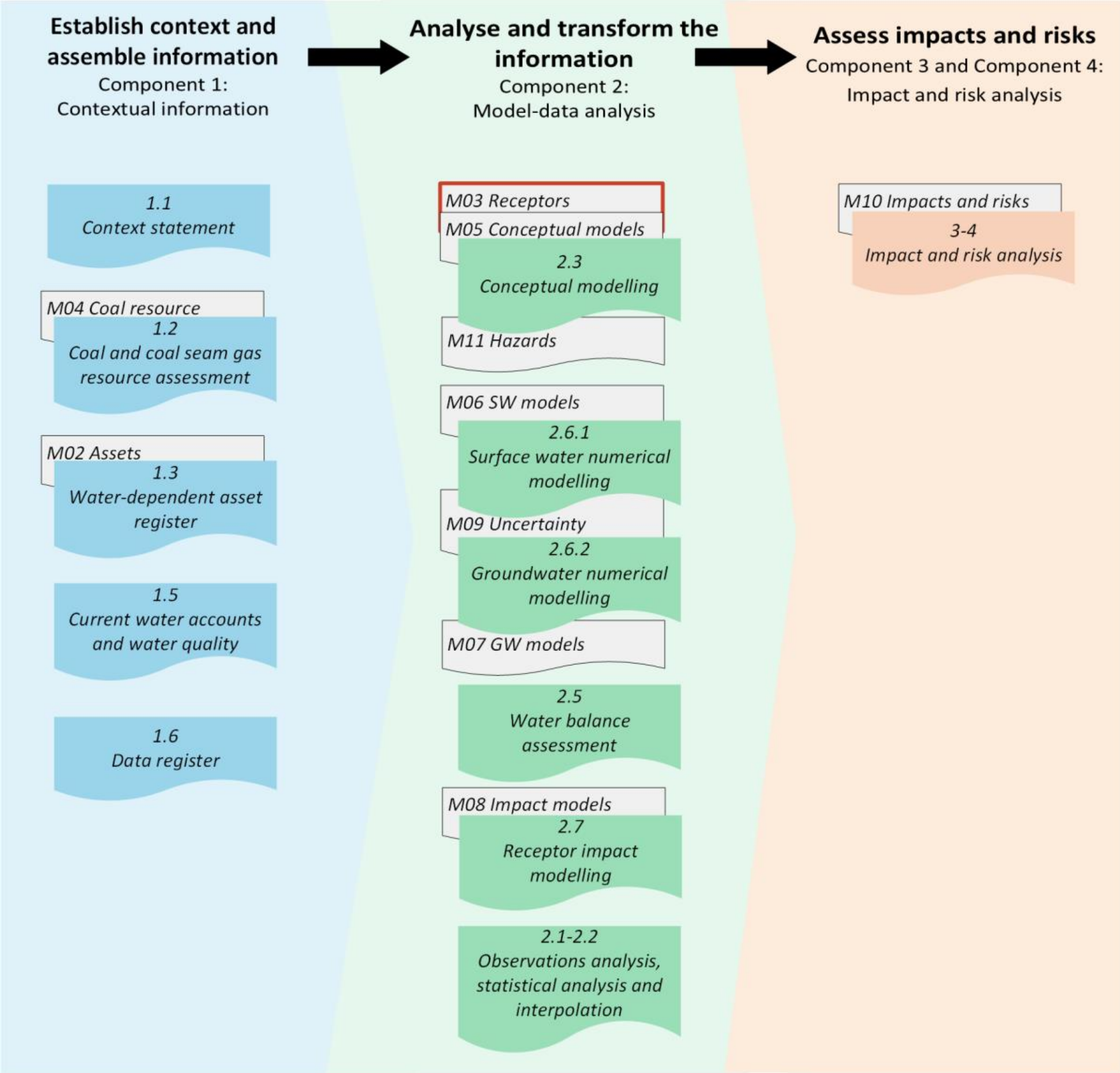

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

In each component (Figure 1) of a bioregional assessment (BA), a number of technical products (coloured boxes, see also Table 2) are potentially created, depending on the availability of data and models. The light grey boxes indicate submethodologies (Table 1) that specify the approach used for each technical product. The red outline indicates this submethodology. The BA methodology (Barrett et al., 2013) specifies the overall approach.

Technical products

The outputs of the BAs include a suite of technical products presenting information about the ecology, hydrology, hydrogeology and geology of a subregion or bioregion and the potential impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are available to the public, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The BA methodology specifies the information to be included in technical products. Figure 2 shows the relationship of the technical products to BA components and submethodologies. Table 2 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it.

Technical products are delivered as reports (PDFs). Additional material is also provided, as specified by the BA methodology:

- unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- lineage of datasets (the origin of datasets and how they are changed as the BA progresses)
- gaps in data and modelling capability.

In this context, unencumbered material is material that can be published according to conditions in the licences or any applicable legislation. All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.

Technical products, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.

Table 2 Technical products delivered by the Bioregional Assessment Programme

For each subregion or bioregion in a bioregional assessment (BA), technical products are delivered online at http://www.bioregionalassessments.gov.au. Other products – such as datasets, metadata, data visualisation and factsheets – are also provided online. There is no product 1.4; originally this product was going to describe the receptor register and application of landscape classes as per Section 3.5 of the BA methodology, but this information is now included in product 2.3 (conceptual modelling) and used in products 2.6.1 (surface water modelling) and 2.6.2 (groundwater modelling). There is no product 2.4; originally this product was going to include two- and three-dimensional representations as per Section 4.2 of the BA methodology, but these are instead included in products such as product 2.3 (conceptual modelling), product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling).

Component	Product code	Title	Section in the BA methodology[a]
Component 1: Contextual information for the subregion or bioregion	1.1	Context statement	2.5.1.1, 3.2
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4
	1.5	Current water accounts and water quality	2.5.1.5
	1.6	Data register	2.5.1.6
Component 2: Model-data analysis for the subregion or bioregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2
	2.3	Conceptual modelling	2.5.2.3, 4.3
	2.5	Water balance assessment	2.5.2.4
	2.6.1	Surface water numerical modelling	4.4
	2.6.2	Groundwater numerical modelling	4.4
	2.7	Receptor impact modelling	2.5.2.6, 4.5
Component 3 and Component 4: Impact and risk analysis for the subregion or bioregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3
Component 5: Outcome synthesis for the bioregion	5	Outcome synthesis	2.5.5

[a]*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (Barrett et al., 2013)

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Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 1 December 2016, http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology.

IESC (2015) Information guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, Australia. Viewed 1 December 2016, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

1 Background and context

Caveat

A large part of this submethodology is superseded by advances in methods for the bioregional assessments (BAs). Specifically, there is now no need to either generate receptors as spatial points across the landscape or to collate them into a receptor register. Instead, receptors are addressed spatially by the asset and landscape class spatial features (polygons, lines and points) and covered conceptually through the development of the landscape classes (product 2.3 (conceptual modelling)), the causal pathways (product 2.3 (conceptual modelling)) and the receptor impact modelling (product 2.7). They are then assessed spatially during the impact analysis using a regular grid of assessment units. Potential impacts on receptors are reported in aggregate via landscape class and asset profiles in product 3-4 (risk and impact analysis) and delivered as spatial datasets at data.gov.au.

As a consequence there is no requirement for a BA to produce a point-based receptor dataset or a receptor register. However, Chapter 3 of this submethodology is still relevant to conducting a BA as it refers to the conceptual basis and criteria for assigning receptors, which informs the relationship between receptors and other parts of the BA process. Chapter 3.2 provides the basis and approach to BA landscape classification, which is then applied to produce the landscape classes in product 2.3 (conceptual modelling).

A *bioregional assessment* (BA) is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential impacts of coal resource development on water and water-dependent assets. The *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) provides the scientific and intellectual basis for undertaking BAs. It is further supported by a series of submethodologies of which this is one. Together, the submethodologies ensure consistency in approach across the BAs and document how the BA methodology has been implemented. Any deviations from the approach described in the BA methodology and submethodologies are to be noted in any technical products based upon its application.

A critical part of the BA requires the definition of a system that links the water and water-dependent assets to the changes in hydrology due to coal resource development. The defined system is based on the concept of spatially located receptors. This submethodology applies overarching principles outlined in the BA methodology to the specifics of assigning receptors to assets and creating product 1.4 (description of the receptor register) (see Table 2 for details of BA products) and the *receptor register*, which is a simple and authoritative list of receptors in a specific BA.

To provide context for this submethodology, Section 1.1 provides an overview of an entire BA from end to end, and the key concepts and relationships between activities within components. See Figure 3 for a simple diagram of the BA components. See Figure 4 for a more detailed diagram of the BA process that includes all the submethodologies, supporting workshops and technical products.

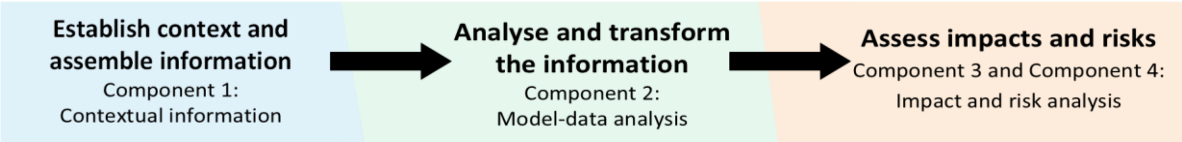

Figure 3 The components in a bioregional assessment

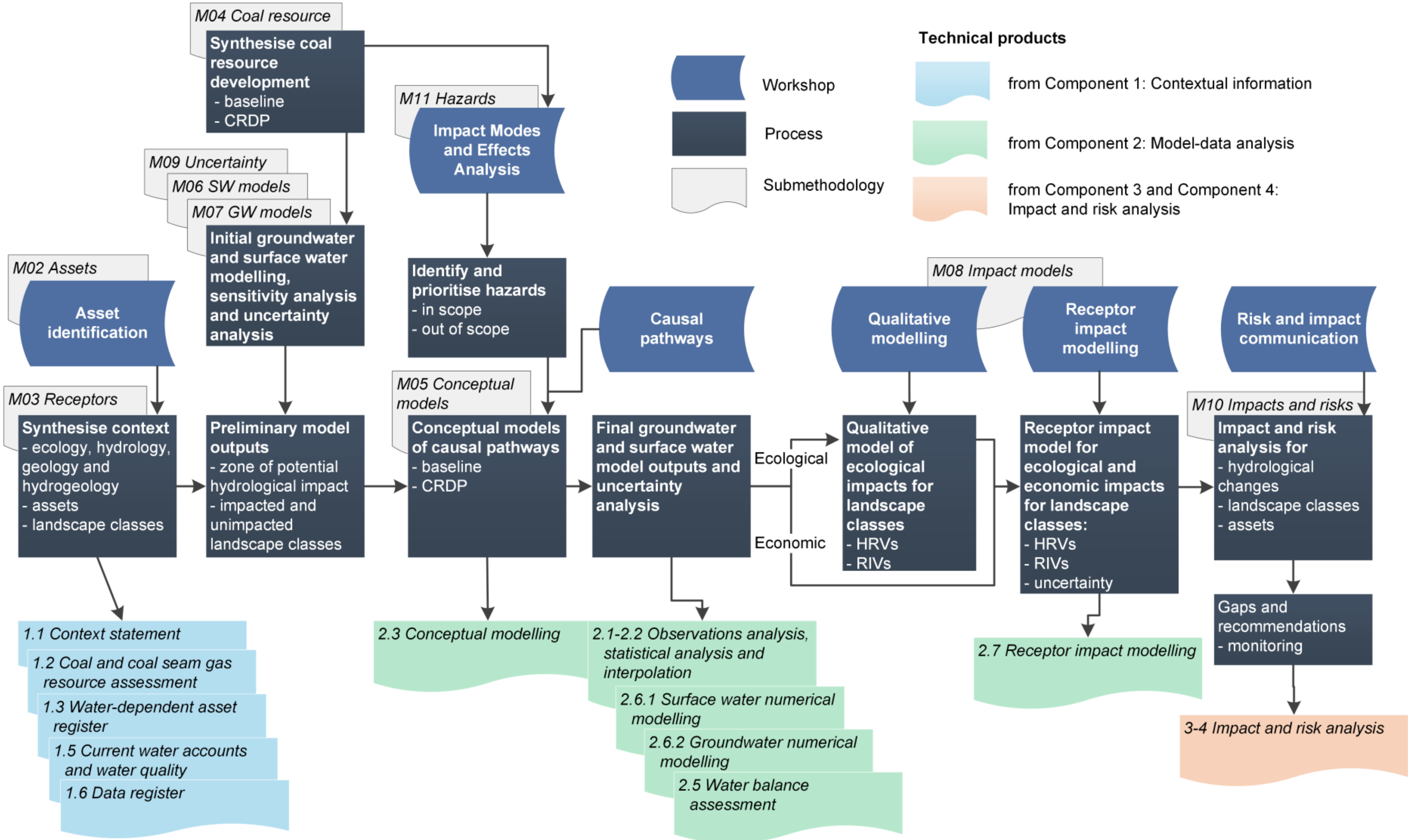

Figure 4 A bioregional assessment from end to end, showing the relationship between the workflow, technical products, submethodologies and workshops

CRDP = coal resource development pathway, HRVs = hydrological response variables, RIVs = receptor impact variables

1.1 A bioregional assessment from end to end

1.1.1 Component 1: Contextual information

In Component 1: Contextual information, the context for the BA is established and all the relevant information is assembled. This includes defining the extent of the subregion or bioregion, then compiling information about its ecology, hydrology, geology and hydrogeology, as well as water-dependent assets, coal resources and coal resource development.

An *asset* is an entity having value to the community and, for BA purposes, is associated with a subregion or bioregion. Technically, an asset is a store of value and may be managed and/or used to maintain and/or produce further value. Each asset will have many values associated with it and they can be measured from a range of perspectives; for example, the values of a wetland can be measured from ecological, sociocultural and economic perspectives.

