Australian Government

BIOREGIONAL ASSESSMENTS

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

Developing the conceptual model of causal pathways

Submethodology M05 from the Bioregional Assessment Technical Programme

1 March 2017

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.

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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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Wards River, NSW, 10 December 2013

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Executive summary

This submethodology describes the process for developing the conceptual model of causal pathways in bioregional assessments (BAs). Causal pathways summarise and synthesise the potential linkages between coal resource development and the impacts on water and water-dependent assets. They are useful for describing the current state of knowledge, establishing common understanding between disciplines, communicating the characteristics of the system, generating hypotheses about potential impacts, and framing the results of a BA.

Conceptual models are abstractions or simplifications of reality. A number of conceptual models are developed for a BA, including the conceptual models for geology, surface water and groundwater, which underpin the numerical modelling. A conceptual model for a BA consists of:

- a clearly documented purpose
- a documentation of the process used to develop the conceptual model
- the elements of the overall conceptual model (e.g. narrative text, pictorial diagrams, influence diagrams)
- conceptual sub-model or sub-models for finer scale representations
- the evidence base underpinning the conceptual model.

A specific type of conceptual model used in BAs is a *conceptual model of causal pathways*, which characterises the *causal pathways*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets. The conceptual model of causal pathways brings together a number of conceptual models developed in a BA.

The construction of the conceptual model of causal pathways requires the Assessment team to first synthesise and summarise the key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion or bioregion. The spatial scale of the synthesis varies with specific requirements and the quality, coverage and availability of data. Finer resolution sub-models may be required in some places. Emphasising gaps and uncertainties is as important as summarising what is known about how various systems work.

Consideration must be given to how the causal pathways link to the 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* is next applied to group together areas to synthesise understanding and 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. 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. The nature and number of landscape classes needs to balance the heterogeneity across the subregion or bioregion, while not combining ecosystems that are hydrologically very different. The landscape classes are an important input to the development of conceptual models of causal pathways and the reporting of impacts and risks from coal resource development.

Conceptual models of causal pathways are developed for the two potential futures 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 causal pathways are initiated by an activity associated with the coal resource development in the two futures (baseline and CRDP). These are identified from a hazard analysis (using the Impact Mode and Effects Analysis method), where development activities, impact causes, impact modes and water-related (hydrological) effects that might result from the specific coal resource development in the subregion or bioregion are considered.

Examples of potential hydrological effects or changes include:

- surface water: disruption of the natural surface drainage (e.g. interception of runoff by the pit or storage dams, as result of subsidence or by diversion of a stream network) or the extraction of water from – and disposal of water to – a local stream network
- groundwater: altered groundwater levels, flows, directions, quality, preferential pathways and inter-aquifer connectivity, as a result of dewatering, depressurisation and other development activities (e.g. wells)
- surface water – groundwater interactions: changes due to altered recharge from the stream network or reduced baseflow from the deeper groundwater to the streams.

For BAs, a consistent set of causal pathways are used across all Assessments. These causal pathways are aggregated into four causal pathway groups:

- subsurface depressurisation and dewatering
- subsurface physical flow paths
- surface water drainage
- operational water management.

Causal pathways commonly overlap or link. For example, the depressurisation of coal seams to extract coal seam gas will also produce water that needs to be managed or disposed of through surface water or groundwater systems.

The relative importance of these causal pathways depends on the consolidated understanding of the key system components, processes and interactions across the geology, hydrogeology and surface water, and a consideration of the specific perturbations to that system that may arise from coal resource development in that subregion or bioregion. The hazard analysis prioritises individual hazards as a first step, but the Assessment teams need to place these priorities within the broader context of the current system understanding and the logic of the causal pathway groups.

The causal pathways are extended to consider potential impacts on landscape classes that result from the potential hydrological changes. While available spatial information, including preliminary modelling results, is used to assist in defining the causal pathways conceptually, more precise spatial representation of the model results and impacts can only be finalised towards the end of the BA. Interactions between the landscape classes and the surface water and groundwater are broadly characterised, which will support the development of receptor impact models in a later stage of the BA. Those receptor impact models will then be used to assess impacts on landscape classes and water-dependent assets. In some cases the characterisation of a landscape class may conceptually rule out potential impacts – for example, a landscape class related to dryland agriculture may not depend on surface water or groundwater.

The causal pathways, and the particular process for creating them, need to be documented as specified in this submethodology. The process includes consultation and testing of causal pathways with domain experts and those with local knowledge through a specific BA workshop on causal pathways and other engagement with individuals.

The causal pathways from coal resource development to hydrological changes are reported in product 2.3 (conceptual modelling). The causal pathways from hydrological changes to impacts on landscape classes and assets is reported in product 2.7 (receptor impact modelling) for only those landscape classes that are potentially impacted. Conceptual models for those landscape classes, and the selection of the most appropriate hydrological response variables and receptor impact variables, occur at that time. The causal pathways are subsequently informed and revised by results from the impact and risk analysis as reported in product 3-4 (impact and risk analysis).

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This technical product was reviewed by several groups:

- Senior Science Leaders: David Post (Projects Director)
- 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.

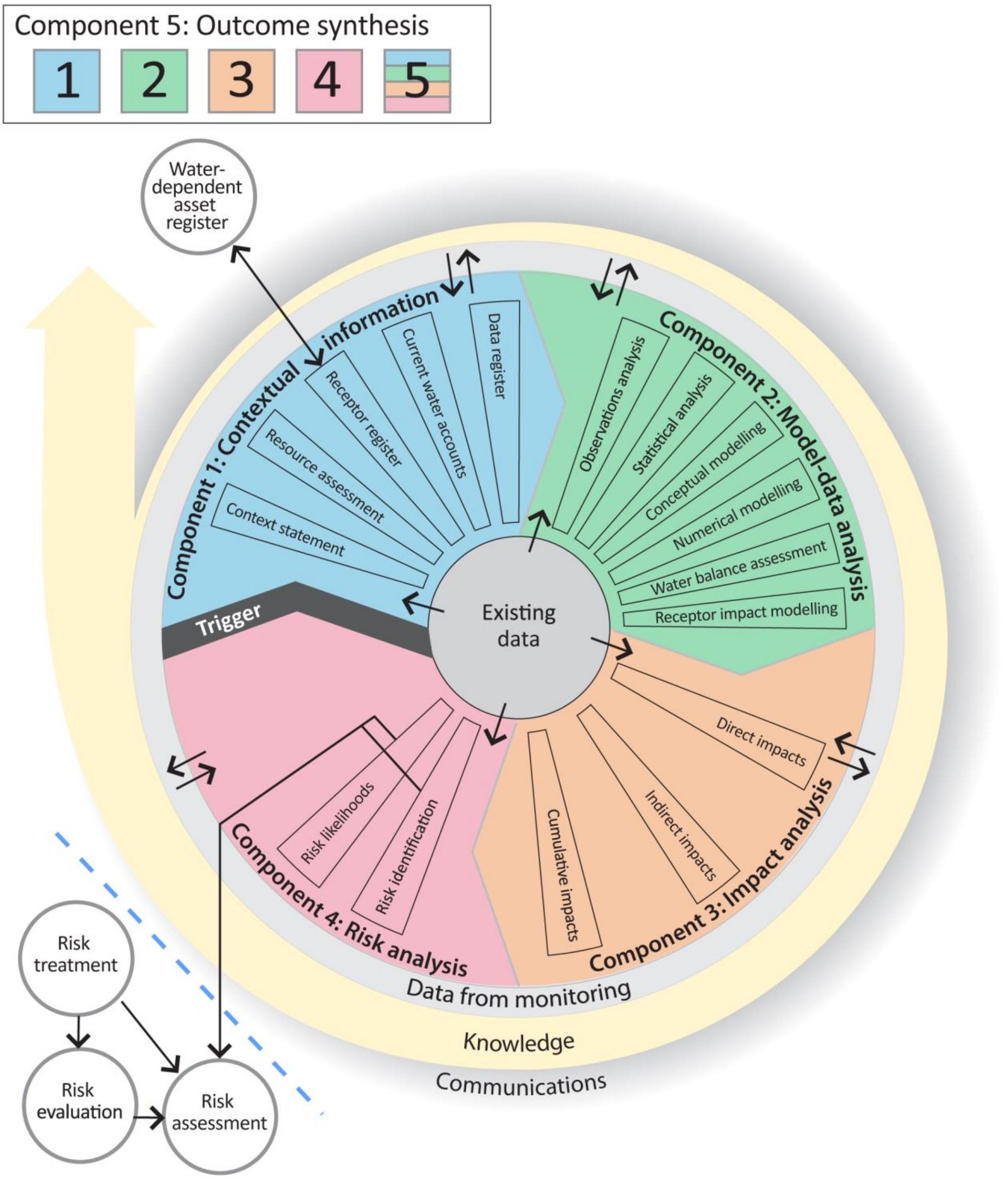

Figure 1 Schematic diagram of the bioregional assessment methodology

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.
- 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 developm ent 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

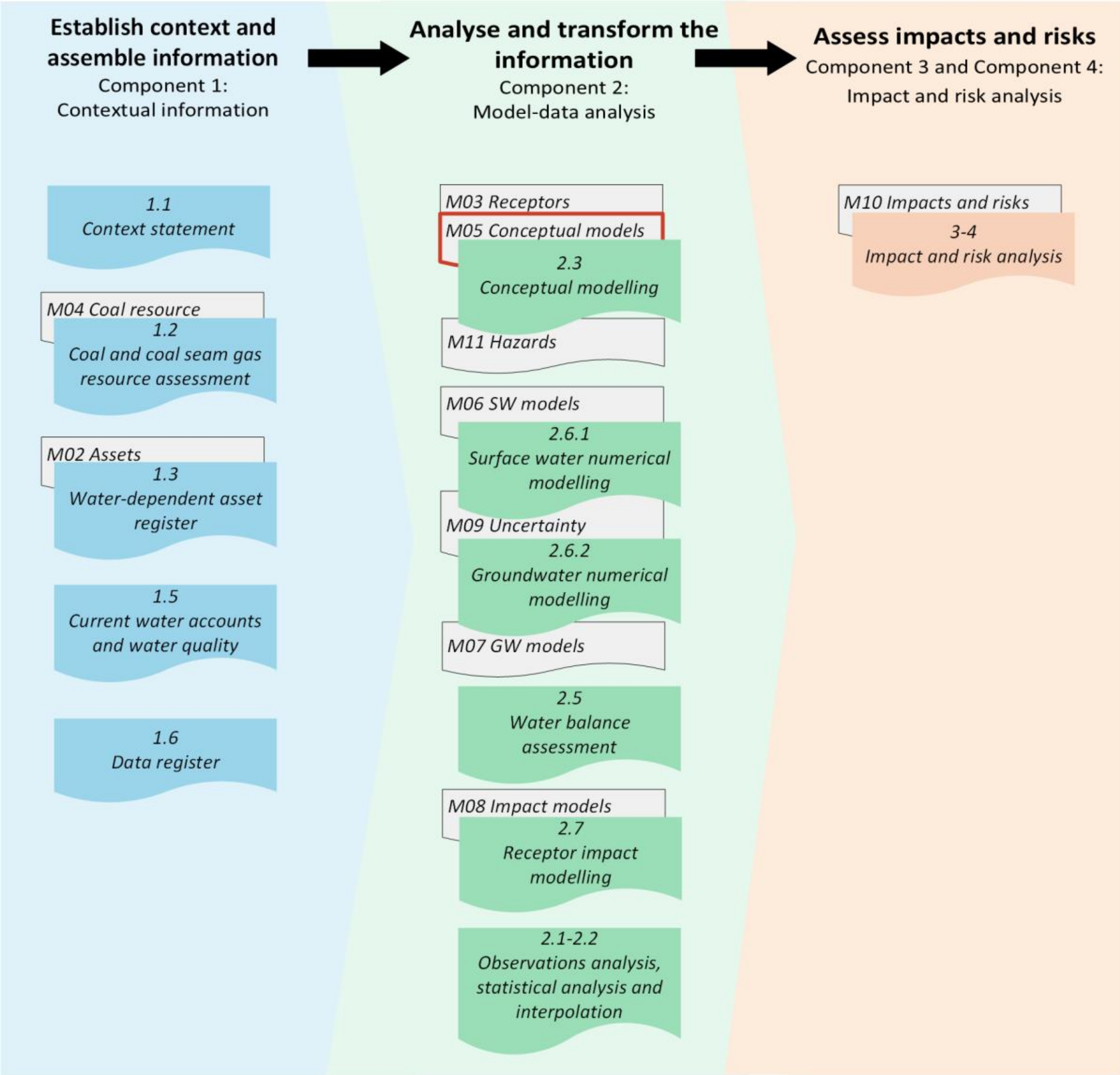

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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)

References

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 May 2017, 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 May 2017, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

1 Background and context

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 identifying and documenting the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets. These *causal pathways* are synthesised from all the assembled contextual information and focus the BA on the *impact modes*, 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). This submethodology applies overarching principles outlined in the BA methodology to the specifics of efficiently generating high-quality causal pathways for BA purposes. These are reported in product 2.3 (conceptual modelling; see Table 2 for details of BA products) and provide input to the numerical groundwater, surface water and receptor impact modelling that follow, as well as the impact and risk analysis.

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.

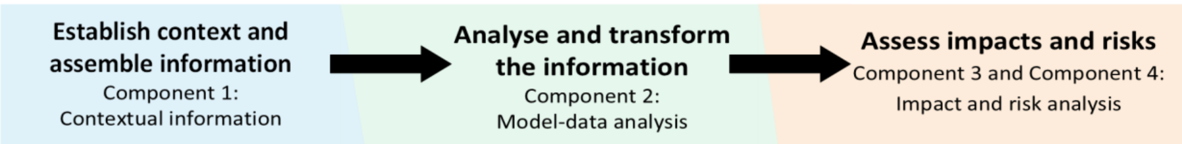

Figure 3 The components in a bioregional assessment

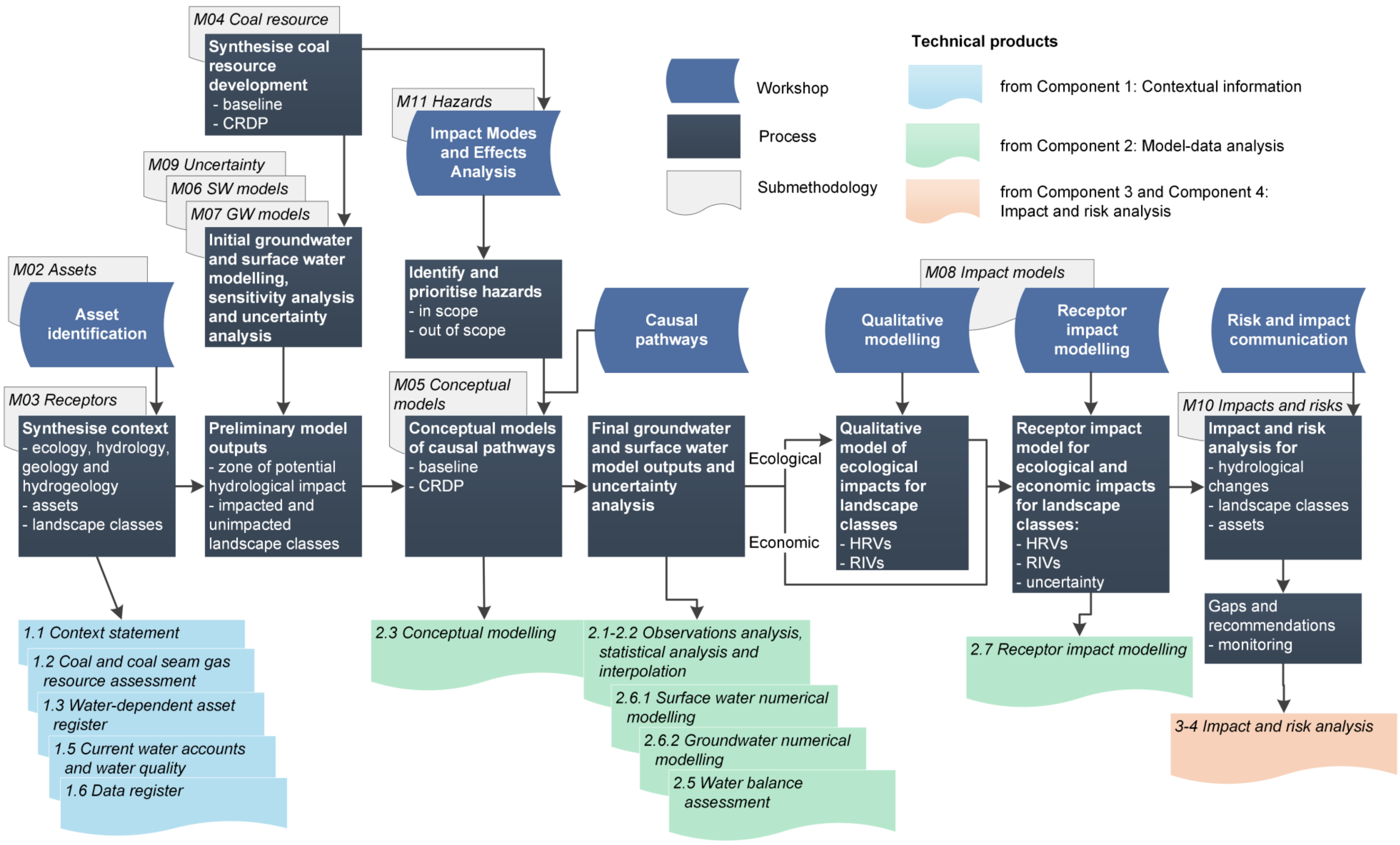

Figure 4 A bioregional assessment from end to end, showing the relationship between the workflow, technical products, submethodologies and workshops

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 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. 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 or landscape class that potentially change due to coal resource development (for example, drawdown or the annual streamflow volume). *Receptor impact variables* are the characteristics of the landscape class or water-dependent assets 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.