A *bioregion* is a geographic land area within which coal seam gas (CSG) and/or coal mining developments are taking place, or could take place, and for which BAs are conducted. A *subregion* is an identified area wholly contained within a bioregion that enables convenient presentation of outputs of a BA.

A *water-dependent asset* has a particular meaning for BAs; it is an asset potentially impacted, either positively or negatively, by changes in the groundwater and/or surface water regime due to coal resource development. Some assets are solely dependent on incident rainfall and will not be considered as water dependent if evidence does not support a linkage to groundwater or surface water.

The *water-dependent asset register* is a simple and authoritative listing of the assets within the *preliminary assessment extent* (PAE) that are potentially subject to water-related impacts. A PAE is the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed. The compiling of the asset register is the first step to identifying and analysing potentially impacted assets.

Given the potential for very large numbers of assets within a subregion or bioregion, and the many possible ways that they could interact with the potential impacts, a *landscape classification* approach is used to group together areas to reduce complexity. For BA purposes, a *landscape class* is an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. They are present on the landscape across the entire BA subregion or bioregion and their spatial coverage is exhaustive and non-overlapping. Note that there is expected to be less heterogeneity in the response within a landscape class than between landscape classes. The rule set for defining the landscape classes is underpinned by an understanding of the ecology, hydrology (both surface water and groundwater), geology and hydrogeology of the subregion or bioregion.

Most assets can be assigned to one or more landscape classes. Different subregions and bioregions might use different landscape classes. Conceptually landscape classes can be considered as types of *ecosystem assets*, which are ecosystems that may provide benefits to humanity. The landscape classes provide a systematic approach to linking ecosystem and hydrological characteristics with a wide range of BA-defined water-dependent assets including sociocultural and economic assets. Ecosystems are defined to include human ecosystems, such as rural and urban ecosystems.

Two potential futures are considered in BAs:

- *baseline coal resource development* (baseline), a future that includes all coal mines and CSG fields that are commercially producing as of December 2012
- *coal resource development pathway* (CRDP), a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012.

The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the additional coal resource development – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012.

Highlighting the potential impacts due to the additional coal resource development, and the comparison of these futures, is the fundamental focus of a BA, as illustrated in Figure 5, with the baseline in the top half of the figure and the CRDP in the bottom half of the figure. In BAs, changes in hydrological response variables and particular receptor impact variables are compared at *receptors* (points in the landscape where water-related impacts on assets are assessed).

Hydrological response variables are defined as the hydrological characteristics of the system that potentially change due to coal resource development (for example, drawdown or the annual streamflow volume). *Receptor impact variables* are the characteristics of the system that, according to the conceptual modelling, potentially change due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums). Each landscape class and/or asset may be associated with one or more hydrological response variables and one or more particular receptor impact variables.

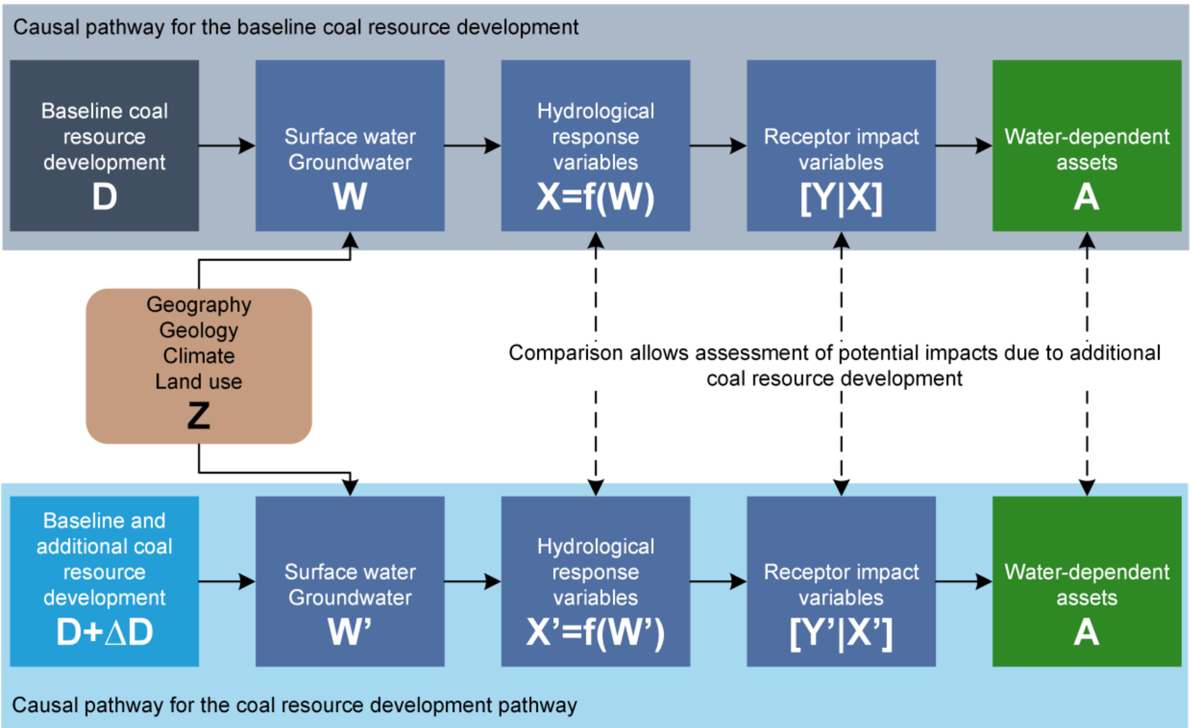

Figure 5 The difference in results for the coal resource development pathway (CRDP) and the baseline coal resource development (baseline) provides the potential impacts due to the additional coal resource development

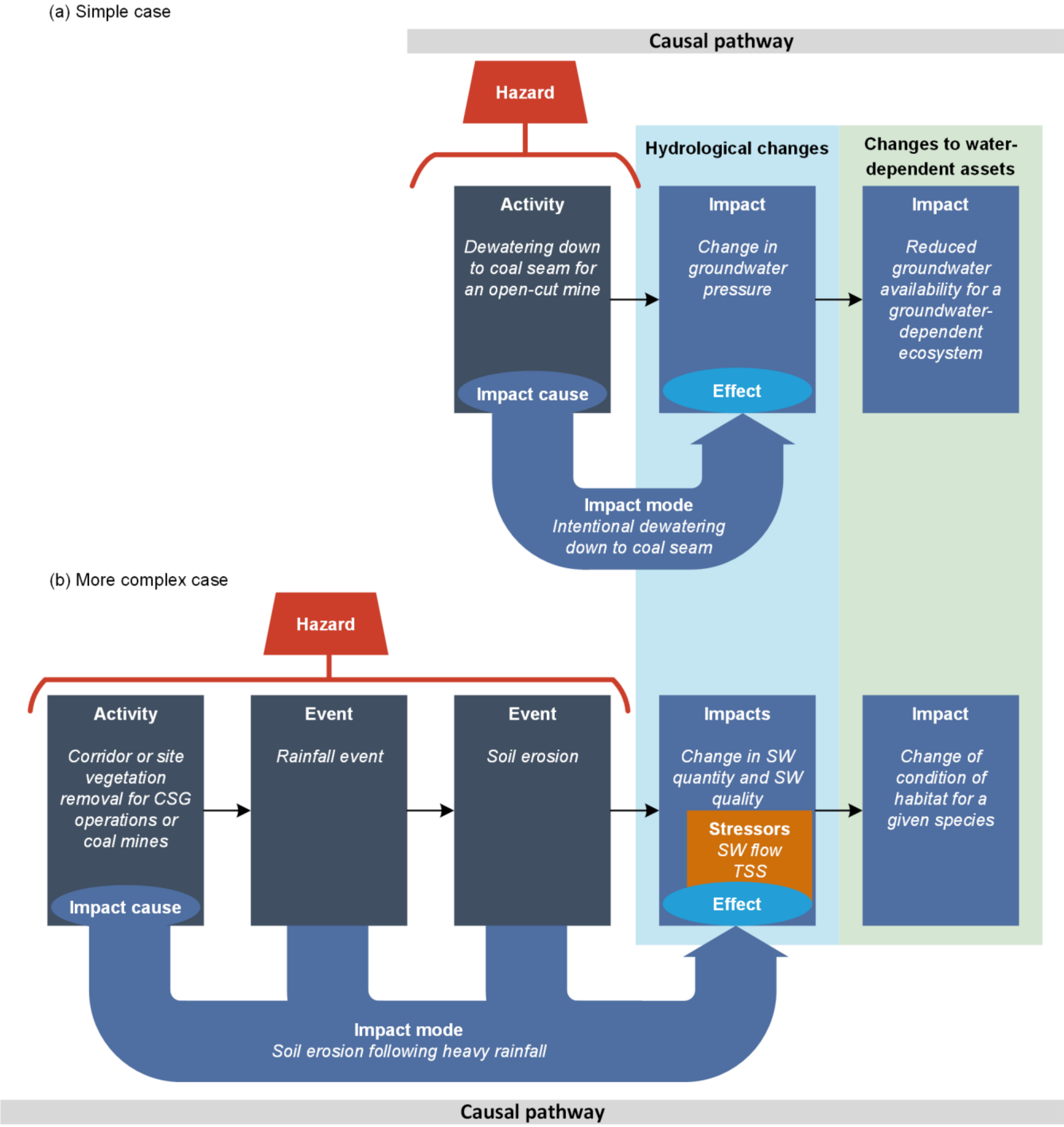

Figure 6 Hazard analysis using the Impact Modes and Effects Analysis (IMEA). This figure shows how hazards identified using IMEA are linked to changes in hydrology and water-dependent assets via causal pathways

The italicised text is an example of a specified element in the Impact Modes and Effects Analysis. (a) In the simple case, an activity related to coal resource development directly causes a hydrological change which in turn causes an ecological change. The hazard is just the initial activity that directly leads to the effect (change in the quality and/or quantity of surface water or groundwater). (b) In the more complex case, an activity related to coal resource development initiates a chain of events. This chain of events, along with the stressor(s) (for example, surface water (SW) flow and total suspended solids (TSS)), causes a hydrological change which in turn causes an ecological change. The hazard is the initial activity plus the subsequent chain of events that lead to the effect.

The hazards arising from coal resource development are assessed using *Impact Modes and Effects Analysis* (IMEA). A *hazard* is an event, or chain of events, that might result in an *effect* (change in the quality and/or quantity of surface water or groundwater). In turn, an *impact* (*consequence*) is a change resulting from prior events, at any stage in a chain of events or a causal pathway (see more on *causal pathways* below). An impact might be equivalent to an effect, or it might be a change resulting from those effects (for example, ecological changes that result from hydrological changes).

Using IMEA, the hazards are firstly identified for all the *activities* (*impact causes*) and *components* in each of the five *life-cycle stages*. For CSG operations the stages are exploration and appraisal, construction, production, work-over and decommissioning. For coal mines the stages are exploration and appraisal, development, production, closure and rehabilitation. The hazards are scored on the following basis, defined specifically for the purposes of the IMEA:

- *severity score*: the magnitude of the impact resulting from a hazard, which is scored so that an increase (or decrease) in score indicates an increase (or decrease) in the magnitude of the impact
- *likelihood score*: the annual probability of a hazard occurring, which is scored so that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the probability of occurrence
- *detection score*: the expected time to discover a hazard, scored in such a way that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the expected time (measured in days) to discover it.

Impact modes and *stressors* are identified as they will help to define the causal pathways in Component 2: Model-data analysis. An *impact mode* is the manner in which a hazardous chain of events (initiated by an impact cause) could result in an effect (change in the quality and/or quantity of surface water or groundwater). There might be multiple impact modes for each activity or chain of events. A *stressor* is a chemical or biological agent, environmental condition or external stimulus that might contribute to an impact mode.

The hazard analysis reflects the conceptual models and beliefs that domain experts hold about the ways in which coal resource development might impact surface water and groundwater, and the relative importance of these potential impacts. As a result, the analysis enables these beliefs and conceptual models to be made transparent.

1.1.2 Component 2: Model-data analysis

Once all of the relevant contextual information about a subregion or bioregion is assembled (Component 1), the focus of Component 2: Model-data analysis is to analyse and transform the information in preparation for Component 3: Impact analysis and Component 4: Risk analysis. The BA methodology is designed to include as much relevant information as possible and retain as many variables in play until they can be positively ruled out of contention. Further, estimates of the certainty, or confidence, of the decisions are provided where possible; again to assist the user of the BA to evaluate the strength of the evidence.

The analysis and transformation in Component 2 depends on a succinct and clear synthesis of the knowledge and information about each subregion or bioregion; this is achieved and documented through *conceptual models* (abstractions or simplifications of reality). A number of conceptual models are developed for each BA, including regional-scale conceptual models that synthesise the geology, groundwater and surface water. Conceptual models of causal pathways are developed to characterise the *causal pathways*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets. The conceptual models of causal pathways bring together a number of other conceptual models developed in a BA, for both the baseline and the CRDP. The landscape classes and the hazard analysis are also important inputs to the process. Emphasising gaps and uncertainties is as important as summarising what is known about how various systems work.

The causal pathways play a critical role in focusing the BA on the impacts and their spatial and temporal context. They provide a basis for ruling out potential impacts for some combinations of location and assets; for example, a particular type of wetland might be beyond the reach of any type of potential impact given the activities and location of the specific coal resource development in the subregion or bioregion. The causal pathways also underpin the construction of groundwater and surface water models, and frame how the model results are used to determine the severity and likelihood of impacts on water and water-dependent assets.

Surface water models and *groundwater models* are developed and implemented in order to represent and quantify the hydrological systems and their likely changes in response to coal resource development (both baseline and CRDP). Surface water models are drawn from the Australian Water Resources Assessment (AWRA) modelling suite, which includes the landscape model AWRA-L for streamflow prediction and river systems model AWRA-R for river routing and management. The latter is only used in a subset of subregions or bioregions and depends on the nature of the river regulation and the availability of existing streamflow data. The groundwater modelling is regional, and the choice of model type and coding is specific to a subregion or bioregion depending on data availability and the characteristics of the coal resource development in the area.

The hydrological models numerically estimate values for the *hydrological response variables* which are further analysed and transformed for the impact analysis. The hydrological response variables are subjected to *sensitivity analysis* and *uncertainty analysis* that test the degree to which each of the model inputs (parameters) affects the model results. It does this by running the model thousands of times and varying the values of the input parameters through a precisely defined and randomised range of values. The most influential parameters identified are taken into an uncertainty analysis, where more carefully chosen prior distributions for those parameters are propagated through to model outputs.

The uncertainty framework is quantitative and coherent. The models are developed so that probabilities can be chained throughout the sequence of modelling to produce results with interpretable uncertainty bounds. Consistent and explicit spatial and temporal scales are used and different uncertainties in the analysis are explicitly discussed. The numerical and uncertainty model results are produced at specific locations known as *model nodes*. Results can be subsequently interpolated to other locations, such as landscape classes and/or assets.

The values for the hydrological response variables estimated by the numerical modelling are critical to assessing the types and severity of the potential impacts on water and water-dependent assets. This is achieved through a staged *receptor impact modelling*.

First, information and estimates are *elicited* from experts with relevant domain knowledge about the important ecosystem components, interactions and dependencies, including water dependency, for specific landscape classes. The experts have complete access to the assembled BA information, including preliminary results from the hydrological numerical modelling. The results are *qualitative ecosystem models* of the landscape classes (or assets) constructed using signed directed graphs.

Based on these qualitative models, the second stage is producing quantitative *receptor impact models* where experts, drawing on their knowledge and the extensive peer-reviewed literature, estimate the relationships between meaningful hydrological response variables and the resulting measurable change in a key characteristic of the landscape class or asset (i.e. receptor impact variables). For example, a receptor impact model could be elicited for the relationship between reduced surface water quality and the change in condition of habitat of a given species (as per Figure 6(b)). As only a small number of receptor impact variables (at least one and no more than three) will be identified for each potentially impacted landscape class, the particular receptor impact variables selected for the receptor impact modelling should be considered to be a measure of a critical ecosystem function (e.g. the base of complex food webs) and/or be indicative of the response of the ecosystem to hydrological change more broadly.

The receptor impact models are, where available, evaluated for each landscape class; this links the numerical hydrological modelling results (hydrological changes due to coal resource development) with ecological changes in water and water-dependent assets of the subregion or bioregion. Therefore, the output of Component 2 is a suite of information of hydrological and ecological changes that can be linked to the assets and landscape classes.

1.1.3 Component 3 and Component 4: Impact and risk analysis

Once all of the relevant contextual information about a subregion or bioregion is assembled (Component 1), and the hydrological and receptor impact modelling is completed (Component 2), then the impact and risk is analysed in Component 3 and Component 4 (respectively).

These components are undertaken within the context of all of the information available about the subregion or bioregion and a series of conceptual models that provide the logic and reasoning for the impact and risk analysis. Coal resource development and potential impacts are sometimes linked directly to assets (e.g. for water sharing plans); however, more often, the impacts are assessed for landscape classes which are linked to assets using conceptual models. Impacts for assets or landscape classes are assessed by aggregating impacts across those assets or landscape classes.

Results can be reported in a number of ways and for a variety of spatial and temporal scales and levels of aggregation. While all the information will be provided in order for users to aggregate to their own scale of interest, BAs report the impact and risk analysis via at least three slices (*impact profiles*) through the full suite of information.

Firstly, the hazards and causal pathways that describe the potential impacts from coal resource development are reported and represented spatially. These show the potential hydrological changes that might occur and might underpin subsequent flow-on impacts that could be considered outside BA. The emphasis on rigorous uncertainty analyses throughout BA will underpin any assessment about the likelihood of those hydrological changes. All hazards identified through the IMEA should be considered and addressed through modelling, informed narrative, considerations of scope, or otherwise noted as gaps.

Secondly, the impacts on and risks to landscape classes are reported. These are assessed quantitatively using receptor impact models, supported by conceptual models at the level of landscape classes. This analysis provides an aggregation of potential impacts at the level of landscape classes, and importantly emphasises those landscape classes that are not impacted.

Finally, the impacts on and risks to selected individual water-dependent assets are reported. These are assessed quantitatively using receptor impact models at assets or landscape classes, supported by the conceptual models. This analysis provides an aggregation of potential impacts at the level of assets, and importantly emphasises those assets that are not impacted. Given the large number of assets, only a few key assets are described in the technical product, but the full suite of information for all assets is provided on http://www.bioregionalassessments.gov.au. Across both landscape classes and assets the focus is on reporting impacts and risks for two time periods: a time related to peak production in that subregion or bioregion, and a time reflecting more enduring impacts and risk at 2102.

The causal pathways are reported as a series of *impact statements* for those landscape classes and assets that are subject to potential hydrological impacts, where there is evidence from the surface water and groundwater numerical modelling. Where numerical modelling results are not available, impact statements will be qualitative and rely on informed narrative. If signed directed graphs of landscape classes are produced, it might be possible to extend impact statements beyond those related to specific receptor impact variables, to separate direct and indirect impacts, and to predict the direction, but not magnitude, of change.

In subregions or bioregions without relevant modelled or empirical data, the risk analysis needs to work within the constraints of the available information and the scale of the analysis while respecting the aspirations and intent of the BA methodology. This might mean that the uncertainties are large enough that no well-founded inferences can be drawn – that is, the hazards and potential impacts cannot be positively ruled in or out.

1.2 Role of this submethodology in a bioregional assessment

This submethodology (M03) is intended to assist those conducting a BA to assign receptors in a representative, efficient and complete manner that is fit for purpose and in accord with high standards of professional scientific practice. It provides the basis for identifying areas of a subregion or bioregion where the hydrological impact of coal resource development is likely to occur and delivers a spatially explicit *receptor register*. Interactions between several components of a BA are involved in assigning receptors (Figure 7).

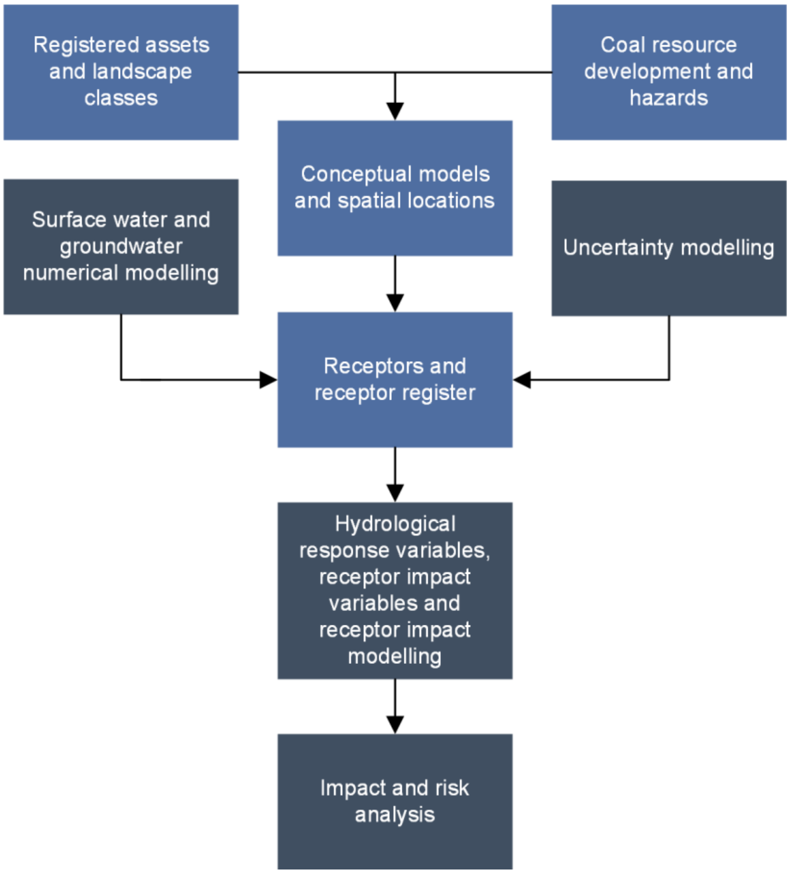

Figure 7 Process for compiling the receptor register (blue boxes) and connections to other bioregional assessment activities (grey boxes)

Firstly, generate conceptual models of the landscape classes and their associated registered assets including potential impacts from hazards due to coal resource development. Next, while referring to available modelling information and requirements and broadly anticipating potential hydrological response variables and receptor impact variables, identify receptor locations and generate the receptor register. The resulting spatially explicit receptors are then used in subsequent activities of the BA: receptor impact modelling (in which changes in receptor impact variables are estimated given changes in hydrological response variables) and ultimately the impact and risk analysis.

The receptor register (described in product 1.4 (description of the receptor register)) is a simple and authoritative list of the receptors, their unique identifier, their location and their landscape class. The development of the receptor register relies on input from:

- the context statement of the subregion or bioregion (product 1.1)
- the coal resource assessment (product 1.2)
- analysis of hazards (impact modes and effects) (reported in product 2.3)
- the water-dependent asset register (product 1.3)
- the conceptual model of causal pathways (product 2.3)
- surface water numerical modelling (product 2.6.1) and groundwater numerical modelling (product 2.6.2).

Readers should consider this submethodology in the context of the complete suite of methodologies and submethodologies from the Bioregional Assessment Programme (see Table 1), particularly the BA methodology (Barrett et al., 2013), which remains the foundation reference that describes, at a high level, how BAs should be undertaken. Submethodology M03 is most strongly linked to the following submethodologies (as listed in Table 1):

- submethodology M02 for compiling water-dependent assets (Mount et al., 2015)
- submethodology M04 for developing a coal resource development pathway (Lewis, 2014)
- submethodology M05 for developing a conceptual model of causal pathways (Henderson et al., 2016)
- submethodology M06 for surface water modelling (Viney, 2016)
- submethodology M07 for groundwater modelling (Crosbie et al., 2016)
- submethodology M11 for hazard analysis (Ford et al., 2016).

The application of M03 to a BA in a subregion or bioregion will deliver a receptor register suitable for use in the uncertainty analysis described in the companion submethodology M09 (as listed in Table 1) for quantifying uncertainty through models (Peeters et al., 2016) and also for receptor impact and risk analysis as described in the companion submethodologies M08 and M10 (as referred to in Table 1).

2 Defining receptors

As outlined in the *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013), anthropogenic or ecological receptors are defined as:

> A discrete attribute or component of a water-dependent asset that may be measurably impacted by a change in water quantity or quality resulting from coal seam gas or coal mining development.

This has since been refined to enhance subsequent applications of the BA methodology (see companion submethodology M02 (as listed in Table 1) for compiling water-dependent assets (Mount et al., 2015)) and the working definition adopted throughout this submethodology is:

> A receptor is a point in the landscape where water-related impacts on assets are assessed.

Receptors are inventoried in a receptor register. Receptors are linked to assets in the water-dependent asset register (product 1.3 (description of the water-dependent asset register); see Table 2 for product details). They have a number of attributes associated with them, including an identifier and location (latitude and longitude coordinates). Information and data can be recorded at a receptor including depth-related information, such as watertable depth, modelled water pressure at specific depths and asset (aquifer) depths. A receptor will not normally be a biological entity (e.g. a bird, frog or plant); rather it must represent key characteristics of the landscape class or asset class it is located within such as the habitat of biological entities. For example, the groundwater-dependent habitat for a biological entity is the asset, rather than the biological entity itself. A receptor can be conceived of as a long thin imaginary line projecting from the centre of the Earth out through the location coordinate (latitude and longitude).

A primary role of a receptor in a bioregional assessment (BA) is that it is the point location in the landscape where detailed information about the responses to changes in the water regime is summarised, including an assessment of the uncertainty in those responses. In practice, receptors are typically located within landscape classes and linked to water-dependent assets. They are where estimates (i.e. parameters, state variables and/or fluxes) from surface water and groundwater models are related to potential impacts (hazards) on water-dependent assets arising from additional coal resource development in the coal resource development pathway (CRDP).

Examples of receptors might include nodes in a river model or points within groundwater or rainfall-runoff models where uncertainty in hydrological response variables can be assessed. Receptors might also be associated with existing physical monitoring points; receptors might include:

- streamflow and water quality gauge points
- surface water access entitlements
- groundwater bores

- existing environmental monitoring or sampling points
- nodes in a river routing model
- groundwater model pixel x,y centroids
- remotely sensed pixel centroids
- rainfall-runoff model pixel x,y centroids
- any other point that may be sensibly interpolated from the preceding information.

Receptors are the focal point for *receptor impact models* (see companion submethodology M08 (as listed in Table 1) about receptor impact modelling) and these will have one or more hydrological response variables and one or more receptor impact variables associated with them. While the detail of defining and selecting the hydrological response variables and receptor impact variables is dealt with in other submethodologies, it is necessary to consider them, at least conceptually, when applying this submethodology to ensure the receptors are suitable for use with the receptor impact modelling. The receptor impact models and the qualitative models that support them are the primary mechanism for determining direct or indirect impacts, and subsequent cumulative impacts of coal resource development.

Hydrological response variables and receptor impact variables will vary by landscape class and impact type and their selection is guided by the relevant conceptual models. When applying this submethodology it is necessary, in every BA, to at least relate the receptors to the landscape classes and the assets using the process defined in Section 3.2 and Section 3.3. The landscape classes are documented in product 2.3 (conceptual modelling) (see Table 2 for BA product details).

There is an important point to clarify. The hydrological modelling, in some cases, might report results at *model nodes* that might not coincide with receptor locations. In these cases, hydrological changes will be interpolated to receptor locations for use in subsequent receptor impact modelling and impact and risk analysis.

3 Assigning receptors

3.1 Overview of process for assigning receptors

The process for assigning receptors for a bioregional assessment (BA) is summarised in Figure 8.