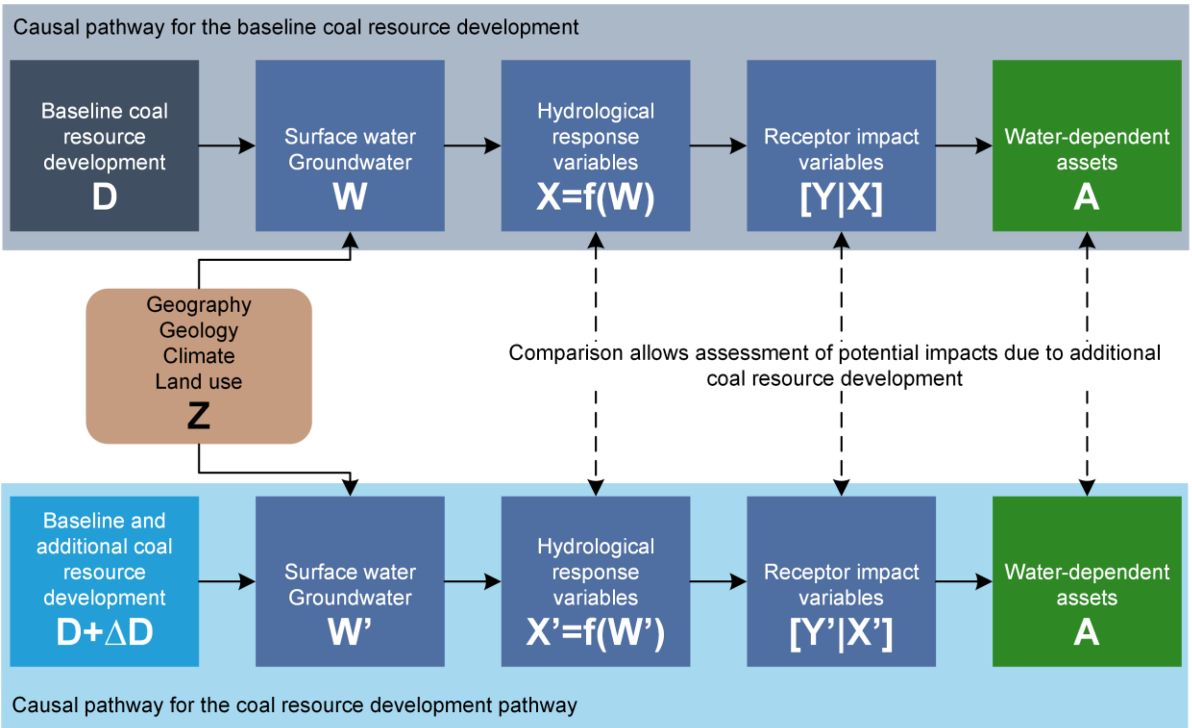

Figure 5 The difference in results for the coal resource development pathway (CRDP) and the baseline coal resource development (baseline) provides the potential impacts due to the additional coal resource development (ACRD)

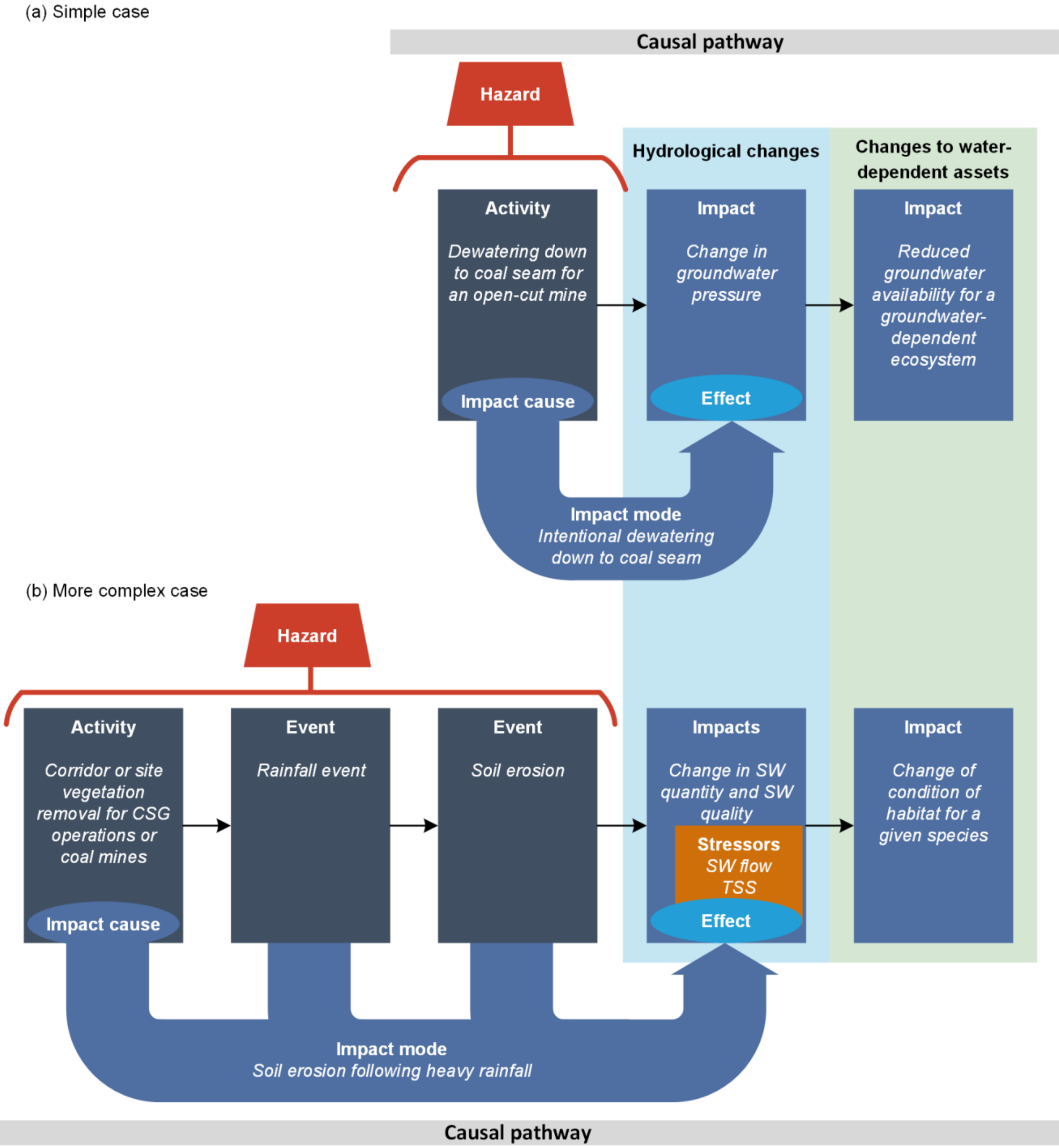

Figure 6 Hazard analysis using the Impact Modes and Effects Analysis (IMEA). This figure shows how hazards identified using IMEA are linked to changes in hydrology and water-dependent assets via causal pathways

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 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 bores); 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

The primary focus of this submethodology is to assist users to efficiently generate high-quality causal pathways for BA purposes. To this end it seeks to:

- describe the role of conceptual modelling more broadly in BAs, and the different types of conceptual modelling that may be undertaken
- identify important linkages between BA products and submethodologies that use causal pathways
- describe how the conceptual model of causal pathways is formed
- ensure documentation of the evidence base and reasoning supporting the causal pathways including any knowledge gaps and uncertainties

- outline the presentation and justification of the CRDP, which characterises the likely future coal resource development (the start of the chain of logic in a causal pathway)
- identify literature and resources, and present guidance on structure and content, to assist Assessment teams complete product 2.3 (conceptual modelling) and product 2.7 (receptor impact modelling).

This submethodology is not intended as a detailed 'how to build conceptual models guide'. A variety of approaches and other resources can assist in that regard (Section 2.6). This submethodology does, however, seek to be explicit about what needs to be in product 2.3 *(conceptual modelling)* and the role of conceptual modelling and causal pathways in other products. The overall aim is to guide Assessment teams that are working on individual bioregions or subregions to maintain a practical and structured approach to the construction of causal pathways. Assessment teams can include more detail where appropriate but this submethodology specifies the minimum.

The application of this submethodology to a BA in a subregion or bioregion relies on all the information assembled in Component 1: Contextual information including all of the Component 1 products. It will deliver causal pathways suitable for use throughout the remaining BA workflow and in all the remaining BA products (Figure 7). The primary product of this submethodology is product 2.3 (conceptual modelling).

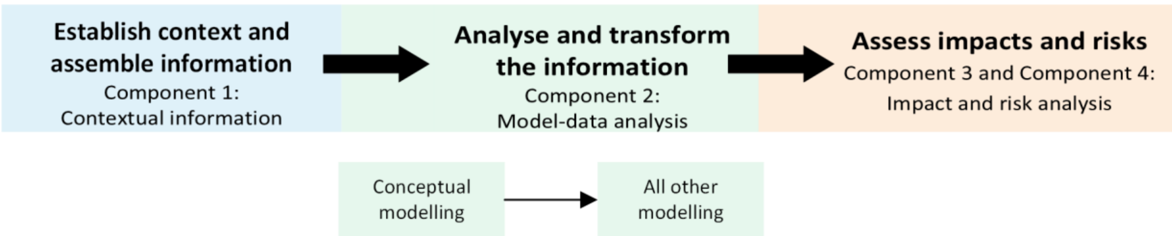

Figure 7 The conceptual modelling synthesises the contextual information and produces the conceptual models underpinning all the other modelling processes in Component 2: Model-data analysis. Conceptual modelling provides the basis for the impact and risk analysis in Component 3: Impact analysis and Component 4: Risk analysis

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 M05 is strongly linked to the following submethodologies (as listed in Table 1):

- submethodology M03 for assigning receptors to water-dependent assets (O'Grady et al., 2016)
- submethodology M04 for developing a coal resource development pathway (Lewis, 2014)
- submethodology M06 for surface water modelling (Viney, 2016)
- submethodology M07 for groundwater modelling (Crosbie et al., 2016)
- submethodology M08 for receptor impact modelling (as listed in Table 1)
- submethodology M09 for propagating uncertainty through models (Peeters et al., 2016)

- submethodology M10 for analysing impacts and risks (as listed in Table 1)
- submethodology M11 for hazard analysis (Ford et al., 2016).

This submethodology is divided into four chapters and two appendices:

- Chapter 1 introduces the background and context of this submethodology.
- Chapter 2 introduces conceptual modelling in a BA.
- Chapter 3 describes how to build a conceptual model of causal pathways and the associated evidence base.
- Chapter 4 provides guidance on outputs for conceptual modelling, particularly product 2.3 (conceptual modelling).
- Appendix A and Appendix B provide diagrams and descriptions of generic causal pathways for hazards, which are used in all subregions and bioregions.

2 Introduction to conceptual modelling in bioregional assessments

2.1 General introduction to conceptual modelling in bioregional assessments

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) defines a conceptual model as:

> a qualitative description of the systems and subsystems within a bioregion. It describes the set of hypotheses as to how these systems interact with impacts of CSG and coal mining development and links closely with the qualitative, semi-quantitative and quantitative models used to describe impacts on receptors. Conceptual models in the BAs describe the causal pathway from CSG and coal mining development to the direct, indirect and cumulative impacts on receptors. They may comprise broad-scale coarse-resolution conceptual models within which fine-scale conceptual sub-models are nested to take into account the range of scales over which processes occur.

For the purpose of an individual development, the IESC (2015) in their guidelines for development proposals define the conceptual model as a:

> descriptive and/or schematic hydrological, hydrogeological and ecological representation of the site showing the stores, flows and uses of water, which illustrates the geological formations, water resources and water-dependent assets, and provides the basis for developing water and salt balances and inferring water-related ecological responses to changes in hydrology, hydrogeology and water quality.

More generally, *conceptual models* are abstractions or simplifications of reality. They describe the most important components and processes of natural and anthropogenic systems, and their response to interactions with extrinsic activities or stressors. They provide a transparent and general representation of how complex systems work, and identify gaps or differences in understanding. They are often used as the basis for quantitative modelling, form an important backdrop for assessment and evaluation, and typically have a key role in communication.

Many types of conceptual models are available to serve many different purposes, whether enhancing the understanding of a system, managing ecosystems or communicating how systems work. Models can represent processes (physical, biological) and subjects (rivers, aquifers) at a range of resolutions including spatial (local to landscape), temporal (seconds to decades) and organisational (simple to complex). They can represent relationships (connectivity) and measurement methods (sampling). Examples include control versus stressor models (Gross, 2003), state and transition models (Fischenich, 2008), and conceptual ecological models (driver, stressor, effect, attribute) (Ogden et al., 2005).

Conceptual models can consist of all or some of the following: (i) verbal descriptions, (ii) pictorial and schematic representations of process models (e.g. formal science communication diagrams), or (iii) schematic box and arrow diagrams. The latter are also known as *influence diagrams* and can be considered 'a series of working hypotheses connected together by arrows to indicate relationships' (Commonwealth of Australia, 2014, p. 78). Other types of models include signed digraphs, directed acyclic graphs and other mathematical expressions of dependencies (Hayes et al., 2012).

A conceptual model for a BA consists of:

- a clearly documented purpose
- a documentation of the process used to develop the conceptual model
- the elements of the overall conceptual model (e.g. narrative text, pictorial diagrams, influence diagrams)
- conceptual sub-model or sub-models for finer scale representations
- the evidence base underpinning the conceptual model.

2.2 Conceptual modelling philosophy

Bioregions and subregions are large, heterogeneous and complex systems, and the clear articulation of potential causal pathways plays a critical role in focusing the attention of the Assessment teams on the most plausible and important *impact modes*, 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). These pathways describe a series of cause-effect relationships, and underpin the construction of the groundwater and surface water models that are subsequently used to assess the severity and likelihood of impacts. Causal pathways can be an emergent property of these models.

Assumptions about the geological, hydrogeological and hydrological systems are made on the basis on the best available knowledge, and the groundwater and surface water models integrate this understanding and determine if a potential causal pathway is plausible. The pivotal nature of the conceptual model of causal pathways is emphasised by their central position in the workflow in Figure 4 where they sit before the final surface water and groundwater model results.

The conceptual models of causal pathways have the following purposes within BAs:

- *summarise the existing scientific knowledge* by collating system knowledge and understanding, and describing how the bioregion or subregion is hypothesised to work and is likely to respond to coal resource development. This requires identifying the important components and processes of the hydrological systems, as well as gaps or differences in understanding. This summary underpins the surface water or groundwater modelling and ensures that all relevant components of the coal resource development and bioregion or subregion are captured in the subsequent stages of the BA

- *provide a general narrative or hypothesis of how the hydrological systems are likely to respond to the coal resource development pathway (CRDP).* This requires predicting how the system's components and processes might react, or, as importantly, *not* react to the activities associated with coal resource development. These narratives underpin Component 3: Impact analysis and Component 4: Risk analysis
- *identify differences in thinking and model structure uncertainty*. Developing and documenting conceptual models with interdisciplinary teams, and with all relevant stakeholders, identifies differences in the mental models that these groups necessarily create. This is important for ensuring that there is adequate breadth in the risk analysis and no surprises occur in later stages of the BA
- *identify the potential for antagonistic and synergistic interactions* between system components or processes and coal resource development, thereby providing the first insights into possible system feedbacks and cumulative impacts
- *contribute to the evidence base for the selection of appropriate hydrological response variables and receptor impact variables that will be considered during the* receptor impact *modelling*
- *develop a shared understanding of the science and goals* among participants and disciplines within a BA
- *communicate the science* behind the BA, the gaps in the science, and the uncertainty associated with it, to users and other interested parties. The conceptual models of causal pathways are a key communication vehicle for the BAs, for explaining complex scientific processes to workshops that are part of BAs, as well as to a broader community (e.g. using two- and three-dimensional visualisation techniques). This should be considered in the presentation of the information.