Assigning receptors is a critical point of engagement within the Assessment team. The selection of receptors and development of the receptor register requires consultation and input from ecologists, hydrologists and hydrogeologists, risk experts and those with domain and local expertise. Some of the processes may occur in parallel; hydrologists can be developing surface water and groundwater models at the same time as ecologists are developing the landscape classification and reviewing the detailed conceptual models. However, even in this situation there needs to be constant interactions within Assessment teams. For example, groundwater-dependent assets such as bores or groundwater-dependent ecosystems (GDEs) may need to be explicitly built into the groundwater model. Simultaneously, key hazards associated with the coal resource development pathway (CRDP) can be documented and used as input into the selection of appropriate receptors.

The target requirement is for receptor coverage that enables the analysis of impacts on the assets listed in the water-dependent asset register (product 1.3; see Table 2 for BA product details). Input from initial hydrological modelling will be critical in helping to scope the extent and magnitude of expected hydrological responses and to focus the effort for subsequent receptor impact modelling and impact and risk analysis. Furthermore, the uncertainty analysis associated with surface water and groundwater models requires that the hydrological response variables (or derived metrics) are identified prior to the development of the model emulators (described in the companion submethodology M09 (as listed in Table 1) for propagating uncertainty through models (Peeters et al., 2016)). An outcome of this is that the number of receptors for which model emulators will be built (model nodes) will be a subset of the total number of receptors required for complete representation of the assets as the number of model nodes needs to be balanced across the number of hydrological response variables, receptor locations and assessment periods. Resolution of this trade-off requires a number of iterations during the assignment of receptors. In some cases, the model nodes might not coincide with receptor locations. In these cases, hydrological changes will be interpolated to receptor locations for use in subsequent receptor impact modelling and impact and risk analysis. It is important that all decisions taken during this period are documented and justified.

In short, the receptors may be best allocated in a two-stage process, with a preliminary distribution across the landscape and then a refinement of that distribution as more information becomes available (Chapter 0). The refinement should include input from internal and external experts.

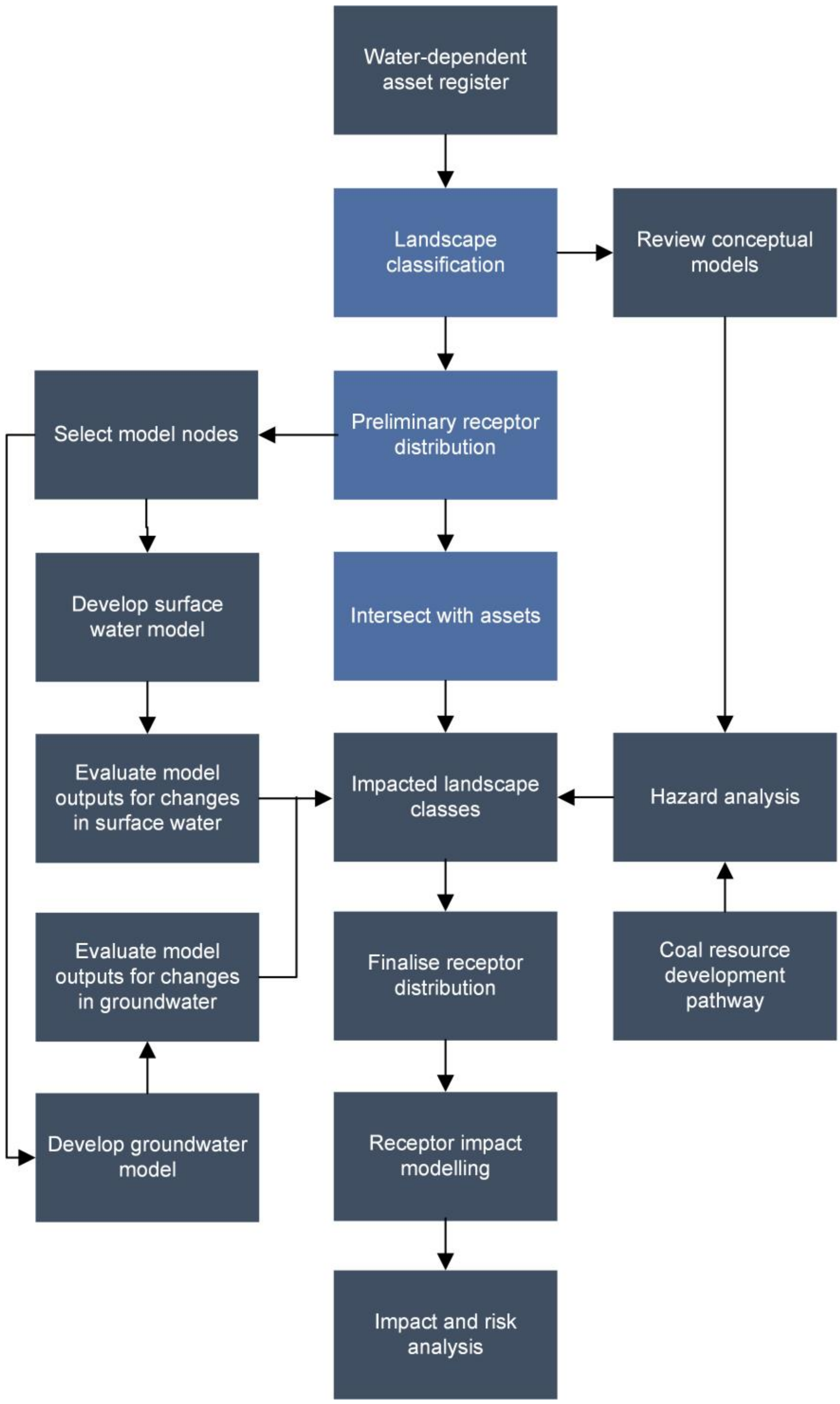

Figure 8 Process for distributing receptors for a bioregional assessment as described in this submethodology (blue boxes) and connections to other bioregional assessment activities (grey boxes)

3.1.1 Overarching principles for assigning receptors

A carefully designed and implemented receptor placement strategy is fundamental to the development of receptor impact models within a BA.

To assist in assigning receptors, the following guiding principles are articulated:

- The assessment is a regional assessment and there are trade-offs between the number of receptors and hydrological response variables that can be analysed in the uncertainty analysis. Such trade-offs require the Assessment team to pay close attention to the spatial and temporal scale of the BA. Those choices must then guide the finalisation of the distribution of receptors.

- A comprehensive distribution of receptors (points in the landscape) will be generated which are then the point locations at which impacts on assets are assessed. A subset of these locations will be selected as ‘model nodes’ and used as the receptors for detailed and specific hydrological modelling of hydrological response variables and associated uncertainty analysis. In some cases, the model nodes might not coincide with receptor locations. In these cases, hydrological changes will be interpolated to receptor locations.
- The selection and/or choice of these ‘model nodes’ from the full set of receptors must be made in consultation with BA surface water and groundwater modellers and incorporate information contained within the CRDP and hazard analysis and facilitate interpolation of hydrological responses and associated uncertainty to all receptors.
- The selection and/or choice of receptors must be tested at each stage against the principles of being complete, efficient and representative:
  - A complete set of receptors adequately covers the range of potential impacts contained within the environmental space occupied by the water-dependent assets.
  - An efficient set of receptors adequately defines the potential impacts of coal resource development on water-dependent assets without the need for defining further receptors.
  - A representative receptor or set of receptors for a water-dependent asset is located so that relevant information is provided on the potential impacts of coal resource development on that water-dependent asset.
- Receptors need only be assigned to landscape classes deemed to be water dependent for the purposes of the Assessment.
- Receptors may be assigned directly to assets where landscape classes are not required or relevant. For example, to bores or subsurface features such as an aquifer.
- Receptors must encompass the complete spatial extent of all water-dependent landscape classes within the preliminary assessment extent (PAE). This is necessary to identify areas potentially impacted by coal seam gas (CSG) and coal resource development and avoids bias or circular reasoning (i.e. the receptor locations should not be used to guide spatial prioritisation of hydrological and hydrogeological modelling). This submethodology (M03) recognises that:
  - Receptors may fall outside of model domains; in which case they will be noted as a knowledge gap in the Assessment.
  - Potentially large numbers of receptors may have no observable hydrological change; this is an important communication outcome from the Assessment and should be noted as ‘No modelled difference in hydrological changes for baseline and CRDP’.
- Expert elicitation will be used extensively to guide selection of landscape classes, and the resultant finalised receptor distribution.

3.2 Landscape classification

Bioregions and their subregions typically contain many thousands of assets. The Galilee subregion within the Lake Eyre Basin bioregion, for example, has over 4,000 assets comprised of over 800,000 individual spatially discrete *elements* (individual spatial features – points, lines and polygons). Similarly, in the Namoi subregion, ecological assets alone exceed 1,800 assets comprised of over 34,000 discrete spatial elements. Many assets have internal heterogeneity or complexity that may influence receptor assignment. For example, a single national park could contain many water-dependent assets including rivers, floodplains, lakes, wetlands and springs, and habitats for a range of threatened species. Given the extremely high number of potential interdependencies, it is impractical to develop receptor impact models for each individual asset.

To overcome this constraint a landscape classification approach is used to systematically define geographical areas into classes that are similar in physical and/or biological and hydrological character. This is a form of ecosystem classification relevant to each BA and, importantly, includes human ecosystems, such as rural and urban areas. Conceptually, the landscape classes can be considered as types of ecosystem asset (Bureau of Meteorology, 2013; United Nations et al., 2014) but are referred to as landscape classes in BAs. An ecosystem asset is an ecosystem that may provide benefits to humanity. Landscape classification aims to:

- reduce asset complexity to a limited number of regional-scale landscape classes (e.g. 10 to 20) appropriate for the Assessment that are mutually exclusive and comprehensive such that all assets in a BA are a member of at least one landscape class
- wherever possible, use existing data sources and classifications (e.g. River Styles, Australian National Aquatic Ecosystem (ANAE) (Aquatic Ecosystems Task Group, 2012), etc.)
- guide the development and review of conceptual models for selection of appropriate hydrological response variables and receptor impact variables associated with water-dependent asset
- provide a natural aggregation for reporting risk and impacts in Component 3 and Component 4 (Figure 2).

While one aim of the landscape classification is to focus the contextual information for the subregion or bioregion, the capacity to classify water-dependent ecosystems within a broader landscape will vary from one subregion or bioregion to another depending on the availability of underpinning datasets. To facilitate classification, the approach should wherever possible use existing information, and be based on existing classifications (Table 3). A diagrammatic representation of the underlying rationale for the landscape classification approach is shown in Figure 9.

The starting point in developing the landscape classification is the information in the context statement for the subregion or bioregion (product 1.1). The context statement summarises existing knowledge of geology, hydrology, hydrogeology, geography and ecology prior to the new model-data analysis for the Assessment. It also provides insights into the important drivers of variability in geology, climate, soils, vegetation and land use that make up the unique character of the subregion or bioregion.

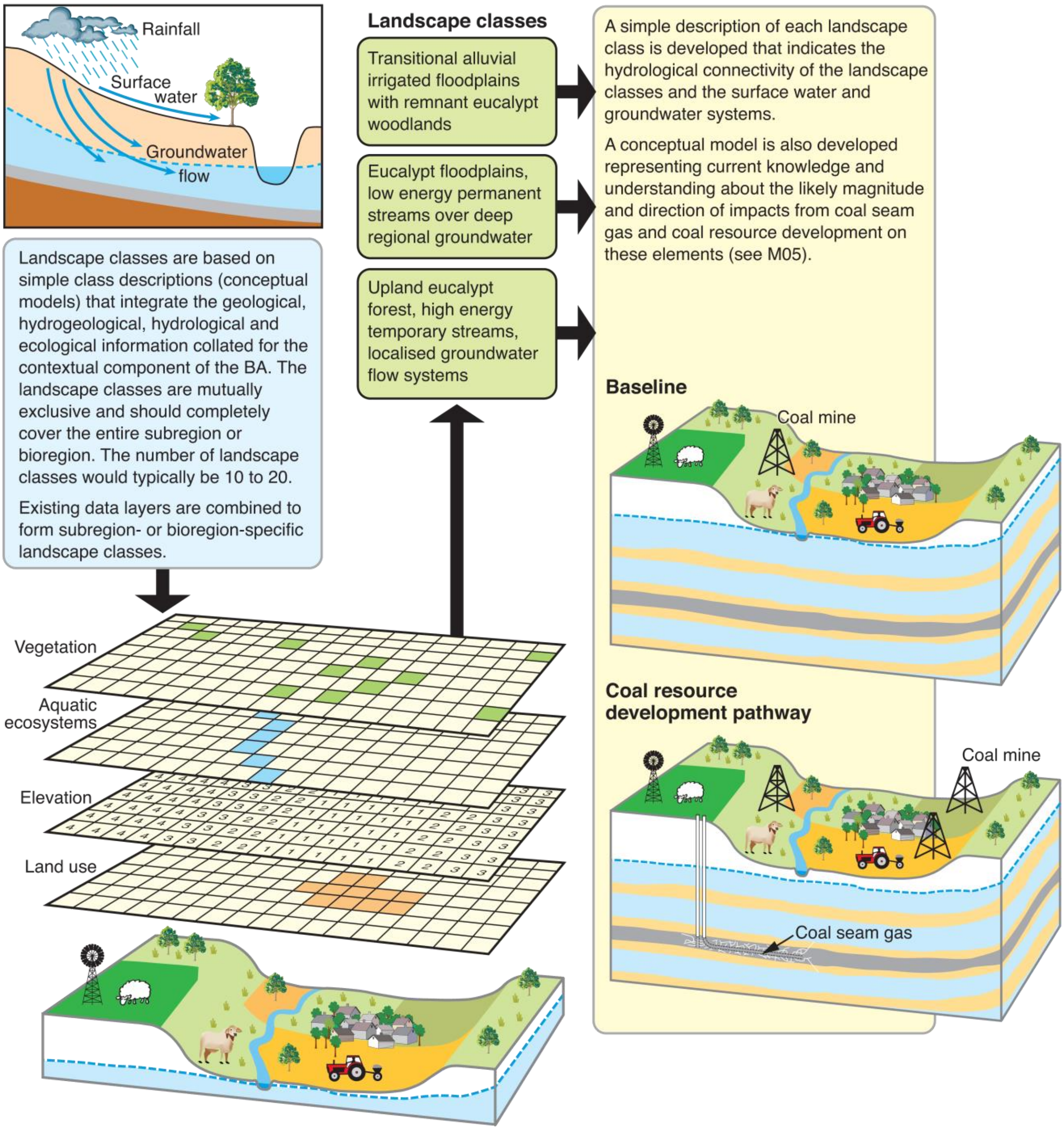

Figure 9 Overview of the approach for classifying unique landscape systems

M05 is companion submethodology (as listed in Table 1) for developing a conceptual model for causal pathways (Henderson et al., 2016).

The primary outcome of the landscape classification is a set of landscape classes that represents areas of similar biophysical characteristics within the subregion or bioregion. Each landscape class requires a basic conceptual model to be documented for product 2.7 (receptor impact modelling) (using methods described in the companion submethodology M05 (as listed in Table 1) for developing a conceptual model for causal pathways (Henderson et al., 2016)). Its basic purpose is to describe the landscape class structures (e.g. wetland type or irrigation bore), functions (e.g. sediment transport processes or groundwater level changes), and the relationships to surface water and groundwater regimes (e.g. dependence of a GDE landscape class on groundwater). The landscape classes and the associated conceptual models contribute to the evidence base for defining the locations and numbers of receptors, such that receptors are located throughout different parts of the landscape in the subregion or bioregion and represent a range of water dependency types.

Once defined, the landscape classification – and the broad, simple conceptual model associated with each class – provides the basis for the more detailed, focused conceptual models produced for the BA during the conceptual modelling activity within Component 2 (product 2.3 (conceptual modelling)) and the receptor impact modelling within the latter stages of Component 2 (product 2.7 (receptor impact modelling)) and in Component 3 (product 3-4 (impact and risk analysis)).

Inputs into the landscape classification should be based on existing classification schemes wherever possible and can be purely physical, biological or predictive (Linke et al., 2011) or a combination of these and:

- *physical surrogates*: abiotic information only. These are commonly applied in data-poor planning regions with severely limited biological data and expert knowledge. These surrogates are derived from geographic information systems (GIS) and make use of best available data and conceptual knowledge about abiotic drivers of aquatic systems
- *biological surrogates*: individual species, species assemblage types or observed processes. The limitation of this approach is survey data being fraught with data gaps and of mixed quality. To address bias, modelled species distributions (Linke et al., 2007; Moilanen et al., 2008) or communities (Turak and Koop, 2008) can be used, but these are still based on environmental attributes
- *biologically informed physical surrogates*: environmental surrogates that have been correlated directly to biological survey data. An empirical model is used to link environmental surrogates to the landscape patterns of biological attributes (Linke et al., 2011). The approach (Leathwick et al., 2001) uses environmental data related to species distributions to discriminate sites (e.g. classify streams) with similar biological characters, and uses detailed segment-specific environmental variables and accounts for longitudinal connectivity. The generalised dissimilarity model is specifically designed to analyse biological turnover and relationship with environments.

Choice of approach depends on the type of asset under consideration (ecological, sociocultural or economic), the availability of data at an appropriate scale, as well as the expertise and resources for undertaking the assessment. However, the primary underlying principles for using landscape classification approaches for a BA are that they should:

- be credible, transparent, logical and consistently applied
- where possible, match other classifications (or at least some of their classes) as long as these relate unambiguously to coal resource development
- provide a conceptualisation of water-dependent assets that assists in the development of receptor impact models and appropriate selection of hydrological response variables and receptor impact variables
- guide the selection, placement and number of receptors

- add value to the assessment of assets
- where possible, consider linkages between receptors and relevant hydrological response variables and receptor impact variables including through appropriate conceptual models
- be feasible within available resourcing.

Receptor selection: the landscape classification approach helps distribute receptors across the subregion or bioregion and the assets under consideration. Efficiencies are gained through interpolation of hydrological response and their associated uncertainty to landscape classes instead of directly estimating the responses at every asset. The resultant receptors are documented in the receptor register and product 1.4 (description of the receptor register) (see Chapter 4).

*Adding valu*e: the classification approach assists in defining the key structural and process attributes associated with assets and facilitates the grouping of assets in a consistent and defensible manner across bioregions or subregions.

Conceptual model selection: the classification approach helps to link receptors to appropriate hydrological response variables and receptor impact variables via conceptual models. Thus, the classification must link explicitly to conceptual models for ecosystems in the subregion or bioregion. The landscape classification approach and the resulting classes are documented in product 2.3 (conceptual modelling).

Resourcing: where feasible and to avoid unnecessary work, use or adapt existing classifications and typologies. To do this the existing classifications need to be evaluated for ‘fitness for purpose’. The criteria for this assessment should encompass the scale of applications, availability and/or access arrangements and quality. New conceptual models should only be defined when existing ones are unsuitable.

A number of classification schemes are already being evaluated and applied in the Bioregional Assessment Programme; these include but are not restricted to those described in Table 3.

Table 3 Some classification schemes being evaluated for use in the Bioregional Assessment Programme

Scheme	Description	Source
Interim Australian National Aquatic Ecosystem (ANAE) Classification Framework	A broad-scale hierarchical attribute-based scheme aimed at providing a nationally consistent framework for classifying aquatic ecosystems.	Aquatic Ecosystems Task Group (2012)
Australian Land Use and Management (ALUM) Classification Version 7	A classification system that provides a nationally consistent method to collect and present land use information for a wide range of users across Australia.	Department of Agriculture (2010)
Queensland Wetland Info	Information about wetland management resources in Queensland including data and conceptual models based on ANAE classification.	Department of Environment and Heritage Protection (2015)
Ramsar	A broad internationally recognised wetland type classification aimed at rapid identification of wetland habitats.	Department of the Environment (2014)
River Styles	A geomorphic approach for examining river character, behaviour, condition and recovery potential.	River Styles (2014)
Groundwater Dependent Ecosystems Atlas (GDE Atlas)	The *National Atlas of Groundwater Dependent Ecosystems* presents the current knowledge of groundwater dependent ecosystems across Australia	Bureau of Meteorology (2014)

3.3 Process for assigning receptors across the landscape

The process for assigning receptors in a BA is iterative in nature and needs to include input from across the Assessment team (Figure 4). The main steps in the process include the following, noting that while steps one and six are the subject of this submethodology they depend on the other steps, which are the subject of other submethodologies:

1. Select appropriate receptor locations to provide a preliminary coverage of the assets and landscape classes (see Section 3.3.2). This will produce a preliminary (draft) receptor register.
2. Commence hydrological response model development and runs (refer to submethodologies M06 and M07 as listed in Table 1) based on the BA's conceptual modelling (refer to product 2.3 (conceptual modelling) and submethodology M05 as listed in Table 1).
3. Conduct sensitivity analysis of model output (refer to product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling) and submethodology M09 as listed in Table 1).
4. Examine model output to identify regions where there are detectable changes in hydrological response variables in relation to the CRDP (refer to product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling) and submethodologies M06 and M07 as listed in Table 1) and to define the potential spatial extent of hydrological responses.
5. Identify key hydrological response metrics representative of the assets and landscape classes within the regions where there are detectable changes in hydrological response variables (refer to submethodologies M08, M09 and M10 as listed in Table 1).
6. Refine the selection of appropriate receptor locations to provide coverage of the assets and landscape classes in a representative, efficient and complete manner that is fit for purpose and in accord with high standards of professional scientific practice (see Section 3.3.2 and Section 3.3.3). This will produce the final, refined receptor register.
7. Build model emulators that summarise the key hydrological responses and specific points in time (refer to submethodologies M09 and M10 as listed in Table 1).
8. Build appropriate sets of rules to interpolate the outputs of the model emulators (i.e. outputs at receptors) to all of the assets within the subregion or bioregion (i.e. develop the summary metrics that provide complete coverage of assets) (refer to submethodologies M08 and M10 as listed in Table 1).

Step five in this procedure is the major point of focus for the entire assessment. The process of identifying areas within the PAE where changes in hydrological response variables are detectable will (in most cases) reduce the spatial extent of the assessment. This step can act to concentrate the statistical emulators associated with the uncertainty analysis into areas where there are non-negligible changes in nominated hydrological response variables, but also provides the opportunity to examine in more detail conceptual models for assets in the location of hydrological impact and ensure that hydrological response variables are representative of potential impacts. This will assist the refinement of the receptor locations.

3.3.1 Hydrological response variables and receptor impact variables

The process for the preliminary distribution of receptors across the landscape (step one for assigning receptors) requires the Assessment team to consider, at least conceptually, the likely or known hydrological response variables and receptor impact variables potentially involved in the assessment (see companion submethodologies M06 and M07 (as listed in Table 1) for surface water modelling (Viney, 2016) and groundwater modelling (Crosbie et al., 2016), respectively, for lists of recommended hydrological response variables). For example, where changes in the water regime caused by coal resource development do not involve surface water, then no surface water hydrological response variables need be considered. The second stage of refining the distribution of receptors (step six for assigning receptors) will require a more detailed knowledge of the potential hydrological response variables and receptor impact variables. This more detailed knowledge will be drawn from the available conceptual modelling, surface water and groundwater modelling, uncertainty analysis and receptor impact modelling work at the time the receptor register is defined.

3.3.2 Spatial distribution of receptors across the landscape

The actual steps for spatially distributing receptors will inevitably vary among subregions or bioregions and depend to some extent on the types of asset in the water-dependent asset register and the subsequent landscape classes. However, it is important to ensure that the receptors are spatially distributed within a subregion or bioregion in a systematic and representative manner. Many approaches for assigning receptors to landscape classes are currently available to Assessment teams including:

1. A generalised random tessellation stratified (GRTS) design proposed by Stevens and Olsen (2004). This approach uses an algorithm that maps two-dimensional space into one-dimensional space thereby defining an ordered spatial address. Stevens and Olsen (2004) argue that sampling designs with some degree of spatial regularity (such as gridded sampling or spatially stratified designs) tend to be more efficient than designs with no spatial structure. This approach is supported by existing standardised scripts but requires high-level spatial analysis skills.
2. A second approach uses a network of the Bureau of Meteorology's 'Geofabric' outlet nodes as anchors. Receptors are then placed within every landscape class element within the catchment at the point closest (in terms of a straight-line distance) to the defined catchment outlet nodes. This approach provides complete coverage of all assets and landscape classes within a PAE but may reduce the sampling efficiency. Scripts have been developed as part of BA to implement this tool. The advantage of this approach is that it ensures that all assets receive at least one receptor (in most cases many); it also recognises that for many receptors there will be no discernible impacts, and that communication of this is in itself an important output.
3. A third approach places receptors in a systematic grid across the PAE with the grid spacing determined by the requirements of the analysis and the rate of change of the available information, including the results of the available models.

These, and other suitable approaches, will enable the development of a preliminary receptor register that contains many thousands of receptors and completely covers the PAE. Care must be taken to ensure that all assets are assigned to or have appropriate receptors. In the event that all assets are assigned to a landscape class this step is relatively straightforward. It is the Assessment team's responsibility to ensure that the final distribution of receptors facilitates the estimation of impacts on assets. This means that receptors within an asset need to be at a sufficient density to provide statistical estimates of impact (see companion submethodology M10 (as listed in Table 1) for identifying and analysing risk). Furthermore, note that these approaches produce a distribution of receptors beyond the capacity of what can be realistically delivered within the constraints of the uncertainty analysis. The Assessment team will need to work together to decide on the number and location of the subset of receptors that will be nominated as *model nodes*, with the understanding that impacts at this subset of model nodes will need to be interpolated to receptors at assets.

For *surface water assessments*, model nodes could be located at the outlet of the river basins (water catchments); here use of the Bureau of Meteorology's 'Geofabric' may be particularly useful in selecting these receptors. The Geofabric is a nationally consistent series of interrelated spatial datasets defining hierarchically-nested river basins, stream segments, hydrological networks and associated cartography (Bureau of Meteorology, 2012). For example, existing Geofabric nodes at the lowest point in each selected river basin can be located, using a digital elevation model (DEM) to generate a network of surface water receptors, densities of which will vary depending on the level of the river basin in the hierarchy. The receptors will cover all flowing and standing water features defined in the landscape class and asset spatial layers (see the worked example in Section 3.3.4). The appropriate river basin level is assessed by ensuring complete and representative coverage of surface water assets. The uncertainty around the nominated flow metrics will be determined by statistical emulators located at these receptors. The Assessment team must then develop appropriate rules to interpolate the hydrological response variables and associated uncertainty to each of the receptors associated with individual assets within the river basins. A key consideration in this decision should be how representative are the outlet nodes of flow regimes within the contributing catchment.

In *groundwater assessments* receptors for groundwater-dependent landscape classes need to be built into the groundwater model before the model is run. In this situation, receptors could be placed in a systematic grid across the PAE (e.g. at the x,y centroid of the model pixel), at bores within a groundwater management zone or at x,y centroids of GDE polygons, or some combination of the three. Regardless of the approach used to assign groundwater receptors, model emulators will only be built at a subset of these receptors. Again, the Assessment team must develop appropriate rules to interpolate the hydrological response variables and associated uncertainty to each of the receptors associated with individual assets within the groundwater system.

All these approaches will provide an extensive preliminary distribution of receptors (step one for assigning receptors). Subsequently, the preliminary distribution must be tested for gaps, bias and efficiency (see Section 3.3.3) and, if required, refined (step six for assigning receptors). For example, an intersection is required to ensure that all assets are represented. If they are not adequately represented, additional receptors should be added. Decisions around the final density of receptors need to be addressed by the Assessment team. Based on the preliminary results of the modelling (step four for assigning receptors) the numbers and location of receptors may be refined. For example, extra receptors may be required directly downstream and upstream of proposed developments. The point-of-truth distribution of receptors is stored as a spatial (point) dataset in the Bioregional Assessment Repository and documented in the receptor register, which is initially published as an Excel spreadsheet (see Chapter 4); the receptor register can be updated at any time during the Assessment and will be published on the Bioregional Assessment Information Platform. However, the associated product 1.4 (description of the receptor register) will not be updated.