Documenting the mental constructs of how a system works and how it is affected by coal resource development makes these constructs available for discussion, evaluation and refinement. This is important to achieve a high level of transparency, a key principle of BAs.

Conceptual models summarise current knowledge, hypotheses and assumptions about the bioregion or subregion. However, these models do not represent 'the truth', are not final or unmodifiable, and are not expected to be complete or include the entire ecosystem. Multiple or alternative conceptualisations of the system are also possible, and are consistent with the desire to be transparent about the evidence base and knowledge gaps or uncertainties. Conceptual models represent a flexible construct that should evolve as understanding of the system increases (Maddox et al., 2001). BAs cover large spatial extents, and the choices about the nesting and scale of the models are even more important than for conceptual models of an individual coal resource development.

While the focus of BAs is regional, it will be important to learn from – and reconcile with – local conceptualisations (including those included in environmental impact statements) about the hydrogeological and hydrological components, processes and interactions from individual coal resource developments where possible.

The conceptual model of causal pathways synthesises and summarises the important components, processes and pathways in a bioregion or subregion. It is the primary mechanism by which the various contributors across disciplines develop a shared understanding of the BA's goals. The detail of important components, processes and pathways will typically sit in a number of products but it is valuable to have a concise summary in product 2.3 *(conceptual modelling*; see Section 4.1 in this submethodology). Getting the right level of resolution, and avoiding excessive detail and complexity, is essential because it focuses effort going forward. What is not in the model is equally important and needs to be balanced with the need to ensure that other plausible pathways are represented and available for consideration in the risk analysis.

Clarity on the evidence base and potential knowledge gaps or uncertainties can add substantially to the credibility of product 2.3 (conceptual modelling) and the entire BA. Where a link or dependency between ecosystem components can be supported through literature or other information sources, then it should be documented; Nichols et al. (2011) describes an approach for documenting evidence to support cause-effect relationships that could be used. They should also leverage off existing and appropriate conceptual models where possible.

2.3 Causal pathways

A causal pathway is the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets. As an example, a potential pathway between several open-cut coal mines and a natural spring might be initiated by the intentional dewatering of aquifers from mining, leading to a local drawdown of the watertable, which in turn reduces connectivity and groundwater availability for the natural spring. Multiple, often related, causal pathways might potentially be relevant for water-dependent assets and need to be accounted for in the conceptual model. The conceptual model of causal pathways will typically represent multiple and nested systems at different resolutions.

The knowledge about these chains of events – that is, how these impacts might occur – is formally documented in the conceptual models compiled for each BA. Constructing and representing these conceptual models is the primary focus of this submethodology.

In a BA, the identification and definition of causal pathways is supported by a formal hazard analysis, known as Impact Modes and Effects Analysis (Ford et al., 2016). The conceptual models are based on the outcomes of this hazard analysis and the current understanding of the way geological, hydrogeological, and hydrological systems and subsystems in the bioregion or subregion work and interact with each other and the ecosystems and landscape classes in the bioregion or subregion. Constructing and representing these models are discussed in more detail in Chapter 3.

Ultimately, the causal pathways will be represented spatially during the impact analysis. For the purposes of the analysis, it will be as important to say where pathways do not exist as where they do as that may rule out parts of the bioregion or subregion where there is no potential for connection or impact and thus address some of the community's concern. The causal pathways must be constructed with this spatially-based method of analysis in mind.

2.4 Baseline coal resource development and coal resource development pathway

At the heart of a BA is a comparison of two potential futures, the *baseline coal resource development* (baseline) and the *coal resource development pathway* (CRDP). The difference in results between CRDP and baseline is the change that is primarily reported in a BA and it is critical that it is captured in the conceptual model of causal pathways. 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. To understand the potential implications of that difference, the changes over time occurring under the baseline will need to provide important context where possible. For instance, the implications of a difference in drawdown of 1 m may alter substantially if drawdown under baseline is 20 m compared to 0.2 m.

The chain of events in a causal pathway can be considered a series of conditional (or cause-effect) relationships. For instance, the CRDP might impact the physical system and affect aspects of water quantity and quality (as represented by the hydrological response variables), which in turn may affect assets and/or landscape classes as represented by receptor impact variables. While feedback loops are possible, for example where changes in ecology may alter the hydrology, the model implementation assumes that the causal pathway can be compartmentalised and that the conditional relationships occur without feedback loops given the short time frames involved. If feedback loops are expected for some reason it is important that they are described conceptually.

This representation of the chain of events means that the full causal pathways can be usefully divided in two:

- the causal pathway from the coal resource development to the hydrological changes (represented by the hydrological response variables)
- the causal pathway from the hydrological changes to the impacts (represented by the receptor impact variables, which are linked to the landscape classes and assets).

The first half of the full causal pathway is reported in product 2.3 (conceptual modelling; see Section 4.1 in this submethodology) and the second half is reported in product 2.7 (receptor impact modelling; see companion submethodology M08 (as listed in Table 1) for receptor impact modelling). The conceptual model of causal pathways is informed and revised by results from Component 3: Impact analysis and Component 4: Risk analysis.

2.5 Landscape classes and construction of causal pathways

The companion submethodology M03 (as listed in Table 1) for assigning receptors to water-dependent assets (O'Grady et al., 2016) explains the rationale and methods for producing a BA landscape classification. *Landscape classes* are ecosystems with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Given that only a subset of the landscape classes will be hydrologically connected to these hydrological changes (represented by hydrological response variables), causal pathways will be extended to this subset. The causal pathway conceptual models will identify the effect on specific ecosystem characteristics (represented by receptor impact variables). Each landscape class has a characteristic set of hydrological response variables and receptor impact variables. In product 2.3 (conceptual modelling), the landscape classes and causal pathways are listed. Those landscape classes that potentially experience hydrological changes are linked to causal pathways and described in more detail in product 2.7 (receptor impact modelling) and product 3-4 (impact and risk analysis).

2.6 Existing conceptual modelling resources

Conceptual models – and the process of building them – feature prominently in the literature, and play a key role in science synthesis, communication and informed decision making. Examples include the ecological conceptual models of the Healthy Waterways Program for Southeast Queensland (EHMP, 2010) and the Queensland Wetlands Program (Department of Environment and Heritage Protection, 2012). While these represent cause-effect linkages, the aspiration within BAs is to be more explicit about these potential causal pathways.

There are several guides in the literature that discuss various steps, processes and methods for building conceptual models (Shoemaker, 1977; Maddox et al., 2001; Jackson et al., 2000; Gross, 2003; White, 2012).

The Queensland Wetlands Program has produced a guide to pictorial conceptual modelling (Department of Environment and Heritage Protection, 2012) that is widely relevant and describes a step-by-step approach to developing and applying pictorial conceptual models. The Bureau of Meteorology has identified conceptual modelling and documentation of an evidence base as a central process in developing ecosystem and environmental accounts in its *Guide to environmental accounting in Australia* (Bureau of Meteorology, 2013).

Gross (2003) suggests that conceptual models can be divided into the two categories of ‘control’ and ‘stressor’ conceptual models. *Control conceptual models* are graphical representations of how the ecosystem is thought to work. They synthesise the current understanding of the key components, processes, interactions and feedbacks in a system. *Stressor conceptual models* are graphical representations of the activities that may impact on the ecosystem and how the components and processes of that system are likely to respond.

The steps to building a conceptual model outlined by Gross (2003) remain one of the strongest articulations of the process and feature prominently in allied work such as *Modelling water-related ecological responses to coal seam gas extraction and coal mining* (Commonwealth of Australia, 2014). This particular work has investigated an approach to ecological conceptual modelling to improve the assessment of water-related ecological impacts from coal seam gas (CSG) extraction and coal mining. While the focus is on individual developments and environmental impact statements rather than regional assessments, it shares some similarities with conceptual modelling in BAs: the steps used to build conceptual models; the emphasis on documenting the evidence base that supports conceptual models; and the use of narrative tables for recording hypothesised dependencies and responses. The contrast between the control (natural) and stressor (with coal mining) conceptual models for the Purga Creek Nature Reserve in the case studies is useful, as is the landscape setting (see Figure 12 in Commonwealth of Australia (2014) for a control conceptual model at a subregion-scale resolution).

The development of conceptual models is also described for specific system components relevant to BAs. For example, Barnett et al. (2012), in their guidelines for the best practice development, application and review of groundwater models, discuss the hydrogeological conceptualisation of the groundwater system and identify some key principles that are relevant beyond the groundwater modelling:

- balancing simplicity of the conceptual model with meeting the objectives
- balancing the availability of data, and the knowledge base and complexity of the groundwater system of interest
- considering different views and alternative conceptual models as part of exploring model uncertainty
- supporting the conceptual model development with observation, measurement and interpretation wherever possible.

3 Building conceptual models in bioregional assessments

3.1 Building conceptual models of causal pathways

The conceptual model of causal pathways describes how the bioregion or subregion works and how it might respond to coal resource development. It is a collection of narratives, diagrams, graphics, hypotheses and supporting evidence base. It will not typically exist as a single conceptual model, but rather as a set of nested conceptual models that focus on certain parts of the bioregion or subregion or portray alternative conceptualisations or hypotheses about the systems.

The causal pathways are identified for the baseline coal resource development (baseline) and the coal resource development pathway (CRDP). Coal resource development is already a considerable part of the baseline in many locations (e.g. the Hunter subregion) while in others there has been no development as of January 2016 (e.g. Galilee subregion). The causal pathways identified for the CRDP will also often be an augmentation of causal pathways for the baseline.

The focus here is primarily on the causal pathways leading from the coal resource development to the hydrological changes (represented by the hydrological response variables). Potentially impacted landscape classes and ecosystems are identified and described in the conceptual model of causal pathways, but these landscape classes and their dependencies are not examined in detail until the receptor impact modelling (product 2.7), and then only for those landscape classes that are likely to be impacted.

While it will be important for final versions of the groundwater and surface water models to be fully cognisant of these causal pathways and include them in the modelling where possible, preliminary versions of the model will typically be available given the time required to build the models. The preliminary model results can focus effort on the parts of the preliminary assessment extent (PAE) that are likely to be impacted – and minimise effort in parts that are unlikely to be impacted. This is emphasised in Figure 4 where the conceptual model of causal pathways sits between boxes with the preliminary and final results for hydrological modelling (which identifies locations of potential hydrological impact).

Figure 8 summarises how to build the conceptual model of causal pathways. It emphasises the need to describe the key geological, hydrogeological and hydrological systems, components and processes in the bioregion or subregion (steps 1 to 3). This is supplemented by a landscape classification of ecosystems, both natural and human dominated, at the surface (step 4). The baseline and CRDP are then determined, and the known water management rules for these summarised (step 5), noting that the difference in results between baseline and CRDP is the primary change assessed in a BA for a given bioregion or subregion. Steps 6 and 7 are the key steps in the conceptual model of causal pathways and begin with a hazard analysis to identify possible changes resulting from coal resource development. The hazards identified can be subsequently aggregated to a set of main causal pathways. Step 8 summarises the causal pathways for baseline and CRDP, from coal resource development to impacts on water and water-dependent assets. The next four subsections provide a richer description of these eight steps.

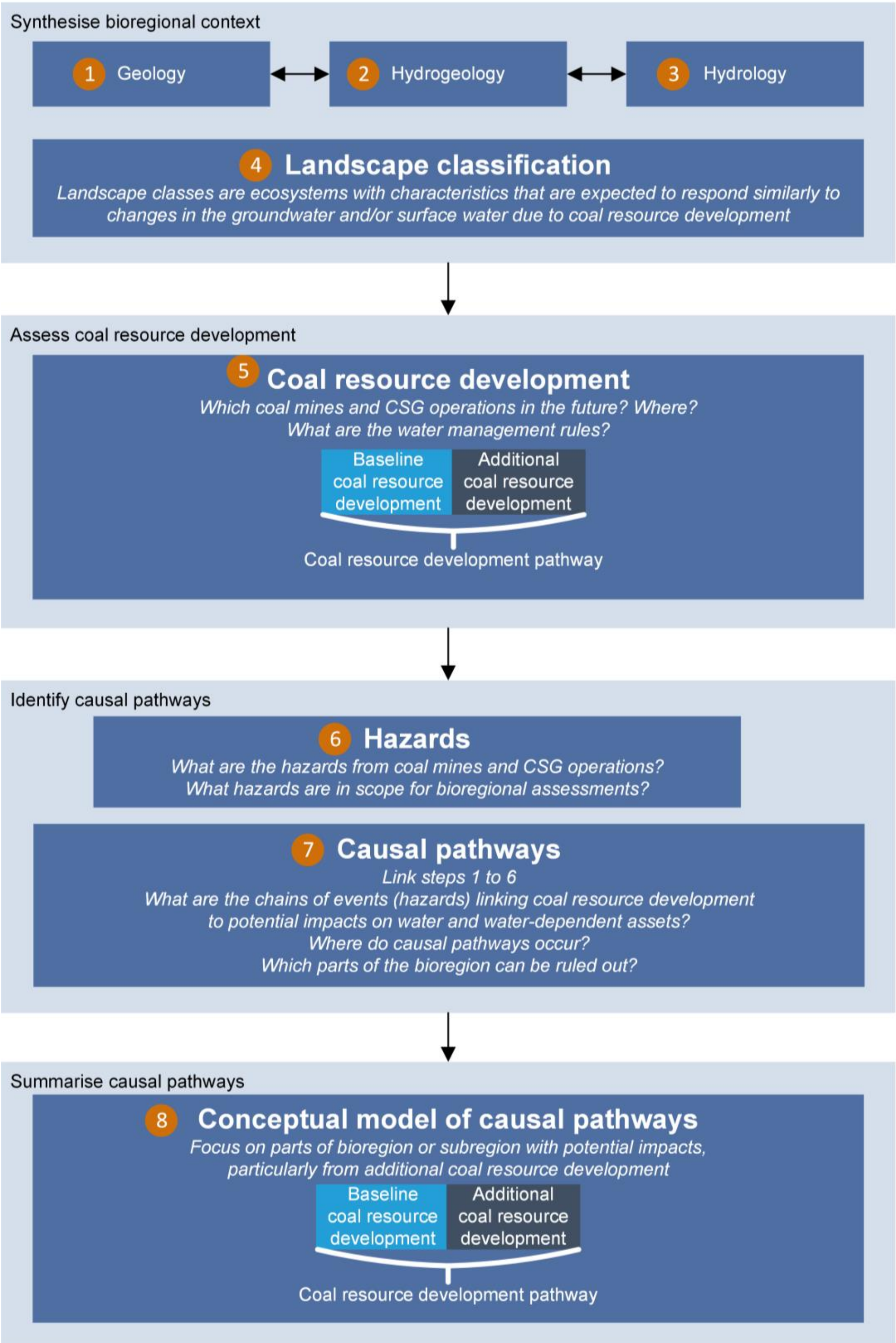

Figure 8 Building the conceptual model of causal pathways

The orange circles indicate the number of the steps referred to in the text. The coal resource developments in the coal resource development pathway (CRDP) are the sum of those in the baseline coal resource development (baseline) and the additional coal resource development (ACRD).

3.1.1 Steps 1 to 4: synthesise bioregional context

The conceptual model of causal pathways needs to describe the key system components, processes and interactions of a bioregion or subregion. The spatio-temporal boundaries of the conceptual model are defined on the basis of the PAE and CRDP. It is reasonable to focus on a smaller area within the PAE if the CRDP localises the area of interest.

3.1.1.1 Geology, hydrogeology and hydrology

The conceptual model of causal pathways summarises the system knowledge and understanding about the geology, hydrogeology and surface water hydrology, including the water balance. It builds on the contextual information from Component 1: Contextual information – particularly the context statement (product 1.1), coal and CSG resource assessment (product 1.2), current water accounts and water quality (product 1.5) and water balance assessment (product 2.5). When describing the conceptual model of causal pathways in product 2.3 (conceptual modelling), the focus is on aspects that might affect hydrological change and thus be relevant to understanding potential pathways to impact on water-dependent assets. For instance, repeating the detailed stratigraphy and descriptions of individual layers from product 1.1 (context statement) is not necessary but it is important to describe the target coal seams, aquifers and aquitards, and those features (e.g. faults) that may otherwise affect the movement of water. Likewise, the details of the water balance are reported in product 2.5 (water balance assessment), but a summary of the dominant mechanisms and locations of recharge, discharge, flows and surface water – groundwater interactions are reported in product 2.3 (conceptual modelling).

The conceptualisations of geology, hydrogeology and hydrology underpin the surface water and groundwater models within a BA. There is, however, no need to be constrained by the specifics of the model implementation. This can be framed according to the extent of available knowledge and (if relevant) specifics can be provided about a particular and possibly more limited conceptualisation that might occur through actual model development. For instance, the conceptual model of causal pathways might represent potential changes to water quality even if they are not addressed through numerical modelling, or the conceptual modelling of the geology might describe layers that fold considerably at the edges of the geological basin, while the specific model implementation may assume a series of horizontal layers.

Preliminary surface water and groundwater model outputs can provide more detailed description of areas that are potentially subject to hydrological change. Parts of the bioregion or subregion can be considered separately where helpful – for example, where coal resource developments are distant from each other and potential impacts are hydrologically disconnected, or local processes and interactions warrant a more detailed focus.

Multiple or alternative conceptualisations of system components, processes or interactions can be considered and documented as they are an important part of being transparent about the evidence base.

3.1.1.2 Landscape classification

The role and construction of a landscape classification for a bioregion or subregion is described in the companion submethodology M03 for assigning receptors to water-dependent assets (O'Grady et al., 2016). By systematically classifying geographical areas into classes that are, within limits, physically, biologically or hydrologically similar, the landscape classification enables a high-level conceptualisation of the bioregion or subregion at the surface – conceptualisation that is akin to the key geological, hydrogeological and hydrological systems and processes. This landscape classification, importantly, includes human ecosystems, such as rural and urban areas. The landscape classification aims to:

- reduce complexity to a limited number of landscape classes (e.g. 10 to 20) appropriate for a regional-scale assessment. These classes are mutually exclusive and comprehensive such that all assets in a BA are a member of at least one landscape class
- guide the review of conceptual models for selection of appropriate hydrological response variables and receptor impact variables associated with water-dependent assets
- aggregate at a level that is useful for reporting impacts and risks in product 3-4 (impact and risk analysis) – that is, at a broader scale than that of individual assets.

It is important to describe how landscape classification has been enacted for each bioregion or subregion, including what data layers have been used as the basis of the classification, the aggregation that has occurred, and the final set of classes adopted to represent the key systems. There will be differences in classes across bioregions and subregions given different biophysical characteristics and existing classifications. For instance, while the Australian National Aquatic Ecosystem classification is likely to be used heavily to classify aquatic ecosystems, it is not available across all bioregions or subregions and other classifications will need to be chosen. A hybrid approach is expected: aquatic ecology will be covered by the ANAE classification or River Styles, and terrestrial or human systems covered by vegetation or land use classifications. See detail in the companion submethodology M03 (as listed in Table 1) for assigning receptors to water-dependent assets (O'Grady et al., 2016) but broadly aim for 10 to 20 landscape classes, and fewer if possible. Landscape classes need to be tested against regional knowledge, either through one-on-one interactions with key experts or a workshop.

The process undertaken to construct these landscape classes – and to document their dependence on surface water and groundwater – needs to be captured and supported with an evidence base where possible. Consider representing some assets in a narrative around landscape classification to provide important context for the reader – for example, describing key matters of national ecological significance that sit within a specific landscape class (e.g. communities and species listed under the Commonwealth's Environment Protection and Biodiversity Conservation Act 1999).

Detailed conceptual models for landscape classes are not required at this stage. They will only be examined through the receptor impact modelling (product 2.7) and impact and risk analysis (product 3-4) if the landscape classes are potentially impacted by coal resource development.

3.1.2 Step 5: assess coal resource development

At the heart of a BA is a comparison of two potential futures, the baseline and the CRDP. These two futures play a critical role in the conceptual model of causal pathways because it is activities associated with coal resource developments in these futures that initiate or modify pathways to impact on water-dependent assets.

3.1.2.1 Developing the coal resource development pathway

The CRDP is clearly presented and justified in product 2.3 (conceptual modelling) for each bioregion or subregion. This product builds upon the information outlined in the catalogue of potential coal resource developments contained in each companion product 1.2 (coal and coal seam gas resource assessment). The process for determining the CRDP is explained in detail in the companion submethodology M04 for developing a CRDP (Lewis, 2014). Consequently, the information presented here focuses on the requirements for reporting the CRDP in product 2.3 (conceptual modelling), and guides Assessment teams to deliver consistent content across different bioregions and subregions.

Assessment teams must critically evaluate available data and information about each coal resource development to determine if it will be included in the CRDP (Lewis, 2014). The two most important criteria are each project's:

- statutory approvals status, especially the stage of its environmental impact statement (EIS) assessment
- classification level in the Australian National Resource Classification Scheme, in particular, the identification of an economically demonstrated resource (EDR).

However, as explained in submethodology M04, other coal or CSG projects that are not yet at the stage of EIS assessment, or do not have a current EDR, can also be included (or excluded) in the CRDP if sufficient evidence is available (Lewis, 2014). The proposed CRDP is independently evaluated with relevant mining and development companies, state government agencies and other external experts as required.

3.1.2.2 Main reporting requirements

The CRDP reported in product 2.3 (conceptual modelling) for each bioregion or subregion describes and justifies the choice of:

- baseline coal mines and CSG fields that were commercially producing as of December 2012
- those that are expected to be commercially producing *after* December 2012 (defined as the additional coal resource development)
- those that have been excluded from the CRDP.

Note that the coal resource developments in the CRDP are the sum of those in the baseline and the additional coal resource development.

The availability and quality of data are assessed for all coal resource developments so that a decision can be made whether they are explicitly modelled or (alternatively) assessed through qualitative methods such as commentary.

The CRDP is best reported with a brief description that includes the main features of each operation, including the name, type, owner, status and expected operational timelines. It should also explicitly recognise that the evaluation is based on the data and information available to the Assessment team at the point in time of their analysis (and the month and year that the CRDP was decided should be reported here). This effectively provides a 'time stamp' for the CRDP, and recognises that the future roll-out of developments might differ, for example, due to unexpected variations in commodity prices or changes in extraction technology. The following description provides an example[1]:

> The coal resource developments in the coal resource development pathway (CRDP) for the X subregion are the sum of those in the baseline coal resource development (baseline) and in the additional coal resource development (ACRD), based on data and information available to the Assessment team in October 2015. The baseline includes three open-cut coal mines (include names here) but no CSG operations. The CRDP includes the coal resource developments in the baseline, plus three new open-cut coal mines (include the names of the proposed mines here), two new underground longwall coal mines (include names here) and one coal seam gas (CSG) operation (include name here). The distribution and characteristics of these developments are shown in the map in Figure A. Figure B shows the most likely timeline as each of these development stages becomes operational, and this timeline will be used when undertaking the surface water and groundwater modelling in the bioregional assessment. Future development operations are expected to involve *this*, *that* and the *other* (to be qualified to the extent possible based on available information). While there are a few other resource projects with economically demonstrated and inferred resources that could potentially be extracted at some stage in the future, these were not included in the CRDP for the following reasons…. A summary of the operations in the baseline and CRDP for this subregion is shown in Table A.

This brief description should be supported by relevant detailed information in an accompanying table. An example is shown in Table 3. It is also important to include a map for spatial context. The map can also be used to display other relevant information about each site, such as proposed extraction rates, projected start and end dates, and expected mining methods. Additionally, to capture the progression in time of coal resource development, a timeline diagram (similar to a Gantt chart) is recommended to show the lifespan (and main stages, if possible) of coal resource development (see an example in Figure 9).

3.1.2.3 Other reporting requirements

In many bioregions and subregions, coal resource development in the CRDP will be incorporated as part of subsequent numerical modelling for the BAs, for example, to evaluate proposed mine development impacts on groundwater flow systems. However, companion submethodology M04 (Lewis, 2014) recognises that there might be insufficient data available to realistically incorporate some projects in surface water and groundwater modelling. Instead, it might be possible to only undertake semi-quantitative analysis or qualitative commentary as part of the subsequent BA. Consequently, it is important to specify in product 2.3 (conceptual modelling) which projects in the baseline and CRDP are expected to be modelled, and which may only be assessed through commentary. This is done in the exemplar Table 3.

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[1] The X subregion name in the example here does not relate to any specific subregion, and is provided only as an illustrative example of how to describe the CRDP. The names of individual coal mines and coal seam gas sites will, of course, vary for each bioregion or subregion, so actual names have not been used in this example. Likewise, the references to Figure A, Figure B and Table A in this statement are purely illustrative and do not relate to any actual figures within this submethodology.

Table 3 Example table: existing operations and proposed developments in the baseline and coal resource development pathway for the Gloucester subregion as at October 2015

Example only; do not use for analysis. This is an early draft of a table published in Dawes et al. (2016). See Dawes et al. (2016) for full explanation and interpretation of the final results, which might vary from that shown here.

The primary activity in bioregional assessments (BAs) is the comparison of two potential futures: (i) the *baseline coal resource development (baseline),* a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012; and (ii) the *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.

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in coal resource development pathway (CRDP)?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mining) or 2P[b] gas reserves (for CSG) (PJ)	Comments
Duralie Coal Mine	Open-cut coal mine	Yancoal Australia Ltd	Yes	Yes – model	2003	2017	ML 1427	148[c]	None needed
Duralie Coal Mine expansion	Open-cut coal mine	Yancoal Australia Ltd	No	Yes – model	2013	2024	ML 1427,ML A1	8.9c	Expansion approved by NSW Land and Environment Court, November 2011
Stratford Mining Complex	Open-cut coal mine	Yancoal Australia Ltd	Yes	Yes – model	1995	2026	ML 1360, ML 1409, ML 1447, ML 1521,ML 1538, ML 1577, ML 1528	98[c]	None needed
Stratford Mining Complex expansion	Open-cut coal mine	Yancoal Australia Ltd	No	Yes – model	2015	2026	ML 1360, ML 1409, ML1447, ML 1521, ML 1528, ML 1538, ML 1577, EL 6904, EL 311, EL 315	24.15[c]	Extension approved by NSW Planning Assessment Commission, May 2015
Rocky Hill Coal Project	Open-cut coal mine	Gloucester Resources	No	Yes – model	2016? If approval granted	2037	EL 6523, EL 6524, EL 6563	25[c]	On hold by NSW Government, as at June 2015

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in coal resource development pathway (CRDP)?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mining) or 2Pb gas reserves (for CSG) (PJ)	Comments
Gloucester Gas Project stage 1	CSG	AGL	No	Yes – model	2016	15–25 years (depending on the extent of the CSG resources)	PEL 285	454[b] for Gloucester Basin exploration to December 2013	Waukivory Pilot Project approved by NSW Government August 2014. AGL final investment decision expected late 2015
Gloucester Gas Project stage 2 and beyond	CSG	AGL	No	Yes – commentary	Unknown (as at June 2015)	Unknown (as at June 2015)	PEL 285	Included in 454[c] for Gloucester Basin exploration to December 2013	Conceptual only as at June 2015. Mainly west and south of stage 1

[a]Indicates the different resource classes that may combine to form the total resource tonnage – typically these are reported in accordance with the Joint Ore Reserves Committee (JORC) Code. For example, the different JORC resource classes of measured, indicated and inferred resources could be shown (or whichever combination of resource classes is applicable for each project).
[b]Proved plus probable reserves
[c]Resource figure is for the entire life of the project.
EL = exploration licence; PEL = petroleum exploration licence; ML = mining lease

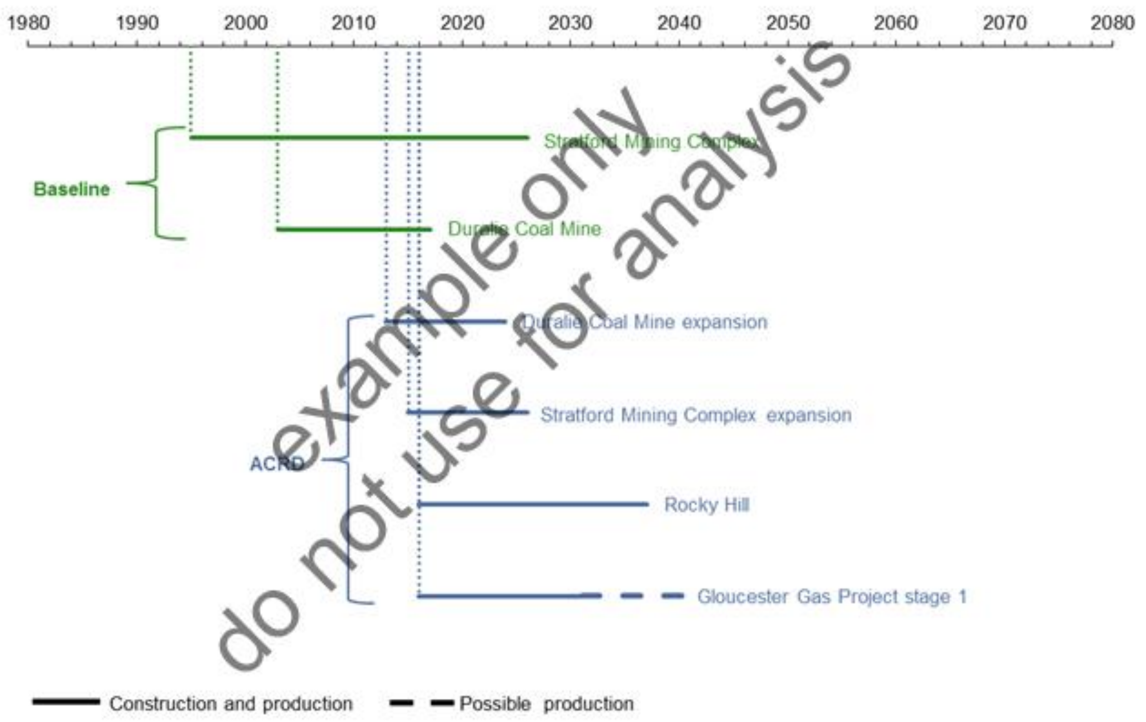

Figure 9 Example diagram: timelines for coal and coal seam gas developments in the Gloucester subregion

Example only; do not use for analysis. This is an early draft of a figure published in Dawes et al. (2016). See Dawes et al. (2016) for full explanation and interpretation of the final results, which might vary from that shown here.
These timelines were used in the hydrological modelling for the bioregional assessment of the Gloucester subregion in 2015. It should be noted that in November 2015, the Rocky Hill development was on hold with the NSW Government and AGL's Stage 1 gas field development area awaited a final investment decision by AGL.
The coal resource developments in the CRDP are equal to the sum of those in the baseline and ACRD.
Baseline = baseline coal resource development, a future that includes all coal mines and coal seam gas (CSG) fields that were commercially producing under an operations plan approved as of December 2012
CRDP = 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
ACRD = additional coal resource development, all coal mines and coal seam gas fields, including expansion of baseline operations, that are expected to begin commercial production after December 2012.

3.1.2.3.1 Coal resource developments excluded from the coal resource development pathway

An equally important part of product 2.3 (conceptual modelling) is to explicitly recognise if there are any coal resource developments that were initially in the catalogue of potential resource developments (Section 1.2.4 of product 1.2 (coal and coal seam gas resource assessment)), but have subsequently been excluded from the CRDP. The reasons for excluding such projects should be clearly outlined and justified in product 2.3 (conceptual modelling). As discussed in companion submethodology M04 (Lewis, 2014), for BA purposes, there may be various reasons to exclude a potential resource project from the CRDP, for example economic or legislative factors, statutory conditions, etc. In general, the known coal or CSG deposits that are most likely to be excluded from the CRDP are those that are currently not well defined nor sufficiently advanced in terms of current understanding of the geological characteristics or the viable extraction options. These are commonly classified as either sub-economic demonstrated resources or inferred resources in the Australian National Resource Classification Scheme (Geoscience Australia, 2015).

Even though a coal resource development might be excluded from the CRDP based on current evidence, this does not mean that development will not take place at some (unknown) time in the future. It simply reflects that on the basis of the current geological and economic understanding of the development potential of the known resource, the Assessment team is unable to sufficiently justify its inclusion as a 'most likely development' at the time of the BA. In such cases, future iterations of the BAs need to reassess and reappraise. A future updated BA might include resource projects that were deemed to not meet the necessary criteria for the current BA.