3.3.3 Criteria for evaluating receptor assignment

Consideration of the suitability of receptors against appropriate criteria provides a basis for inclusion of receptors within the receptor register. To be useful as receptors, there needs to be the capacity to demonstrate a causal pathway from the identified hazards to the receptor. This causal pathway should be documented in the conceptual model as hypothesised statements with, where available, supporting evidence (see M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016) for details). The Assessment team must not only rely on their own evaluation of these criteria but include consultation with domain expertise or those with local knowledge. Input should be obtained via a number of mechanisms including one-to-one conversations, at least one workshop and external review and potentially through the use of online survey tools. Criteria against which receptors may be evaluated include:

- ability to model the change in the hydrological response variables associated with the receptor in response to coal resource development
- ability to represent the phenomenon of interest (e.g. an asset–impact relationship)
- availability of data to establish a baseline prior to coal resource development (i.e. establish existing trends)
- tractability for measuring, modelling and monitoring
- ability to quantify the uncertainty in measuring the receptor
- suitability of the receptor to indicate the condition and predicted impact on multiple assets.

3.3.4 An example of surface water receptors for the Namoi subregion

The following case study is intended as an example to illustrate a process for assigning the initial distribution of surface water receptors. The final landscape classification and distribution of receptors for the Namoi subregion (as reported in product 1.4 (description of the receptor register) and product 2.3 (conceptual modelling)) may differ from that presented in this section. As the purpose is to demonstrate a process for assigning receptors, detail on the methodology for the landscape classification is intentionally brief.

3.3.4.1 Background

The Namoi subregion is part of the Northern Inland Catchments Bioregional Assessment. The landforms of the Namoi subregion are characterised by nine Interim Biogeographic Regionalisation of Australia (IBRA; SEWPaC, 2012) subregions (Welsh et al., 2014). There are marked climate gradients across the bioregion with mean annual rainfall decreasing and mean annual temperature increasing from south-east to north-west.

The subregion is dominated by land cleared for agriculture, and much of the remaining remnant vegetation has been substantially altered. Drainage of the subregion is predominantly via the Namoi River and its tributaries and distributaries including the Mooki River, Coxs Creek, Pian Creek and Turragulla Creek. These support many important wetlands, floodplains and lagoons. The forests and woodlands of the Pilliga and Pilliga outwash IBRA subregions represent the largest intact woodlands remaining on the western slopes of NSW (Welsh et al., 2014).

The water-dependent asset register lists in excess of 1800 water-dependent ecological assets (including GDEs, rivers, wetlands lakes and floodplains) that provide habitat for numerous threatened ecological species. Irrigated agriculture is an important industry in the subregion and there are 21 groundwater management units that support a large number of groundwater extraction licences. Thus, the water-dependent asset register also contains 168 economic assets and 41 sociocultural assets (O'Grady et al., 2014).

3.3.4.2 Landscape classification

For the purposes of this example, a preliminary landscape classification of the surface water features in the Namoi subregion was implemented. Briefly, 18 landscape classes based on surface water characteristics were identified using the Australian National Aquatic Ecosystem (ANAE) classification framework (Aquatic Ecosystems Task Group, 2012) as the primary classification dataset including riverine, palustrine, lacustrine and floodplain wetlands.

3.3.4.3 Defining the preliminary distribution of receptors

The allocation of receptors was undertaken as a staged process. The preliminary distribution of model nodes was assigned using the Bureau of Meteorology's Geofabric (Dataset 1). The Geofabric is a specialised GIS consisting of nationally consistent spatial data that identifies important water features in the landscape, and the connectivity between these water bodies. Detailed descriptions of the Geofabric can be found in the Geofabric product guide (Bureau of Meteorology, 2012). The Geofabric identifies approximately 7800 surface water river basins in the Namoi subregion. River basins are delineated in a hierarchical fashion and each has a unique code (based on the Pfafstetter Coding system, developed by Otto Pfafstetter (1989); a methodology for assigning unique river basin IDs based on the topology of the land surface – sometimes referred to herewith using a shortened form of 'Pfaf').

Table 4 Preliminary classification of landscape classes of the Namoi subregion based on surface water characteristics

Example only; do not use for analysis.

Landscape class
Intermittent river red gum swamp
Intermittent woodland swamp
Permanent high energy upland streams
Permanent lakes
Permanent low energy upland streams
Permanent lowland streams
Permanent sedge/grass/forb marshes
Permanent springs
Permanent transitional zone streams
Permanent wetland
Temporary clay pans
Temporary high energy upland streams
Temporary lakes
Temporary low energy upland streams
Temporary lowland streams
Temporary sedge/grass/forb marsh
Temporary transitional zone streams
Temporary wetland

Surface water modelling in the Namoi will be initialised using a rainfall-runoff model with a 0.5 degree resolution (~2500 ha grid). This delineates the minimum resolution of the hydrological modelling within the Geofabric surface water river basin hierarchy. In the Namoi subregion, 'Pfafstetter 8' river basins were identified for initialisation of the distribution of receptors as most river basins at this scale were larger than 2500 ha. By intersecting the existing Geofabric node network with the 9-second DEM (i.e. a digital elevation model with approximately 300 m grid cell resolution), the node at the lowest point in each 'Pfafstetter 8' river basin was selected as the receptor for that surface water river basin. This resulted in a distribution of receptors across the surface water network shown in Figure 10. The same procedure was run for 'Pfafstetter 9' river basins and for 'Pfafstetter 10' river basins. The resultant distribution of receptors is shown in Figure 11.

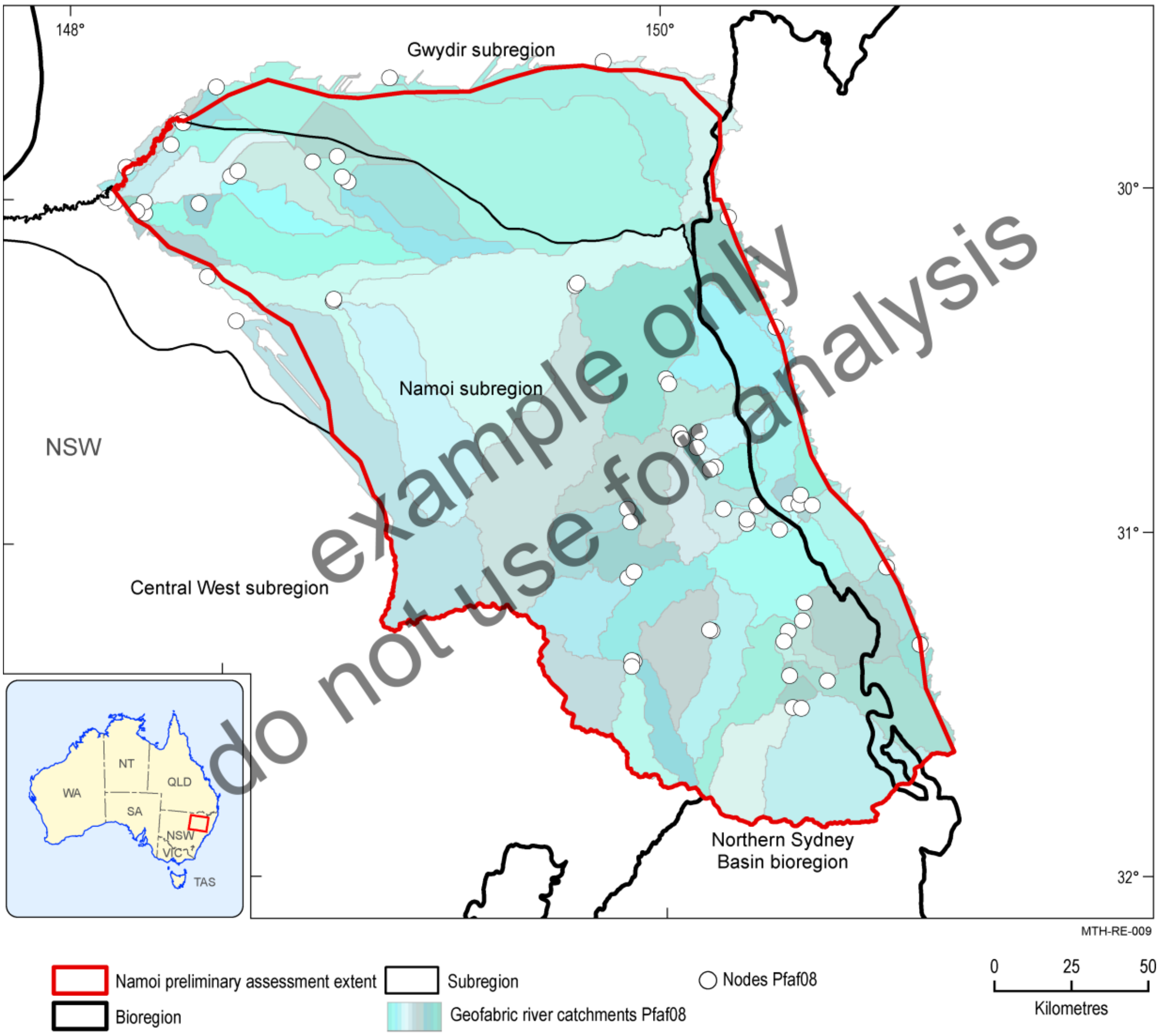

Figure 10 Preliminary distribution of surface water receptors for the Namoi subregion

Receptors represent the lowest Geofabric node, identified using a 9-second digital elevation model (DEM), in each of ‘Pfafstetter 8 river basins.
Data: example data derived from Bureau of Meteorology (Dataset 1)

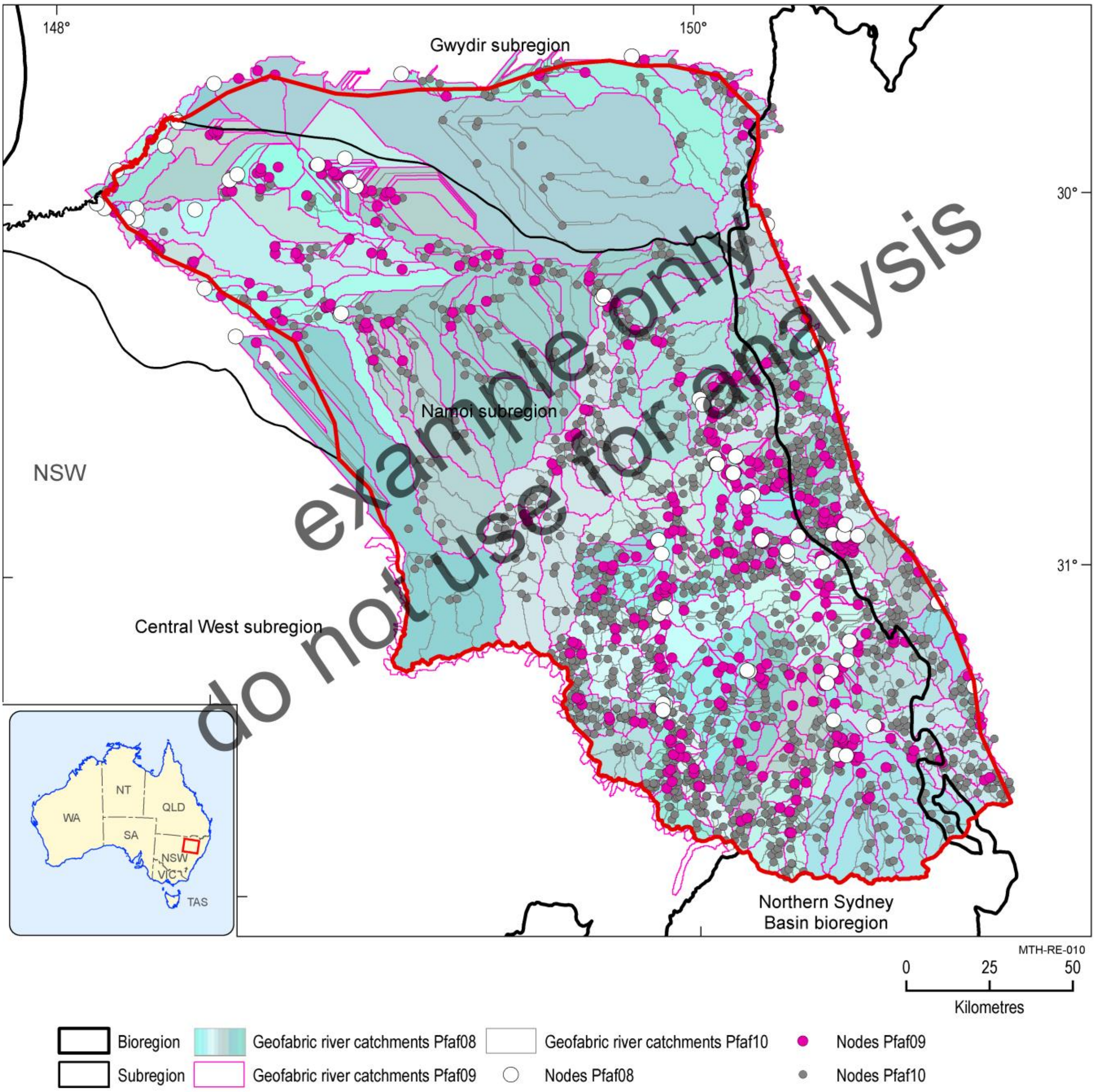

Figure 11 Distribution of receptors for 'Pfafstetter 8, 9 and 10' river basins in the Namoi subregion

Receptors were chosen by selecting the lowest nodes in each of 'Pfafstetter 8,9 and 10' river basins within the Geofabric.
Data: example data derived from Bureau of Meteorology (Dataset 1)

Two important questions need to be answered at this point in the process:

- What is a representative distribution of receptors? In particular, how representative are the receptors of the assets and the potential impacts upon them?
- How to interpolate responses from the model emulators to individual receptors associated with assets?