3.1.2.3.2 Information updates

As there might be considerable lengths of time between publication of the coal and coal seam gas resource assessment (product 1.2) for the bioregion or subregion, and the subsequent release of product 2.3 (conceptual modelling), Assessment teams may become aware of updates or modifications to some proposed coal resource developments. For example, this could include updated resource tonnages for specific projects (i.e. resulting from further drilling and resource characterisation studies), or variations to initial development plans. Consequently, it is useful to acknowledge if any such variations exist, and a minor part of the description of the CRDP in product 2.3 (conceptual modelling) can be used to specify any updates to information on projects initially outlined in product 1.2 (coal and coal seam gas resource assessment).

3.1.2.4 Water management for coal resource developments

It is important to describe how mine and CSG developments within the CRDP manage water extraction and disposal as part of their operations. These activities can be important to identifying hazards and potential causal pathways. The specific details of the operations for individual developments need to be considered in building the conceptual model of causal pathways – for example, the rules under which produced water is discharged to a local stream, or whether all produced water is evaporated in holding ponds, or how the water is extracted for CSG operations, or whether the water is being treated before release into surface water or aquifer. This information is provided in several products:

- Product 2.3 (conceptual modelling) includes an overall summary, either quantitative or qualitative.
- Product 2.1-2.2 (observations analysis, statistical analysis and interpolation) provides additional detail for individual coal resource developments (noting that given the large number of developments in some bioregions and subregions, only those included in the CRDP should be summarised).
- Product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling) specify how the water management rules for individual developments are implemented in the hydrological models.

Specific assumptions about mine and CSG water management will typically require access to industry data. Where it does not exist, the Assessment team will need to approximate it in order for it to be incorporated in the part of the CRDP that can be modelled. There are also river management operations that rely on unpredictable human decision making (e.g. the Hunter River

Salinity Trading Scheme) that is hard to represent as a series of water management rules (e.g. discharge triggers) in numerical models.

3.1.3 Steps 6 to 7: identify causal pathways

The identification of the causal pathways is the key step in building the conceptual model of causal pathways (Figure 8). It needs to capture the logical chain of events starting from an activity associated with coal resource development to the potential change in groundwater or surface water, and the subsequent potential impact on water-dependent assets. The logic must be supported by the best available scientific knowledge, which may consist of peer-reviewed evidence through to reasoned, though untested, hypotheses. More evidence may subsequently be produced by the BA modelling and analysis.

The focus in product 2.3 (conceptual modelling) is on the first half of the causal pathway, from the coal resource development to the hydrological changes. Potentially impacted landscape classes should be identified but will not be considered in detail until the receptor impact modelling (product 2.7). This might include further refinement of the hydrological stressors identified; for example, change in flow might be identified as a hazard but the hydrological response variable in the receptor impact modelling may relate more to reduction in summer flows.

3.1.3.1 Hazard analysis

The essential role of the hazard analysis in building causal pathways is described in Chapter 1 and Section 2.3. Submethodology M11 (Ford et al., 2016) details the systematic approach for identifying water-related hazards associated with coal mines and CSG operations. It uses the Gloucester subregion as a case study, but standalone hazard identification reports are generated for each bioregion or subregion and must be considered in building the causal pathways.

Within product 2.3 (conceptual modelling), it is necessary to: (i) outline the specific hazard analysis undertaken for the bioregion or subregion, and (ii) identify and summarise the potential effects that may result from the coal resource development and its associated water management within that bioregion or subregion. At this point there is no need to think about whether that development is included in the baseline or the CRDP.

The standalone hazard identification reports (registered as a dataset in product 2.3 (conceptual modelling)) provide a strong summary narrative and a range of key tables and figures that summarise the impact modes and water-related effects. Two summary hazard ranking scores are used: an overall *hazard score* based on severity and likelihood, and a *hazard priority number* that considers the ability to detect an impact in addition to the severity and likelihood. The top 30 hazards under each ranking score should be considered along with any other unique hazards for CSG operations, open-cut coal mines and underground coal mines separately.

Some of these top 30 hazards will likely have the same impact mode or impact cause and relate to similar activities occurring in different life-cycle stages. For instance, wells will be drilled during exploration as well as production stages and may present the pathways to impact via well integrity but with quite different severity and likelihoods given the different intensity of drilling.

Consider also those hazards that may not be ranked as highly but that occur more frequently, as they may potentially accumulate. The use of top 30 here is subjective and indicative. It will be important for the Assessment teams to consider a threshold that represents hazards that are as plausible for the bioregion or subregion. Ultimately it makes more sense to scale the attention individual hazards receive to their relative importance rather than imposing thresholds; hazards that have low scores should be acknowledged, and their potential to accumulate considered, but given much less emphasis than counterparts with high scores.

3.1.3.1.1 Hazard handling and scope

The hazard analysis generates a long list of hazards due to coal mines and CSG operations for each bioregion or subregion. BAs focus on those hazards that extend beyond the development site and that may have cumulative impacts because these are consistent with the regional focus of BAs as well as the opportunity for BAs to add value beyond site-specific EISs. However, ultimately BAs need to be able to address all identified hazards, although different approaches might be used for different hazards:

- Some hazards are outside the scope of BAs (e.g. accidents) and are not further assessed.
- Some are addressed by numerical modelling.
- Some are addressed by consulting literature and providing a narrative.
- Some hazards cannot be addressed due to science gaps, and these are noted.

The following guiding principles were considered in deciding how individual hazards are handled:

- BAs are constrained by considering only impacts that can happen via water, and so hazards such as dust, fire or noise are deemed out of scope and addressed by site-based risk management unless there is a water-mediated pathway.
- Leading practice is assumed and accidents are deemed to be covered adequately by site risk management procedures and beyond the scope of BAs, for example the failure of a pipe between the pit and a dam is covered by site risk management.
- Hazards that pertain to the development site and with no off-site impacts will typically be covered by site risk management procedures.
- The hazard priority number or hazard score indicates the relative importance of the hazard. Hazards with low numbers or scores are of lower priority and their impacts may be considered negligible or implausible.

For those hazards that are considered, some will be addressed through the numerical modelling but others can only be addressed through informed narrative. Quantitative risk statements will only be possible where modelling is undertaken. For CSG operations, some hazards will be modelled (such as aquifer depressurisation (target and non-target) or the extraction of surface water for operations); others are expected to be covered through narrative only (such as hydraulic fracturing chemicals, disruption of natural surface drainage or watercourses, changes to aquifer properties, or subsidence). Similarly, for open-cut and underground coal mines, dewatering and changes to the natural surface water drainage will be modelled, while well integrity and erosion will be addressed through narrative only.

The ability for modelling to shed light on certain hazards will depend on the model resolution. Pipelines and site infrastructure for CSG operations will typically not be at a resolution that can be addressed with BA modelling. Water quality will be narrative only, though changes in salinity will be addressed qualitatively and there is potential for particle tracking to be used as a post-processing step to assess changes. The latter will be on a case-by-case basis and depend on the modelling undertaken in the bioregion or subregion (see companion submethodology M07 (as listed in Table 1) for groundwater modelling (Crosbie et al., 2016)).

3.1.3.2 Causal pathways

At the highest level, water-dependent assets may be impacted by changes to quantity, quality or timing of surface water or groundwater or both (see Figure 10 for an example for open-cut coal mines for the Maranoa-Balonne-Condamine subregion). For surface water, the pathways to these changes may primarily come from disruption of the surface drainage (e.g. interception of runoff by the pit or storage dams, as result of subsidence or by diversion of a stream network) or the extraction of water from and disposal of water to a local stream network. From a groundwater perspective, dewatering, depressurisation and other development activities (e.g. wells) can induce pathways to change by altering groundwater levels, flows and directions, quality, preferential pathways and inter-aquifer connectivity. Surface water – groundwater interactions might also change, either by altering recharge from the stream network or as reduced baseflow from the deeper groundwater to the streams. Additional causal pathways also follow on from some of these. For instance, changes to surface water flow due to a mine’s interception of runoff may alter the connectivity of a wetland to a river.

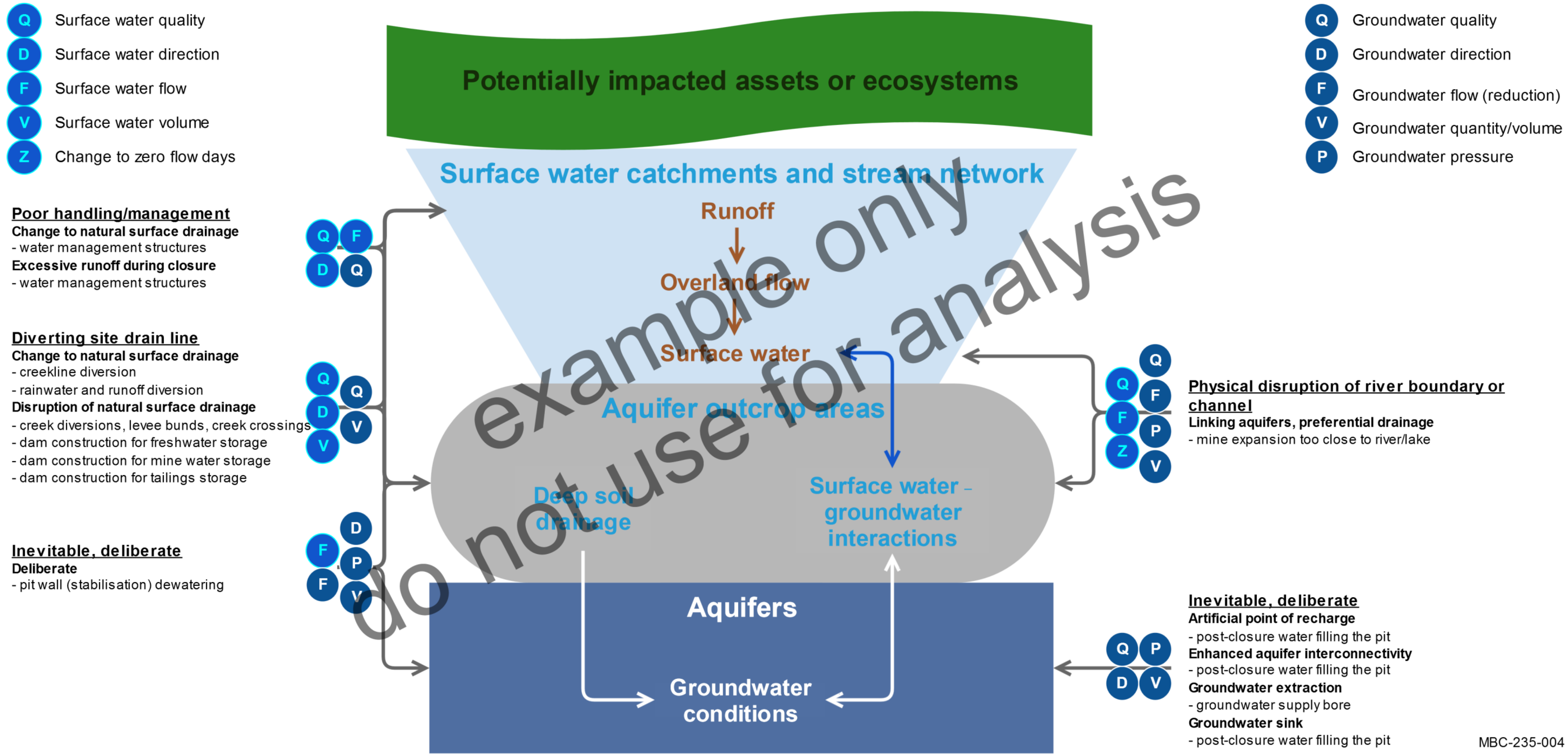

Figure 10 Example diagram: hazards (impact causes, impact modes and activities) and associated effects identified for the life-cycle stages of open-cut coal mines that are considered to be in scope in the Maranoa-Balonne-Condamine subregion

Example only; do not use for analysis. This is an early draft of a diagram published in Holland et al. (2016). See Holland et al. (2016) for full explanation and interpretation of the final results, which might vary from that shown here.
Impact causes are underlined, impact modes are bold and activities are bullet points. Arrows indicate the spatial context for each hazard: aquifers, aquifer outcrop areas, watercourses, catchments. Hydrological effects to system components may cause potential impacts to assets or ecosystems that rely on surface water and/or groundwater. Hydrological effects are denoted by the round circles, where the light blue circles represent surface water hydrological effects and the dark blue circles represent groundwater hydrological effects. The system components are represented by the light blue triangle, grey oval and dark blue rectangle.
GDEs = groundwater-dependent ecosystems
Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1).
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

While these high-level causal pathways are important for concentrating effort and communicating the science, more detail and structure needs to be provided at finer levels of resolution. The hazard analysis identifies a long list of potential impacts that might occur due to CSG operations and coal mines. For CSG operations and open-cut coal mines in the Gloucester subregion, over 600 potential individual hazards (impact modes) were identified, along with impact causes (Dawes et al., 2016). There is, however, considerable structure and hierarchy within these lists of hazards, with the finer level hazards aggregating to successively coarser resolutions. For example, a range of activities that are part of CSG operations might require the removal of site vegetation (the impact cause), including ground-based geophysics and the construction of pipeline networks, storage ponds, site processing plants, water treatment plants and access roads. All of these activities might potentially result in changes to surface water quality from soil erosion following heavy rainfall (impact mode).

It is sensible to aggregate hazards with the same causal pathway even if they occur because of different activities or at different life-cycle stages or at different time scales. These aggregated causal pathways are fairly generic and have substantial commonality between bioregions and subregions. Four causal pathway groups are specified to be used consistently in BAs:

- ‘Subsurface depressurisation and dewatering’ causal pathway group
- ‘Subsurface physical flow paths’ causal pathway group
- ‘Surface water drainage’ causal pathway group
- ‘Operational water management’ causal pathway group.

These causal pathway groups are presented as conceptual diagrams for coal mines and CSG operations in Figure 11 and Figure 12, respectively. They represent some of the key system components, activities and features of the coal resource development, and highlight some of the potential causal pathways that may occur in each of these causal pathway groups. These pictorial representations are generic and not drawn to scale, but provide a compelling way to visualise how potential impacts may eventuate.

For more detail about these causal pathway groups, as well as the causal pathways within them, see Appendix B. The names of these causal pathway groups and causal pathways are used to ensure consistency across all BAs.

For each aggregated impact cause, it is necessary to represent the chain of logic for that cause, either uniquely or in conjunction with other associated impact causes. There is no need to make the distinction between the causal pathways for baseline and the CRDP. Many of the pathways that exist will be common to both and will often result in similar effects in different places.