A number of approaches could be used to assess the representativeness of the surface water receptor distribution. Ultimately both questions need to be decided by the Assessment team working in close collaboration – particularly the hydrologists, the ecologists and the risk experts. In the example, representativeness was assessed by examining the number of landscape classes within 1, 2.5, 5, 10 and 20 km of the receptor node. In the 'Pfafstetter 8' river basins a radius of greater than 20 km was required to intersect with the 18 landscape classes in the BA; in the 'Pfafstetter 10' river basins, this radius was reduced to 5 km (Table 5). In this example a core principle was to minimise the internal heterogeneity. Alternative indicators of representativeness are clearly possible (e.g. the density of receptors per landscape class or some other areal unit. Whatever indicator of representativeness is used, the choice of receptor placement and density needs to support an objective assessment of potential impact. An asset that is fairly homogeneous may be adequately assessed by fewer receptors than one that is more diverse.

A complete distribution of receptors was achieved by placing a receptor on each polygon at the nearest point of each element in each asset class (Figure 12). For pragmatic purposes, in this example, a point on the edge closest to the node was selected. However, the Assessment team could define the rules related to the placement of the receptor that are relevant to the landscape class (e.g. centroids).

The outcome of this step is that there is a receptor associated with every element in each landscape class. While complete, this may not be an efficient distribution as there may be many thousands of receptors that are redundant; similarly, the distribution of receptors in large assets should be checked for representativeness. Existing approaches, such as that outlined by Stevens and Olsen (2004), might be used to help decide on the final, refined distribution of receptors for inclusion in the receptor register.

Table 5 Number of landscape elements within each landscape class in relation to nodes from three Pfafstetter classifications

Values within each row represent the number of elements within set distances of the receptors. Note that the Pfafstetter code is presented using the shortened form of ‘Pfaf’. Example only; do not use for analysis.

Landscape class	1 km			2.5 km			5 km			10 km			20 km		
Pfafstetter code	Pfaf08	Pfaf09	Pfaf10	Pfaf08	Pfaf09	Pfaf10	Pfaf08	Pfaf09	Pfaf10	Pfaf08	Pfaf09	Pfaf10	Pfaf08	Pfaf09	Pfaf10
Intermittent river red gum swamp	25	67	125	58	130	285	99	211	395	138	285	487	245	366	510
Intermittent woodland swamp	6	64	158	20	127	362	58	277	581	97	495	840	240	692	948
Permanent high energy upland streams	10	14	27	14	21	38	15	30	46	15	44	49	21	46	49
Permanent lakes		3	29	2	6	34	4	9	36	5	17	43	11	20	51
Permanent low energy upland streams	2	4	4	5	5	5	5	5	5	5	8	6	8	8	6
Permanent lowland streams	64	218	333	151	388	574	273	567	778	343	654	893	467	706	935
Permanent sedge/grass/forb marshes	7	28	29	28	60	68	36	71	80	49	77	88	57	77	88
Permanent springs		1	3		2	9		3	12	2	8	16	5	13	20
Permanent transitional zone streams	4	11	27	10	25	42	13	38	50	29	49	52	36	52	52
Permanent wetland	31	74	164	57	131	271	100	207	393	130	274	513	195	306	519
Temporary clay pans	15	85	183	58	227	445	118	373	654	237	541	800	433	692	908
Temporary high energy upland streams									1		1	1		2	2
Temporary lakes			6		5	7	5	11	15	21	22	30	23	24	30
Temporary low energy upland streams						1		4	4		6	8	6	6	8
Temporary lowland streams	1	6	29	6	23	57	15	49	113	27	73	131	53	97	166
Temporary sedge/grass/forb marsh	5	21	48	22	63	118	32	117	162	48	129	181	74	133	183
Temporary transitional zone streams			1	1	1	4	1	2	5	1	4	5	3	7	7
Temporary wetland	5	24	40	19	53	88	37	84	144	72	132	228	95	214	230

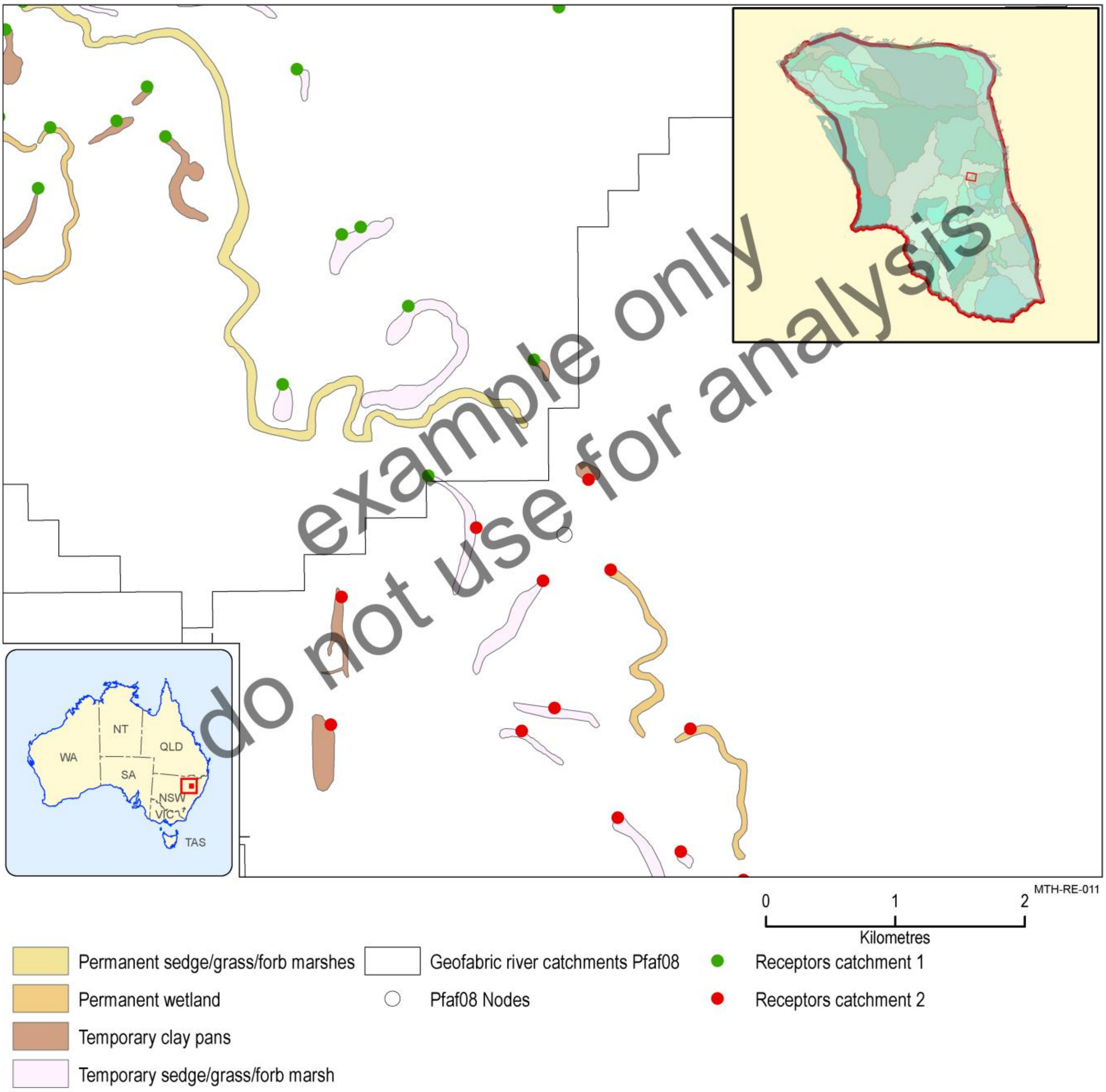

Figure 12 Example of the distribution of surface water receptors in the Namoi subregion

In this example, a receptor is placed within each landscape class polygon at the location closest to the nearest downstream Pfafstetter river basin node.
Data: example data derived from Bureau of Meteorology (Dataset 1) and SEWPaC (Dataset 2)

4 Developing a receptor register

For a bioregional assessment (BA), attributes associated with receptors are compiled and documented in a spatial (point) dataset in the Bioregional Assessment Repository. The receptor register is a relatively simple table that contains all the individual receptors and their unique attributes including latitude and longitude.

Though the receptor register is relatively simple, the Assessment team will need to ensure the receptor register is capable of supporting complex linkages (causal pathways) between hazards, landscape classes and assets for impact assessment purposes in other components of the BA. For example, each receptor may be linked to many assets and may have different classes of hydrological response variables and receptor impact variables associated with it. Similarly, any individual asset may have one or many receptors associated with it (Barrett et al., 2013). In more detail, the relationships between receptors and assets fall into one of four classes:

- one-to-one
- one-to-many
- many-to-one
- many-to-many.

For example, a one-to-one assignment is where a single receptor represents a single asset, for example a spring. An example of one-to-many is where a single receptor is located within multiple overlapping assets, such as where a wetland is listed as a Ramsar site and is also mapped as an aquatic ecosystem and as an Indigenous site. An example of many-to-one is where a complex asset, such as a floodplain, may need to be represented by many receptors. The many-to-many relationship most often describes the systematic relationships between assets; examples might include floodplains that are linked to many other assets such as wetlands, riparian zones, surface water offtake entitlements and/or local and regional groundwater resources.

A simpler relationship exists between receptors and landscape classes because the landscape classes are mutually exclusive and completely cover the entire subregion or bioregion. This means that each receptor can exist in only one landscape class (many-to-one) and that particular landscape class is recorded against each receptor in the receptor register.

These cross-references will require a many-to-many relational database structure. In summary, the receptor register is a simple listing of the receptors and their locations stored as a dataset in the Bioregional Assessment Repository that will enable the more complex relationships to be formed at later stages of the assessment.

The preliminary receptor register is an important mechanism for engagement with domain expertise and those with local knowledge. The preliminary receptor register, with associated maps and data, may be presented to experts and organisations with local knowledge at relevant workshops (e.g. the conceptual modelling workshop). Participants typically should include land managers, water managers, environmental managers, councils, government and coal resource development industry. Their feedback is sought about whether the register is complete and correct; appropriate refinements are then made by the Assessment team. Project Leaders can make arrangements for a final viewing of the register by workshop participants before completion if they think it is necessary.

It is at this stage – when the refined and additional receptors have been recorded in the receptor register, and the register is checked for errors and deposited in the Bioregional Assessment Repository – that the receptor register is complete for the purposes of publication.

A snapshot version of the receptor register is published in association with product 1.4 (description of the receptor register) and the process is defined in the next section.

4.1 Preparation of product 1.4 (description of the receptor register) and the receptor register

For each BA, two items are published: product 1.4 (description of the receptor register) and an associated receptor register (initially as an Excel spreadsheet; subsequent updates are published on the Bioregional Assessment Information Platform). This section describes the process, structure, content and standards for publishing product 1.4 (description of the receptor register) and the associated receptor register as an Excel spreadsheet.

The process for preparing product 1.4 (description of the receptor register) for publication is likely to be in three stages driven by the degree of dependency with other BA activities, such as engagement with external expertise, conceptual modelling, uncertainty modelling, water modelling and receptor impact modelling.

The *first stage* is to produce the preliminary distribution of receptors across the landscape classification (as per Section 3.3). The methods and decisions for assigning receptors should be documented in an initial draft of the product 1.4 (description of the receptor register) and a summary of the set of receptors produced in the form of a table. The methods and detailed description for the landscape classes is presented in the conceptual model and reported in product 2.3 (conceptual modelling) (see Table 2 for BA product details).

In the *second stage*, as more information becomes available from other BA activities and review by external expertise, the preliminary receptor register may be refined and amended with any new information, such as results of the process for assigning hydrological response variables and receptor impact variables, and the linkages of receptors to specific conceptual models and landscape classes. A new point-of-truth receptor register may be produced at any particular moment in time and deposited into the Bioregional Assessment Repository.

The *third stage* focusses on publication and is initiated by delivering product 1.4 (description of the receptor register) and the receptor register for review and approval. Once any revisions have been made and approval given it will be published and be made available for download. Updates will be published at www.bioregionalassessments.gov.au.

4.1.1 Preliminary receptor register and draft product 1.4 (description of the receptor register)

In more detail, the preliminary version of the receptor register is prepared as follows:

1. The initial distribution of receptors and the associated landscape classes are compiled into a point dataset (e.g. shapefile) and checked by the Assessment team and the Bioregional Assessment Information Platform team for the following:
    a. Every receptor has location attributes (latitude and longitude using the GDA_94 coordinate system)
    b. Every receptor has a unique ID (BARID, defined as the BA receptor identifier (sequential and unique per receptor across all receptors in the Bioregional Assessment Technical Programme); authoritative source of BARIDs is the Bioregional Assessment Information Platform team).
    c. The preliminary receptor register fields (e.g. field names) are formatted consistently with the receptor register template (see Table 6 for recommended content).
    d. Any other checks needed for either BA analysis or Bioregional Assessment Information Platform needs.
2. The checked version of the preliminary receptor register is loaded into the Bioregional Assessment Repository by the Assessment team as a point dataset (e.g. shapefile). On completion, the following must be notified:
    a. all discipline leads
    b. the Bioregional Assessment Information Platform team.
3. The preliminary receptor register is used to assist other BA processes including:
    a. providing input to the conceptual modelling, uncertainty analysis, surface water and groundwater modelling, and receptor impact modelling
    b. any engagement with domain or local expertise including specific review of the receptor register
    c. the Bioregional Assessment Information Platform and information modelling.
4. The methods and decisions for assigning receptors should, ideally, be documented in an initial draft of the product 1.4 (description of the receptor register).