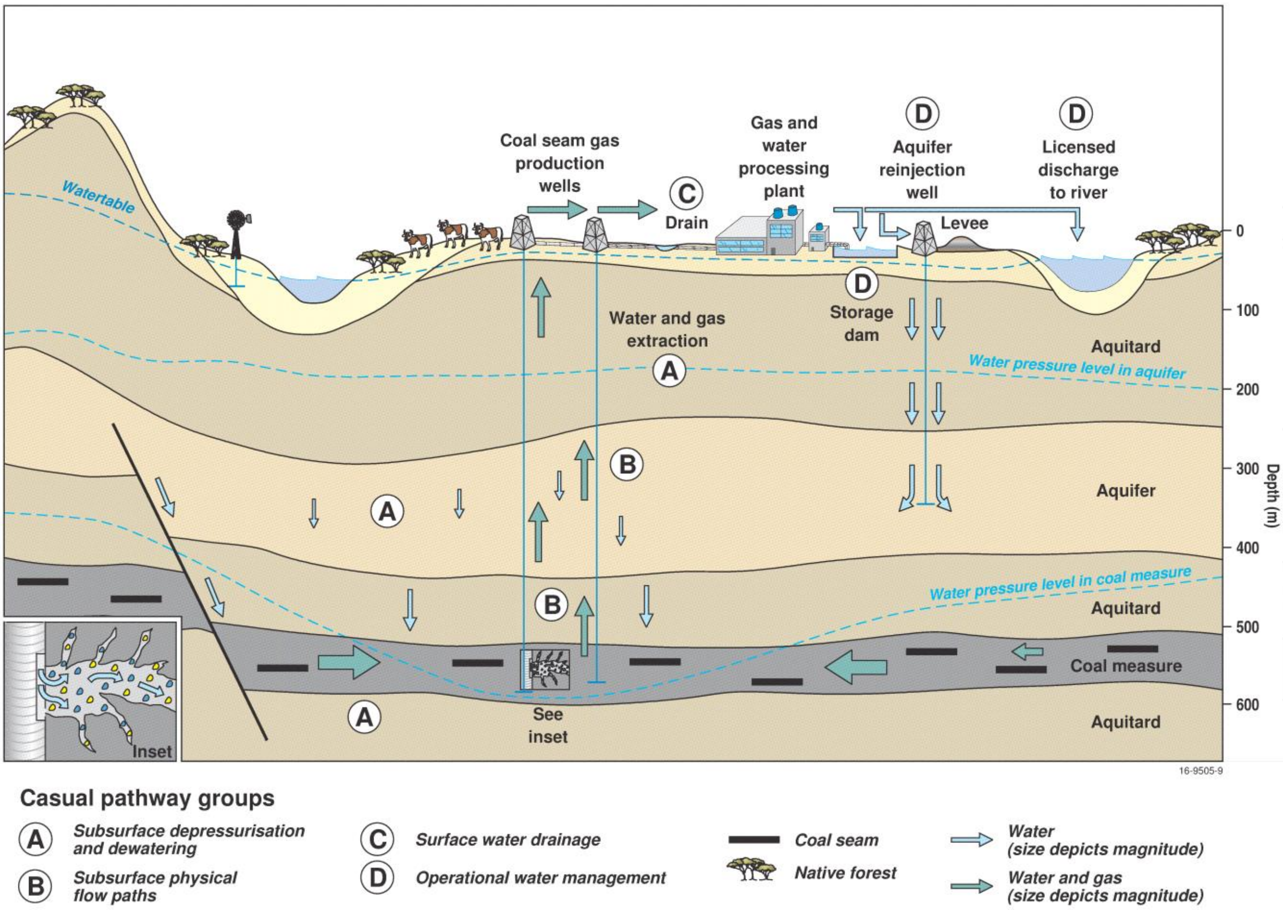

Figure 11 Conceptual diagram of the causal pathway groups associated with coal seam gas operations

This schematic diagram is not drawn to scale and is generic. In a hydrologically confined aquifer or coal measure, the water pressure level may rise above the top of the geological layer. Drawdown caused by coal seam gas extraction does not necessarily translate to changes in depth to the watertable.

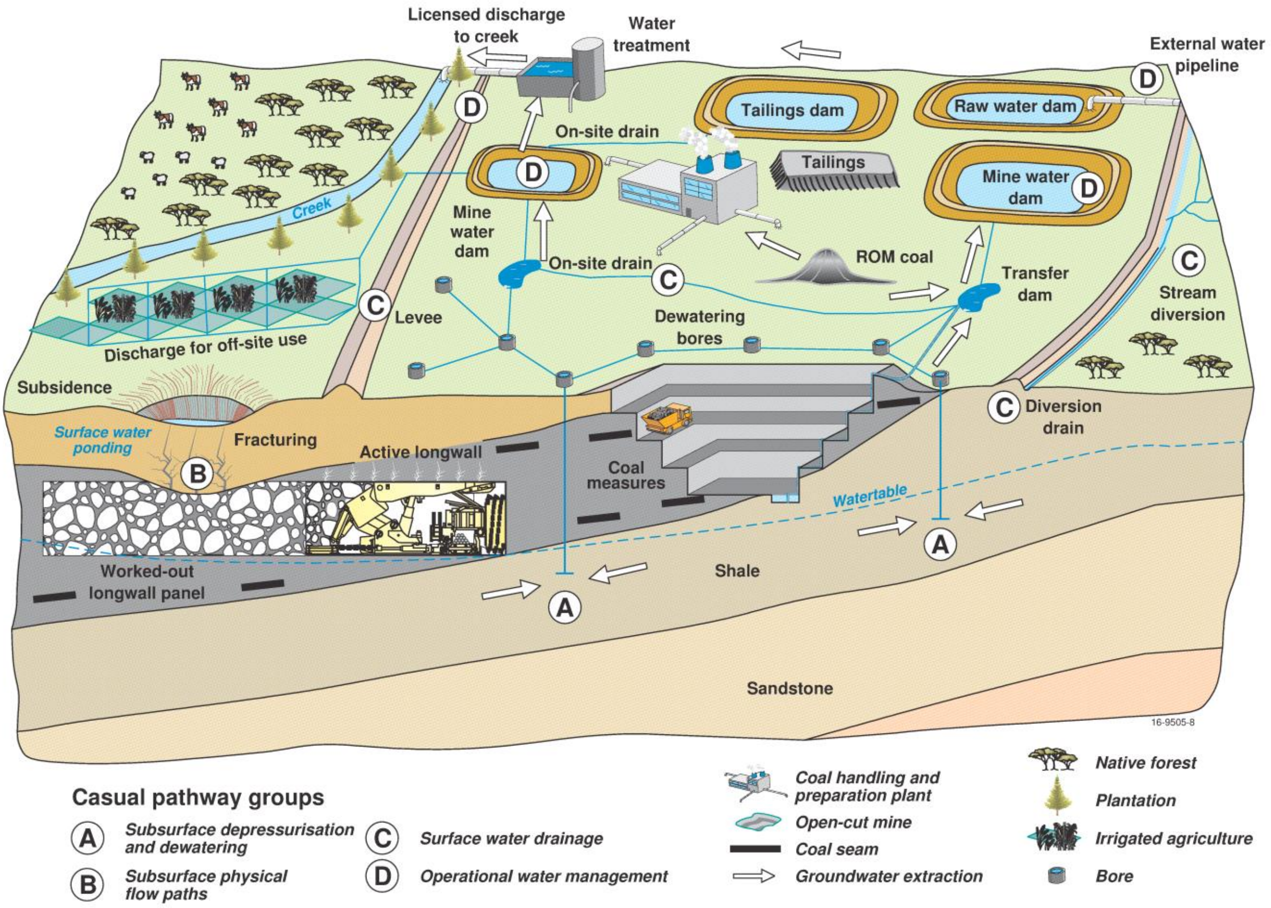

Figure 12 Conceptual diagram of the causal pathway groups associated with coal mines

This schematic diagram is not drawn to scale and is generic.

Figure 13 represents some of the causal pathways for hazards (impact causes, impact modes and activities) arising from CSG operations and open-cut coal mines in the Maranoa-Balonne-Condamine subregion. In particular, it illustrates two causal pathways form the 'Subsurface depressurisation and dewatering' causal pathway group (Table 7 in Appendix B). In Figure 13, there is no consideration of the hazard handling or scope discussed in Section 3.1.3.1.1. It is desirable to frame the hazards and pathways broadly to acknowledge what may change exhaustively before focusing on the highest priority causal pathways from a BA perspective.

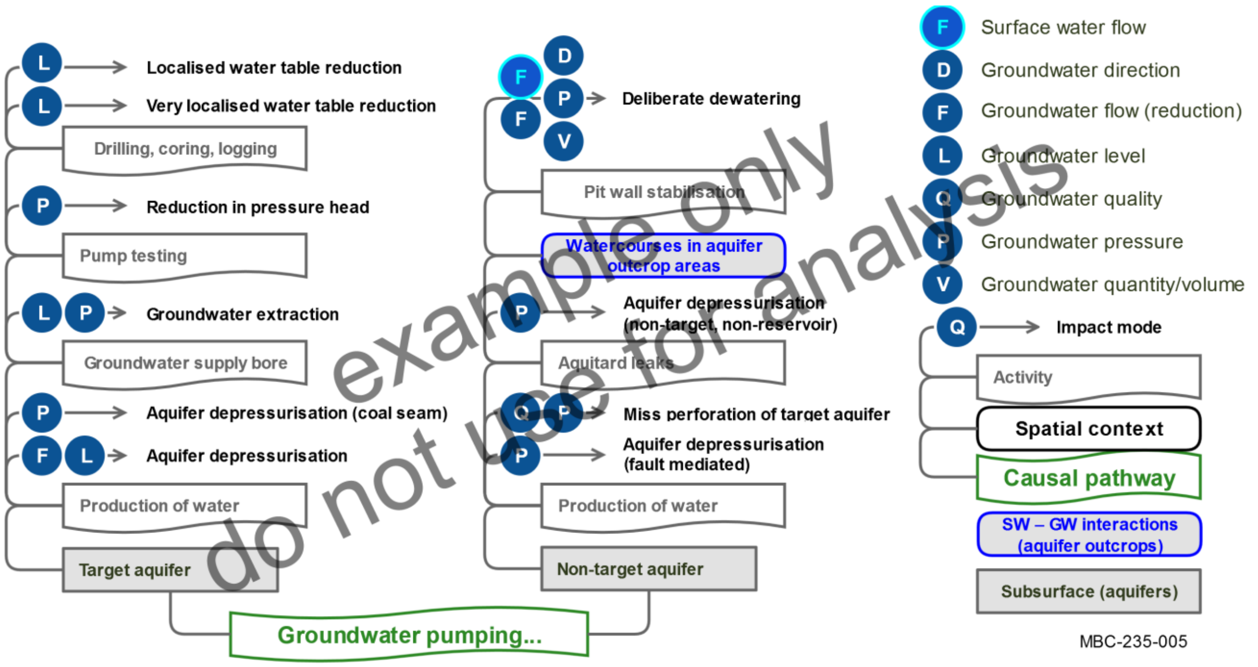

Figure 13 Example diagram: 'Subsurface depressurisation and dewatering' causal pathway group arising from coal seam gas operations and open-cut coal mines in the Maranoa-Balonne-Condamine subregion

Example only; do not use for analysis. This is an early draft of a diagram published in Holland et al. (2016). See Holland et al. (2016) for full explanation and interpretation of the final results, which might vary from that shown here.
Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1).
'Groundwater pumping…' is shortened form for 'Groundwater pumping enabling coal seam gas extraction' and 'Groundwater pumping enabling open-cut coal mining causal pathways'.

A more exhaustive set of causal pathway diagrams analogous to Figure 13 are presented in Appendix A. Collectively these set of diagrams represent the IMEA hazard spreadsheets graphically and allow a great number of the hazards and their natural groupings to be visualised simultaneously.

Influence or box-and-arrow diagrams are also useful for illustrating causal pathways. See Entrekin et al. (2011) for an influence diagram that indicates the potential causal pathways from hydraulic fracturing. Figure 14 is a preliminary causal pathway for CSG water management from the Clarence-Moreton bioregion. It presents a cross-section from the three-dimensional geological model with flow directions and highlights the particular layers that are important for CSG water management. It also illustrates specific water management pathways, including the extraction of surface water or groundwater for operations and the potential hydrological effects (i.e. reduced surface water flow and groundwater levels). Figure 14 also shows the potential pathways to impact through the storage and disposal of produced water, as well as the connection to other pathways (i.e. the groundwater extraction impact mode).

The stratigraphy will be different in other bioregions and subregions, and the details of the provision, storage and disposal of water will be specific to each development, but generally Figure 14 provides a template for communicating the logic of the causal pathway. The influence or box-and-arrow diagrams represent the more generic chain of logic while the stratigraphy shown in Figure 14 supports the required region-specific narrative.

The description so far has concentrated on the pathways to change but not *where* changes might be expected. It is important to consider the higher level spatial context for the aggregated hazards, considering where they occur (e.g. whether impacts will extend beyond the site, which aquifers will be depressurised or which landscape class might be affected). To constrain focus, the Assessment team must seek to rule out areas of the bioregion or subregion that will not be subject to any of the listed hazards.

At this stage the ruling out occurs on the basis of sound scientific reasoning. A groundwater divide might mean that certain parts of the bioregion or subregion cannot be impacted by mine-related drawdown, or it might not be plausible for a section of a stream network upstream of the coal resource development to be impacted hydrologically. Create a table or a matrix that lists and describes potential causal pathways and the unique landscape classes that may be impacted. The objective is to identify which landscape classes are potentially subject to multiple causal pathways and rule out any landscape classes that will not be affected by any.

It is not necessary, nor possible, to enumerate all the causal pathways, particularly spatially. Numerical hydrological models will integrate understanding and ultimately represent the causal pathways spatially, for those BAs that are developing such models. Product 2.3 (conceptual modelling) focuses on laying out the underpinning understanding through the various conceptual models and the numerical hydrological models, and emphasising the most important causal pathways. It is essential to annotate and support the hypothesised causal pathways with a narrative and detailed scientific evidence base for both the generic pathways and the local context wherever possible in order to achieve the aim of transparency and to demonstrate the underlying science quality and credibility.

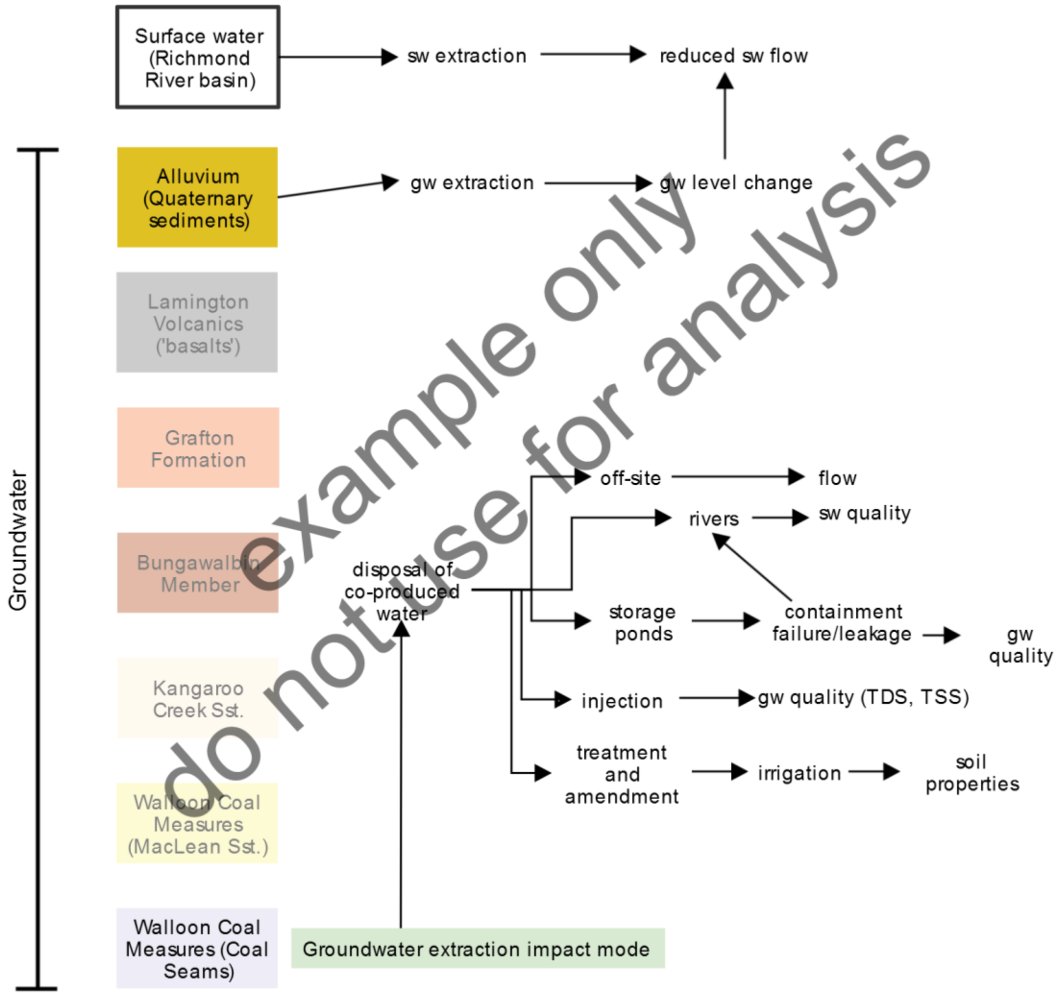

Figure 14 Example diagram: causal pathway group 'Operational water management' arising from coal seam gas operations in the Clarence-Moreton bioregion

Example only; do not use for analysis. This is an early draft of a figure published in Raiber et al. (2016). See Raiber et al. (2016) for full explanation and interpretation of the final results, which might vary from that shown here.
GW corresponds to groundwater; SW corresponds to surface water; TDS corresponds to total dissolved solids; TSS corresponds to total suspended solids.

3.1.4 Step 8: summarise causal pathways

The last step in Figure 8 is to identify, compare and contrast the causal pathways for baseline and the CRDP, including differences in their spatial and temporal extent, and potentially impacted landscape classes.

Three-dimensional visualisations or pictorial representation of the bioregion or subregion, and contrasts between the causal pathways for the baseline and the CRDP, are not expected as part of product 2.3 (conceptual modelling) though can be included if they exist. Detailed three-dimensional visualisations or pictorial representation may, however, be created as part of product 3-4 (impact and risk analysis) and will incorporate additional evidence from the numerical modelling.

3.1.5 External engagement

It is essential to seek external input and confirmation of the causal pathways, given the critical role they will play in the modelling, impact and risk work that follows. This is the opportunity to rigorously test our understanding with local expertise while there is an opportunity to make changes or reframe. If something is missed and surprises occur later in the process it will be much more difficult to address.

This engagement is expected to be done through an external workshop, although alternative and more distributed forms of consultation may be appropriate in some circumstances, for example if there are logistical challenges in getting everyone in the same room. A two-day workshop is probably necessary given the context setting required and the detailed conversation that may be required around specific causal pathways and their spatial and temporal contexts.

Many of the causal pathways need to be prepared prior to the workshop. It is recommended that these be substantially complete, so the participants can move through the non-contested pathways quickly and focus on those that are more contentious or potentially incomplete or missing. This discussion will need to be structured so that targeted questions can be asked to test the boundaries of thinking, but also flexible so that alternative views can be accepted and used to update the understanding. For example, if the presence and location of faults is a knowledge gap that may potentially affect the connectivity between aquifers, it will make sense to focus on faults specifically, reflecting the BA synthesis of the current state of knowledge and its evidence base, before seeking any additional workshop input around the location and role of any faults that may exist.

Frame the identification of causal pathways broadly by considering all hazards that are identified and noting those that are out of scope, handled by other processes (e.g. site-based risk management) or assessed by hazard analysis as lower priority. Concentrate on finding reasons to rule out specific pathways or pathways from particular parts of the PAE. The more the Assessment team can focus on pathways that might cause impacts, or on areas that might receive impact, and away from pathways or areas that will not, the better. This ruling out needs to be done in a principled and conservative way by using a strong logic and evidence base, but will help ensure that resources are used efficiently in the BA.

It is important to give people enough time to digest and make suggestions. Circulating material prior to workshop may be useful. It also may be beneficial to give people the chance to leave at the end of the day, but then come back later with fresh eyes and the opportunity to provide further feedback. Draw on generic BA material where possible, as many of the causal pathways will be common across bioregions and subregions and need to be only tailored for local conditions.

The audience needs to be chosen so that they can speak confidently about the pathways and avoid potential blind spots. Where possible, more than one expert should be consulted in each discipline. Consider inviting different participants for different sessions; the landscape classification might require different participants than a development-focused session.

Pictures worth a thousand words: a guide to pictorial conceptual modelling (Department of Environment and Heritage Protection, 2012) is a useful guide to running a science synthesis workshop for conceptual modelling.

It is important for the Assessment teams to carefully consider bioregion- or subregion-specific conceptual modelling resources that exist (see Section 2.6). Leveraging off existing work and expertise wherever possible will help ensure that BA conceptual models will resonate with the local community. These specific resources are too numerous to consider in this submethodology but are an essential part of the evidence base.

3.2 Knowledge gaps and uncertainties

Where there is knowledge in how the physical and biological systems work and interact with coal resource developments, it is important for that knowledge to be embedded in the conceptual modelling and supported by a scientific evidence base. If there are known knowledge gaps and uncertainties in those systems, a key objective of the conceptual modelling is to highlight them. One approach is to aim for a sufficiently general depiction of the system that nonetheless identifies or encompasses alternative interpretations. Where greater detail or emphasis is required then one can proceed with the development of alternatives or variant model depictions. Such alternative models can be a key feature of engagement with stakeholders that lends credibility to the overall risk analysis, but also serves as a means to focus research or risk analyses on key uncertainties. Any model is an abstraction of reality, and here it is purposefully incomplete, and thus always lacking or wrong by some measure. The measure of worth of the model is not only how faithfully it represents the real world, but also how well it focuses researchers and stakeholders on the essential details of a shared understanding of how the system works.

4 Outputs from conceptual modelling

4.1 Outputs for product 2.3 (conceptual modelling)

Table 4 outlines the main content to include in product 2.3 (conceptual modelling):

- Section 2.3.1 provides an overview of the high-level method, cross-referencing this submethodology and identifying deviations. Details of generally developing the conceptual model of causal pathways are presented here, but the details of methods for landscape classification, hazard analysis, etc., are included instead in the appropriate section.
- Section 2.3.2 summarises how the bioregion or subregion works, synthesising the information from product 1.1 (context statement, which covers geology, hydrogeology and surface water hydrology) and product 2.5 (water balance assessment).
- Section 2.3.3 describes the ecosystems in a bioregion or subregion in terms of landscape classes.
- Section 2.3.4 outlines the potential change that might occur in a bioregion or subregion by describing and documenting the baseline and coal resource development pathway (CRDP) that underpin the BA. A summary of the water management for coal resource developments follows.
- Section 2.3.5 concludes product 2.3 (conceptual modelling) by presenting a summary of the hazard analysis and the *causal pathways*, from coal resource developments through to hydrological changes, for both baseline and CRDP. See Table 5 for an example table that is recommended to be included.

Product 2.7 (receptor impact modelling) extends the causal pathways from the hydrological changes to potential impact on assets via qualitative models and conceptualisations of landscape classes and their dependency on surface water and groundwater.

In writing product 2.3 (conceptual modelling), it is important to note that more detail will sit in other products and that a key role of product 2.3 is to synthesise and summarise to preface the impact and risk analysis that follows. Ask the question: is this piece of information essential for this role? If it is then it should be in product 2.3 (conceptual modelling). If, on the other hand, it is not, then leave the detail elsewhere. For instance, while it is necessary to summarise the geology, particularly as relevant to water pathways, the details about any geological model developed for BAs should sit instead in product 2.1-2.2 (observations analysis, statistical analysis and interpolation).

Throughout product 2.3 (conceptual modelling), acknowledge knowledge gaps, uncertainties and alternative formulations that may exist. The synthesis in a conceptual model can reflect alternative hypotheses or understanding of interaction pathways if it represents uncertainty or gaps in the extent of the knowledge base. As more data or information is collected, conceptual models should be updated and refined. This will happen through the BAs where Component 2: Model-data analysis, Component 3: Impact analysis and Component 4: Risk analysis will clarify the importance of some links and dependencies in the conceptual model.

Table 4 Recommended content for product 2.3 (conceptual modelling)

Section number	Title of section	Main content to include in section
2.3.1	Methods	**Summary** **2.3.1.1 Background and context** **2.3.1.2 Developing causal pathways**
2.3.2	Summary of key system components, processes and interactions	Summary **2.3.2.1 Scope and overview** • define spatio-temporal boundaries of the conceptual model on the basis of the preliminary assessment extent (PAE) and coal resource development pathway (CRDP). Focus on a smaller area within the PAE if the CRDP (and the resulting conceptual model of causal pathways) localises the area of interest **2.3.2.2 Geology and hydrogeology** • summarise the two- and three-dimensional representations and cross-sections of the geology and hydrogeology in the bioregion or subregion, including a representation of the coal-bearing sediments, aquifers and aquitards, as well as hydrodynamics • summarise the major stratigraphic units, faults and other hydrogeological features, such as distribution of hydraulic conductivity and porosity, trends in groundwater level and flow characteristics, and assumptions about interconnectivity of strata • summarise groundwater conceptual model (from product 2.6.2 (groundwater numerical modelling), including groundwater divides and the current knowledge of groundwater inflows and outflows. **2.3.2.3 Surface water** • identify boundaries of river basins • summarise surface water inflows and outflows to a bioregion or subregion, noting large-scale climate gradients and resulting gradients in hydrological systems • identify dominant mechanisms and locations of recharge, discharge, flows and surface water – groundwater interactions **2.3.2.4 Water balance** • summarise the water balance, including other consumptive uses (note that detail should instead sit in product 2.5 (water balance assessment)) **2.3.2.5 Gaps**

Section number	Title of section	Main content to include in section
2.3.3	Ecosystems	**Summary** **2.3.3.1 Landscape classification** • describe the method and approach used for the landscape classification • define a set of landscape classes that represent the main biophysical and human systems for the bioregion or subregion at the surface. It is likely to be a hybrid classification where the aquatic ecological components will covered by classifications such as the Australian National Aquatic Ecosystem (ANAE) or River Styles, and other terrestrial or human systems picked up by vegetation, land use or other classifications. See companion submethodology M03 for assigning receptors to water-dependent assets (O'Grady et al., 2016) for additional detail on landscape classes • document how the landscape classes are constructed • describe the dependence of those landscape classes on surface water and/or groundwater, and the internal heterogeneity in the landscape class • detailed conceptual models for landscape classes are not required at this stage and will only be examined through the receptor impact modelling (product 2.7) and impact and risk analysis (product 3-4) for any landscape classes that are potentially impacted • summarise the results of the landscape classification in maps and tables **2.3.3.2 Gaps**
2.3.4	Baseline and coal resource development pathway	**Summary** **2.3.4.1 Developing the coal resource development pathway** • describe the methods, process and literature sources used to construct the CRDP • justify the CRDP decisions for all developments listed in Section 1.2.4 of product 1.2 (*coal and coal seam gas resource assessment*). Comment on the approval process, workshops and external facilitation • describe baseline activity • table of coal resource developments (in baseline and additional coal resource development (ACRD), which together are the developments in the CRDP) • map of developments (baseline and ACRD, which together are the developments in the CRDP) • timeline of developments (baseline and ACRD, which together are the developments in the CRDP) • describe any limitations and further research **2.3.4.2 Water management for coal resource developments** • describe process to identify water management rules and the data and literature sources used • summarise water management practices for coal and coal seam gas (CSG) developments in the baseline and the CRDP. Details of the water management are instead reported in product 2.1-2.2 (observations analysis, statistical analysis and interpolation). Specific implementation rules for the numerical modelling are instead reported in product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). **2.3.4.3 Gaps**

Section number	Title of section	Main content to include in section
2.3.5	Conceptual model of causal pathways	**Summary** **2.3.5.1 Methodology** • describe the methods and the process undertaken to identify, construct and test the causal pathways for a subregion or bioregion • describe Impact Modes and Effects Analysis (IMEA) (refer to detail in the subregion- or bioregion specific hazard report) and describe process for aggregating hazards to causal pathways and considering spatial and temporal context • summarise the workshops held for hazards and for causal pathways **2.3.5.2 Hazard analysis** • summarise the hazard identified for coal mines and CSG operations • emphasise the hazard scope and handling **2.3.5.3 Causal pathways** • describe the causal pathways for coal mines and CSG operations • represent the causal pathways graphically (e.g. using influence diagrams) • summarise causal pathways for the baseline and CRDP • identify potentially impacted landscape classes **2.3.5.4 Gaps**

Table 5 Example table: all causal pathway groups arising from open-cut mines and coal seam gas operations in the Gloucester subregion

Example only; do not use for analysis. This is an early draft of a table published in Dawes et al. (2016). See Dawes et al. (2016) for full explanation and interpretation of the final results, which might vary from that shown here.

Type of coal resource development	Causal pathway group	Baseline coal resource development	Coal resource development pathway	Potentially impacted landscape class
Open-cut mines	Subsurface depressurisation and dewatering	Yes	Yes	Intermittent – gravel/cobble streams Forested wetlands (GDE landscape group) Perennial – gravel/cobble streams
	Subsurface physical flow paths	Yes	Yes	
	Operational water management	Yes	Yes	
	Surface water drainage	Yes	Yes	
Coal seam gas operations	Subsurface depressurisation and dewatering		Yes	Intermittent – gravel/cobble streams
	Subsurface physical flow paths		Yes	
	Operational water management		Yes	
	Surface water drainage		Yes	

4.2 Outputs for other products

Product 2.3 (conceptual modelling) and product 2.7 (receptor impact modelling) fully describe the potential causal pathways between coal resource development and possible impacts on water and water-dependent assets. Product 2.3 focuses on the causal pathways from the coal resource development to the hydrological changes (represented by the hydrological response variables), with less focus on the links through to the ecological and human-dominated systems at the surface (landscape classes). Following the outputs from the numerical modelling (product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling)) and identifying locations of potential hydrological change, product 2.7 (receptor impact modelling) considers only those potentially impacted landscape classes and creates qualitative, or signed digraph, models that describe the impacted landscape classes; the functions, processes and interactions within them; and their dependency on specific attributes of groundwater and surface water. Thus product 2.7 completes the causal pathways, from the hydrological changes to the impacts (represented by the receptor impact variables, which are linked to the landscape classes and assets).

Table 6 describes the specific role for conceptual modelling in all products and their links to product 2.3 (conceptual modelling).

Table 6 Role of conceptual modelling and links to product 2.3 (conceptual modelling) by product

Product code	Title	Description
1.1	Context statement	The context statement summarises the geography, geology, hydrogeology, groundwater, surface water and ecology of a bioregion or subregion. Product 2.3 (conceptual modelling) provides a further and more integrated representation of the key systems, components and processes identified initially in product 1.1 (context statement).
1.2	Coal and coal seam gas resource assessment	The catalogue of identified coal and CSG resources in Section 1.2.4 provides the basis for the decision on the coal resource development pathway (CRDP) that is described in detail in product 2.3 (conceptual modelling).
1.3	Description of the water-dependent asset register	Assets feature indirectly in product 2.3 (conceptual modelling) through the landscape classification, where assets may be used to provide context for individual landscape classes.
2.1-2.2	Observations analysis, statistical analysis and interpolation	No conceptual modelling is required in this product but analysis conducted here may be important to summarise the science and provide the evidence base for conceptual models. In some cases the development of the three-dimensional geological model is reported here.
1.5 2.5	Current water accounts and water quality Water balance assessment	The water balance is summarised qualitatively in product 2.3 (conceptual modelling), but more details are provided in product 2.5 (water balance assessment). Some conceptual representation is required for assessing the movement of water and salt between stores within key system components, and assessing the variability and changes over time.
2.6.1	Surface water numerical modelling	The hydrological conceptual model (Section 2.6.1.3 in product 2.6.1 (surface water numerical modelling) that underpins the development of the surface water model is a key part of product 2.3 (conceptual modelling).
2.6.2	Groundwater numerical modelling	The hydrogeological conceptual model (Section 2.6.2.3 in product 2.6.2 (groundwater numerical modelling)) that underpins the development of the groundwater model development is a key part of product 2.3 (conceptual modelling).
2.7	Receptor impact modelling	Receptor impact models will be underpinned by fine-scale conceptual models that characterise, in more detail, landscape-scale conceptual models and link receptor impact variables and hydrological response variables at receptor locations. Whereas product 2.3 (conceptual modelling) describes the pathway from coal resource development through to hydrological change (represented by hydrological response variables), product 2.7 (receptor impact modelling) details the pathway from hydrological change to impacts (represented by receptor impact variables).
3-4	Impact and risk analysis	Product 2.3 (conceptual modelling) plays a critical role in framing the impact and risk analysis, by determining the hazards (through the Impact Modes and Effects Analysis), dependencies and the causal pathways that need more detailed analysis in product 3-4 (impact and risk analysis). While qualitative in nature in the conceptual model, Component 3: Impact analysis and Component 4: Risk analysis use the results from numerical hydrological modelling and the receptor impact modelling to make quantitative assessments of the potential impacts, and their severity and likelihood. At the end of product 3-4 (impact and risk analysis), the conceptual model of causal pathways is updated to reflect the modelling, impact and risk analyses.

4.3 Bioregion- and subregion-specific considerations and workflow

While there are some differences in the nature of BAs across bioregions and subregions, product 2.3 (conceptual modelling) is a consistent product, though it is only developed where there is an agreed CRDP.

The potential causal pathways identified in product 2.3 (conceptual modelling) are extended to a detailed consideration of landscape classes that the groundwater and surface water modelling results suggest might be affected. Where receptor impact modelling is undertaken, conceptual models for these landscape classes are reported in the product 2.7 (receptor impact modelling). Where receptor impact modelling is not undertaken, these conceptual models will be described in product 3-4 (impact and risk analysis). In either case, these conceptual models will underpin some of the essential narrative around impacts and risks.

Appendix A Diagrams of causal pathways

Figure 15 to Figure 20 represent the causal pathways for hazards by identifying the activities, impact causes and impact modes for open-cut and underground coal mines and coal seam gas (CSG) operations. These were developed for the Maranoa-Balonne-Condamine subregion initially (Holland et al., 2016) but are generically useful across all subregions and bioregions. The hazard handling or scope discussed in Section 3.1.3.1.1 is not considered in this representation. Collectively Figure 15 to Figure 20 graphically represent the hazard spreadsheets arising from the Impact Modes and Effects Analysis (IMEA) and allow many hazards and their natural groupings to be visualised simultaneously.