4.1.2 Requirements for product 1.4 (description of the receptor register) and the receptor register

The published receptor register and product 1.4 (description of the receptor register) are finalised as follows:

1. The Assessment team begins by drafting product 1.4 (description of the receptor register) (see Table 7 for recommended content) and ensuring a refined set of all receptors included in the BA are ready for upload into the Bioregional Assessment Repository as a point dataset (e.g. shapefile).

2. The receptor data are checked by the Assessment team and the Bioregional Assessment Information Platform team for the following:
    a. Every receptor has location attributes (latitude and longitude using the GDA_94 coordinate system).
    b. Every receptor has a unique ID (BARID, defined as the BA receptor identifier (sequential and unique per receptor across all receptors in the Bioregional Assessment Technical Programme); authoritative source of BARIDs is the Bioregional Assessment Information Platform team).
    c. Every asset and landscape class is completely and efficiently represented by at least one receptor.
    d. Any other IDs are maintained and unique, for example RegRID (defined as the BA receptor identifier unique to the specific subregion or bioregion (sequential and unique per receptor across all receptors in the subregion or bioregion); authoritative source of RegRIDs is the Assessment team).
    e. The receptor register fields (e.g. field names) are formatted consistently with the receptor register template (see Table 6 for recommended content).
    f. Any other checks needed for either BA analysis or Bioregional Assessment Information Platform needs.
3. The Assessment Project Leader must ensure the receptor register dataset is correct and agrees with product 1.4 (description of the receptor register); if not, amendments are made as required.
4. The checked version of the receptor register dataset is loaded into the Bioregional Assessment Repository by the Assessment team and the following notified:
    a. all discipline leads
    b. the Bioregional Assessment Information Platform team.
5. The receptor register spreadsheet is extracted by the Assessment team from the receptor register dataset and formatted according to the receptor register template (see Table 6 for recommended content).
6. The final version of product 1.4 (description of the receptor register) and the receptor register spreadsheet is completed for delivery to internal review.
7. Any subsequent updates of the receptor register are published on www.bioregionalassessments.gov.au.

Table 6 Recommended content for the receptor register

The receptor register is initially delivered as an Excel spreadsheet entitled *Receptor register for the [insert 'XX subregion' or 'YY bioregion' here] on [DD Month YYYY]*, with columns as specified in this table. Any subsequent updates are published on the Bioregional Assessment Information Platform.

Column heading in spreadsheet	Description	Code in point dataset
Receptor ID	The bioregional assessment (BA) receptor identifier (sequential and unique per receptor across all receptors in the Bioregional Assessment Technical Programme)	BARID
Regional receptor ID	The bioregional assessment (BA) receptor identifier unique to the specific subregion or bioregion (sequential and unique per receptor across all receptors in the subregion or bioregion)	RegRID
Latitude	The latitude of the location of the receptor. The coordinate system is the Geocentric Datum of Australia 1994 (GDA94)	Latitude
Longitude	The longitude of the location of the receptor. The coordinate system is the Geocentric Datum of Australia 1994 (GDA94)	Longitude
Landscape class	Landscape classes represent areas of similar biophysical characteristics within the subregion or bioregion (see companion submethodology M03 for assigning receptors to water-dependent assets (O'Grady et al., 2016)).	LandscapeClass

A large part of this submethodology is superseded by advances in methods for the bioregional assessments (BAs). Specifically, there is now no need to either generate receptors as spatial points across the landscape or to collate them into a receptor register. Instead, receptors are addressed spatially by the asset and landscape class spatial features (polygons, lines and points) and covered conceptually through the development of the landscape classes (product 2.3 (conceptual modelling)), the causal pathways (product 2.3 (conceptual modelling)) and the receptor impact modelling (product 2.7).

Table 7 Recommended content for product 1.4 (description of the receptor register)

A large part of this submethodology is superseded by advances in methods for the bioregional assessments (BAs). Specifically, there is now no need to either generate receptors as spatial points across the landscape or to collate them into a receptor register. Instead, receptors are addressed spatially by the asset and landscape class spatial features (polygons, lines and points) and covered conceptually through the development of the landscape classes (product 2.3 (conceptual modelling)), the causal pathways (product 2.3 (conceptual modelling)) and the receptor impact modelling (product 2.7).

Section number	Title of section	Main content to include in section
1.4.1	Methods	**Summary** **1.4.1.1 Background and context** • This is a 'fixed' generic statement drawn from this submethodology. As per Section 1.3.1.1 in product 1.3 (description of the water-dependent asset register) but modified by deleting some material and adding material about landscape classes and their links to receptors and assets. **1.4.1.2 Description** • Descriptions of the methods and assumptions used for the placement of receptors in landscape classes within the preliminary assessment extent (PAE).
1.4.2	Receptors	**Summary** **1.4.2.1 Description** • Cross-reference receptor register (spreadsheet) including unique receptor ID, longitude, latitude and landscape classes of receptors only (the spreadsheet does not include assets). • Include map of locations of receptors. • Text will cover content such as ‘These receptors are in landscape class X, and these receptors are in landscape class Y.’ • Provide overarching description including (i) the most relevant principles of selection and criteria for evaluating receptors and (ii) the distribution of receptors (coverage, efficiency and representativeness of landscape classes and assets). • Note that hydrological response variables and receptor impact variables are not included in either product 1.4 (description of the receptor register) or the spreadsheet of receptor register that accompanies it. Rather, hydrological response variables and receptor impact variables are reported in product 2.7 (receptor impact modelling). **1.4.2.2 Gaps** • Identify existing knowledge gaps and hypotheses that need testing.

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Glossary

The register of terms and definitions used in the Bioregional Assessment Programme is available online at http://environment.data.gov.au/def/ba/glossary (note that terms and definitions are respectively listed under the 'Name' and 'Description' columns in this register). This register is a list of terms, which are the preferred descriptors for concepts. Other properties are included for each term, including licence information, source of definition and date of approval. Semantic relationships (such as hierarchical relationships) are formalised for some terms, as well as linkages to other terms in related vocabularies.

activity: for the purposes of Impact Modes and Effects Analysis (IMEA), a planned event associated with a coal seam gas (CSG) operation or coal mine. For example, activities during the production life-cycle stage in a CSG operation include drilling and coring, ground-based geophysics and surface core testing. Activities are grouped into components, which are grouped into life-cycle stages.

additional coal resource development: all coal mines and coal seam gas (CSG) fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012

aquifer: rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit quantities of water to bores and springs

asset: an entity that has value to the community and, for bioregional assessment purposes, is associated with a subregion or bioregion. Technically, an asset is a store of value and may be managed and/or used to maintain and/or produce further value. Each asset will have many values associated with it and they can be measured from a range of perspectives; for example, the values of a wetland can be measured from ecological, sociocultural and economic perspectives.

baseline coal resource development: a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012

bioregion: a geographic land area within which coal seam gas (CSG) and/or coal mining developments are taking place, or could take place, and for which bioregional assessments (BAs) are conducted

bioregional assessment: a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion, with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and coal mining development on water resources. The central purpose of bioregional assessments is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of coal seam gas and coal mining development.

Bioregional Assessment Repository: a collection of systems that together store source and derived datasets, products and maps, accompanying metadata, lineage and supporting material. It consists of the Data Store, Metadata Catalogue and the Repository website. The Repository is not available to the public.

bore: a narrow, artificially constructed hole or cavity used to intercept, collect or store water from an aquifer, or to passively observe or collect groundwater information. Also known as a borehole or piezometer.

causal pathway: for the purposes of bioregional assessments, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets

coal resource development pathway: a future that includes all coal mines and coal seam gas (CSG) fields that are in the baseline as well as those that are expected to begin commercial production after December 2012

component: for the purposes of Impact Modes and Effects Analysis (IMEA), a group of activities associated with a coal seam gas (CSG) operation or coal mine. For example, components during the development life-cycle stage of a coal mine include developing the mine infrastructure, the open pit, surface facilities and underground facilities. Components are grouped into life-cycle stages.

conceptual model: abstraction or simplification of reality

connectivity: a descriptive measure of the interaction between water bodies (groundwater and/or surface water)

context: the circumstances that form the setting for an event, statement or idea

cumulative impact: for the purposes of bioregional assessments, the total change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered

dataset: a collection of data in files, in databases or delivered by services that comprise a related set of information. Datasets may be spatial (e.g. a shape file or geodatabase or a Web Feature Service) or aspatial (e.g. an Access database, a list of people or a model configuration file).

direct impact: for the purposes of bioregional assessments, a change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments without intervening agents or pathways drawdown: a lowering of the groundwater level (caused, for example, by pumping). In the bioregional assessment (BA) context this is reported as the difference in groundwater level between two potential futures considered in BAs: baseline coal resource development (baseline) and the coal resource development pathway (CRDP). The difference in drawdown between CRDP and baseline is due to the additional coal resource development. Drawdown under the baseline is relative to drawdown with no coal resource development; likewise, drawdown under the CRDP is relative to drawdown with no coal resource development.

ecosystem: a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit. Note: ecosystems include those that are human-influenced such as rural and urban ecosystems.

ecosystem asset: an ecosystem that may provide benefits to humanity. It is a spatial area comprising a combination of biotic and abiotic components and other elements which function together.

ecosystem function: the biological, geochemical and physical processes and components that take place or occur within an ecosystem. It refers to the structural components of an ecosystem (e.g. vegetation, water, soil, atmosphere and biota) and how they interact with each other, within ecosystems and across ecosystems.

effect: for the purposes of Impact Modes and Effects Analysis (IMEA), change in the quantity and/or quality of surface water or groundwater. An effect is a specific type of an impact (any change resulting from prior events).

extraction: the removal of water for use from waterways or aquifers (including storages) by pumping or gravity channels

formation: rock layers that have common physical characteristics (lithology) deposited during a specific period of geological time

Geofabric: a nationally consistent series of interrelated spatial datasets defining hierarchically-nested river basins, stream segments, hydrological networks and associated cartography

groundwater: water occurring naturally below ground level (whether in an aquifer or other low permeability material), or water occurring at a place below ground that has been pumped, diverted or released to that place for storage there. This does not include water held in underground tanks, pipes or other works.

groundwater-dependent ecosystem: ecosystems that rely on groundwater - typically the natural discharge of groundwater - for their existence and health

groundwater system: see water system

hazard: an event, or chain of events, that might result in an effect (change in the quality or quantity of surface water or groundwater)

hydrogeology: the study of groundwater, including flow in aquifers, groundwater resource evaluation, and the chemistry of interactions between water and rock hydrological response variable: a hydrological characteristic of the system that potentially changes due to coal resource development (for example, drawdown or the annual streamflow volume)

impact: a change resulting from prior events, at any stage in a chain of events or a causal pathway. An impact might be equivalent to an effect (change in the quality or quantity of surface water or groundwater), or it might be a change resulting from those effects (for example, ecological changes that result from hydrological changes).

impact cause: an activity (or aspect of an activity) that initiates a hazardous chain of events

impact mode: the manner in which a hazardous chain of events (initiated by an impact cause) could result in an effect (change in the quality or quantity of surface water or groundwater). There might be multiple impact modes for each activity or chain of events.

Impact Modes and Effects Analysis: a systematic hazard identification and prioritisation technique based on Failure Modes and Effects Analysis

indirect impact: for the purposes of bioregional assessments, a change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments with one or more intervening agents or pathways

landscape class: for bioregional assessment (BA) purposes, an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Note that there is expected to be less heterogeneity in the response within a landscape class than between landscape classes. They are present on the landscape across the entire BA subregion or bioregion and their spatial coverage is exhaustive and non-overlapping. Conceptually, landscape classes can be considered as types of ecosystem assets.

likelihood: probability that something might happen

model node: a point in the landscape where hydrological changes (and their uncertainty) are assessed. Hydrological changes at points other than model nodes are obtained by interpolation.

preliminary assessment extent: the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed

receptor: a point in the landscape where water-related impacts on assets are assessed

receptor impact variable: a characteristic of the system that, according to the conceptual modelling, potentially changes due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums)

receptor register: a simple and authoritative list of receptors in a specific bioregional assessment

risk: the effect of uncertainty on objectives

runoff: rainfall that does not infiltrate the ground or evaporate to the atmosphere. This water flows down a slope and enters surface water systems.

sensitivity: the degree to which the output of a model (numerical or otherwise) responds to uncertainty in a model input severity: magnitude of an impact

source dataset: a pre-existing dataset sourced from outside the Bioregional Assessment Programme (including from Programme partner organisations) or a dataset created by the Programme based on analyses conducted by the Programme for use in the bioregional assessments (BAs)

spring: a naturally occurring discharge of groundwater flowing out of the ground, often forming a small stream or pool of water. Typically, it represents the point at which the watertable intersects ground level.

stressor: chemical or biological agent, environmental condition or external stimulus that might contribute to an impact mode

subregion: an identified area wholly contained within a bioregion that enables convenient presentation of outputs of a bioregional assessment (BA)

surface water: water that flows over land and in watercourses or artificial channels and can be captured, stored and supplemented from dams and reservoirs

uncertainty: the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence, or likelihood. For the purposes of bioregional assessments, uncertainty includes: the variation caused by natural fluctuations or heterogeneity; the incomplete knowledge or understanding of the system under consideration; and the simplification or abstraction of the system in the conceptual and numerical models.

water-dependent asset: an asset potentially impacted, either positively or negatively, by changes in the groundwater and/or surface water regime due to coal resource development

water-dependent asset register: a simple and authoritative listing of the assets within the preliminary assessment extent (PAE) that are potentially subject to water-related impacts

water system: a system that is hydrologically connected and described at the level desired for management purposes (e.g. subcatchment, catchment, basin or drainage division, or groundwater management unit, subaquifer, aquifer, groundwater basin)

watertable: the upper surface of a body of groundwater occurring in an unconfined aquifer. At the watertable, pore water pressure equals atmospheric pressure.

well: typically a narrow diameter hole drilled into the earth for the purposes of exploring, evaluating or recovering various natural resources, such as hydrocarbons (oil and gas) or water. As part of the drilling and construction process the well can be encased by materials such as steel and cement, or it may be uncased. Wells are sometimes known as a ‘wellbore’.

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