See Holland et al. (2016) for full explanation and interpretation of the final results, which might vary from that shown in these figures. Impact causes are underlined, impact modes are bold and activities are bullet points. Arrows indicate the spatial context for each hazard: aquifers, aquifer outcrop areas, watercourses, catchments. Hydrological effects to system components may cause potential impacts to assets or ecosystems that rely on surface water and/or groundwater. Hydrological effects are denoted by the round circles, where the light blue circles represent surface water hydrological effects and the dark blue circles represent groundwater hydrological effects. The system components are represented by the light blue triangle, grey oval and dark blue rectangle.

A.1 Open-cut coal mines

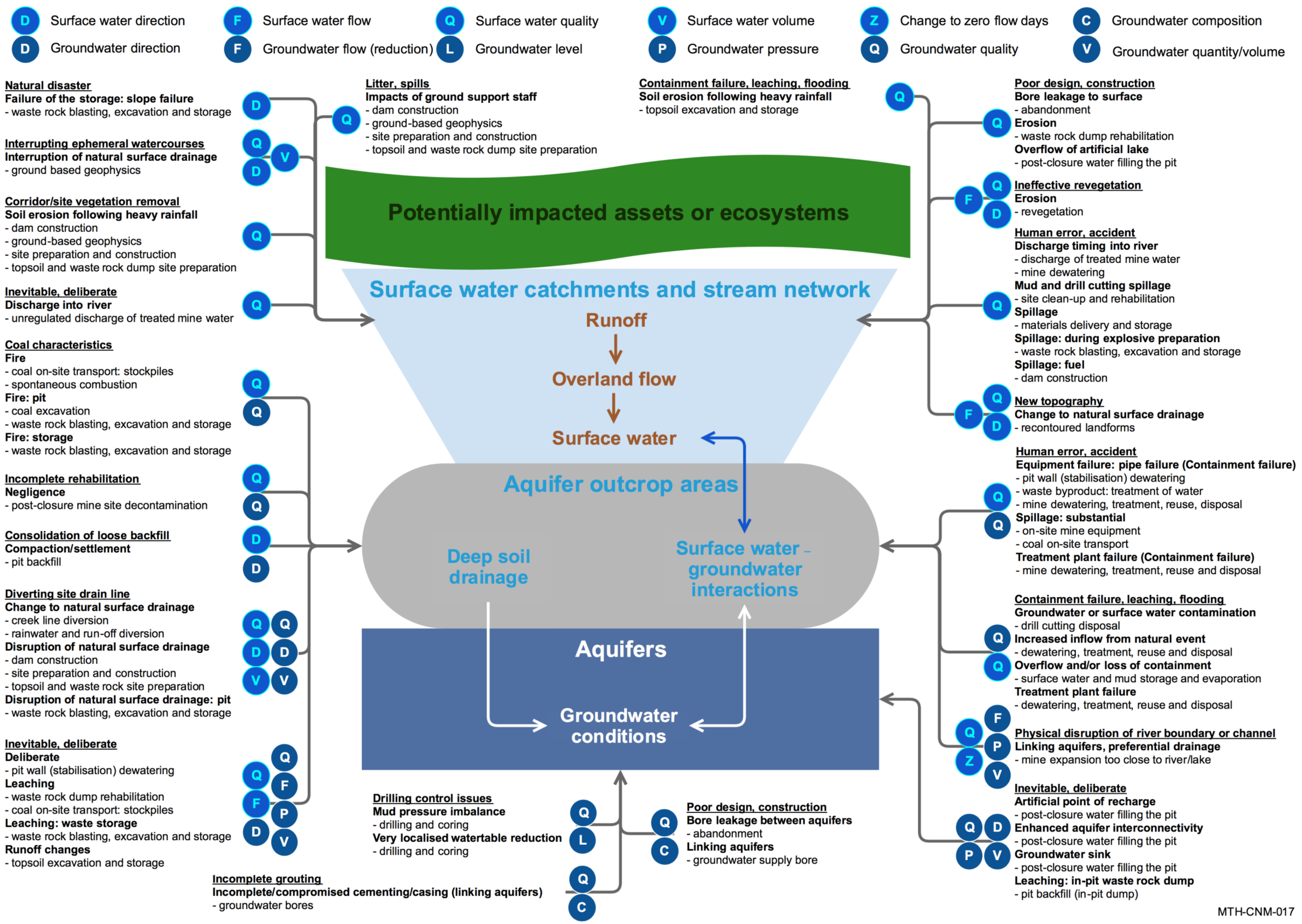

Figure 15 Causal pathways for hazards (impact causes, impact modes and activities) related to the open-pit component for open-cut coal mines

Impact causes are underlined, impact modes are bold and activities are preceded by hyphens.
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

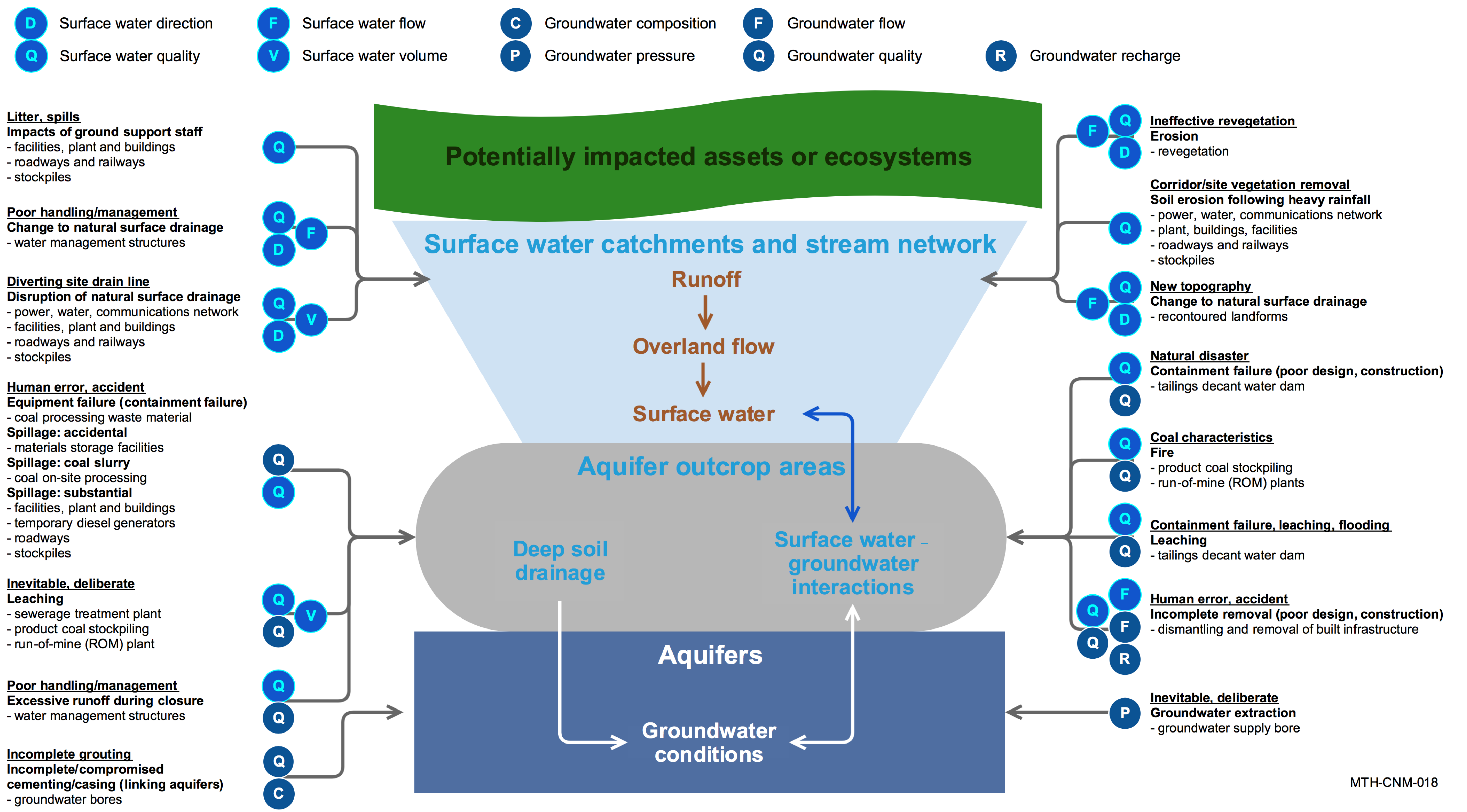

Figure 16 Causal pathways for hazards (impact causes, impact modes and activities) related to the surface facilities and infrastructure component of open-cut coal mines

Impact causes are underlined, impact modes are bold and activities are preceded by hyphens.
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

A.2 Underground coal mines

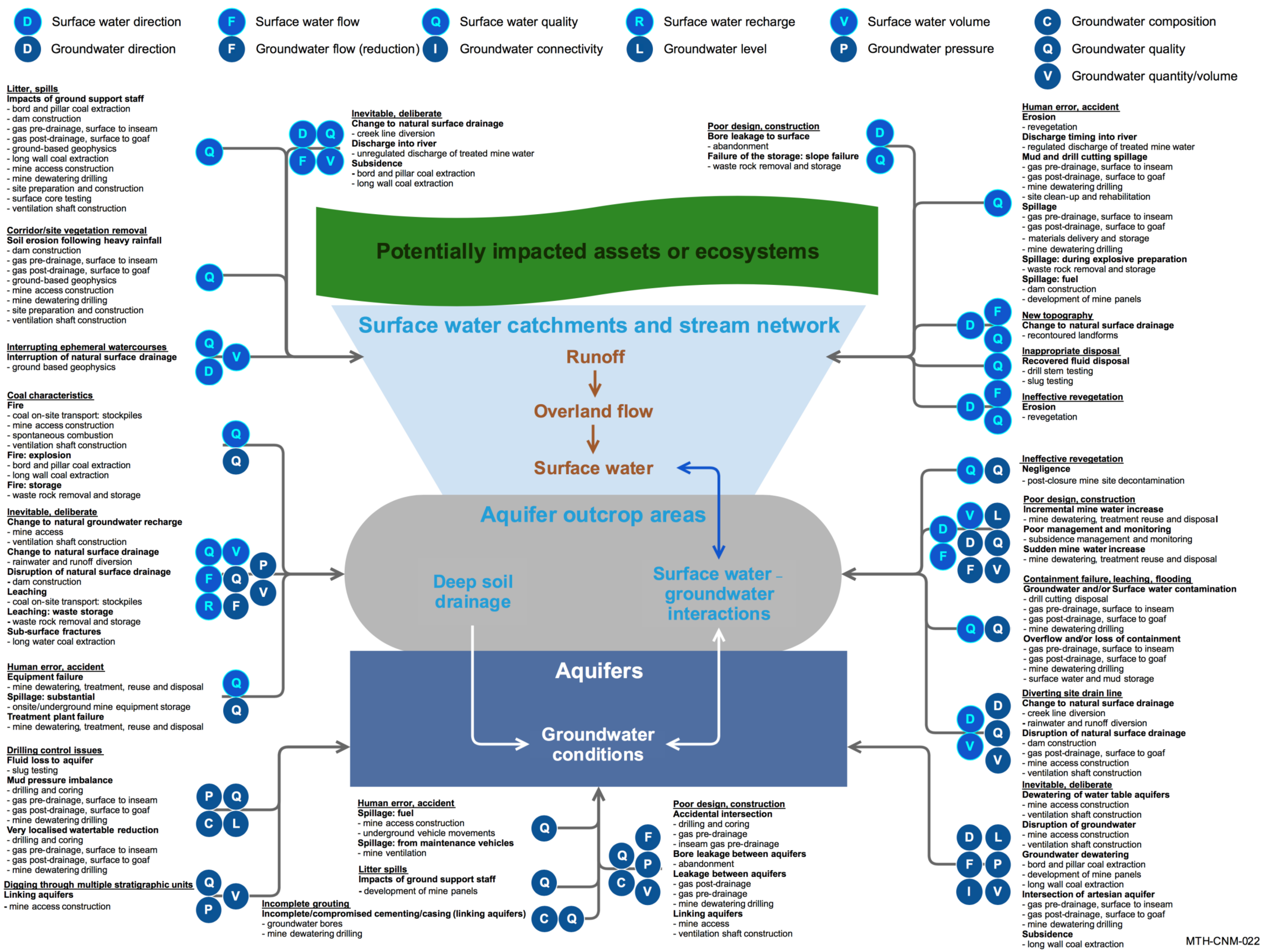

Figure 17 Causal pathways for hazards (impact causes, impact modes and activities) related to the underground component for underground mines

Impact causes are underlined, impact modes are bold and activities are preceded by hyphens.
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

A.3 Coal seam gas operations

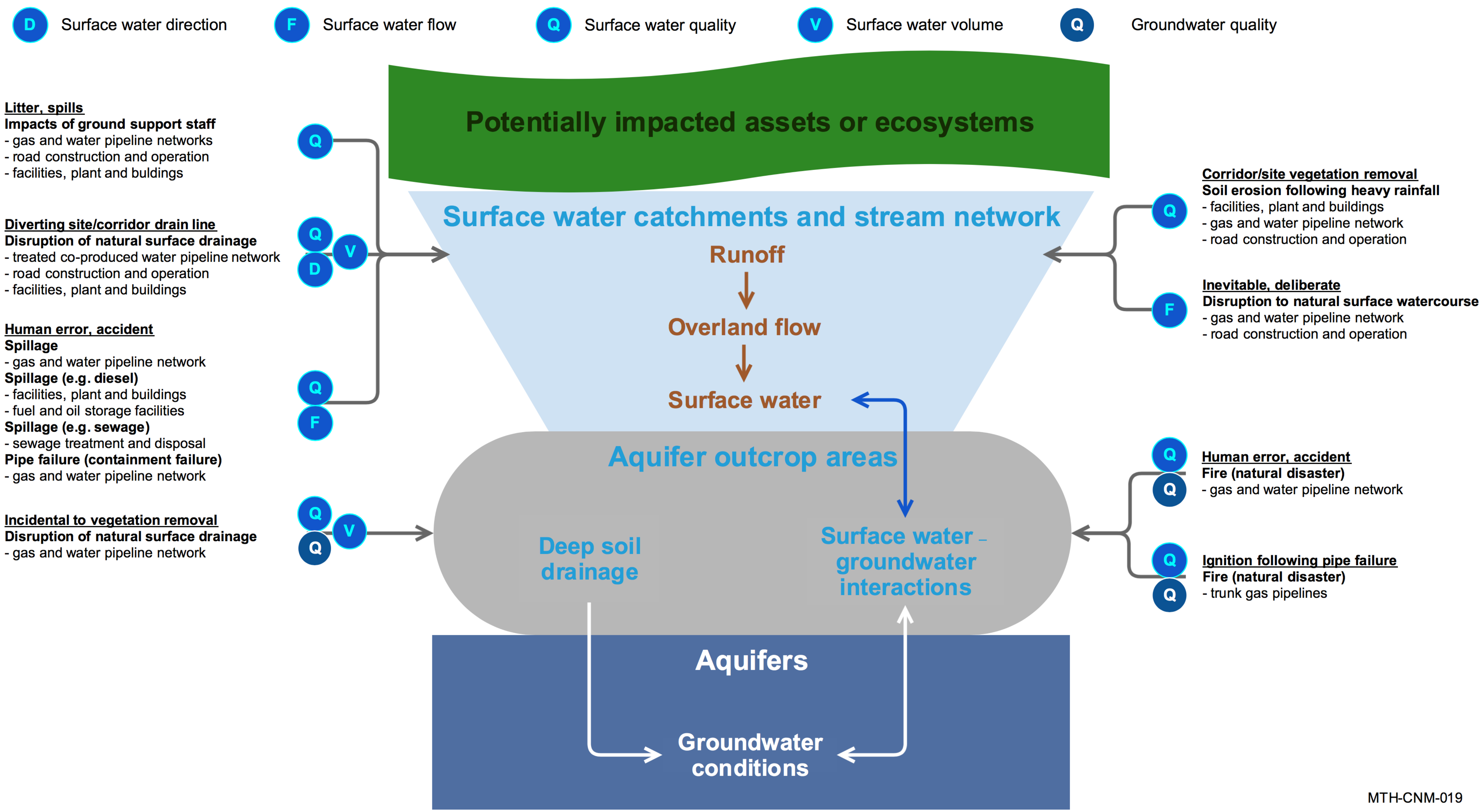

Figure 18 Causal pathways for hazards (impact causes, impact modes and activities) related to the pipelines, roads and associated infrastructure component for coal seam gas operations

Impact causes are underlined, impact modes are bold and activities are preceded by hyphens.
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

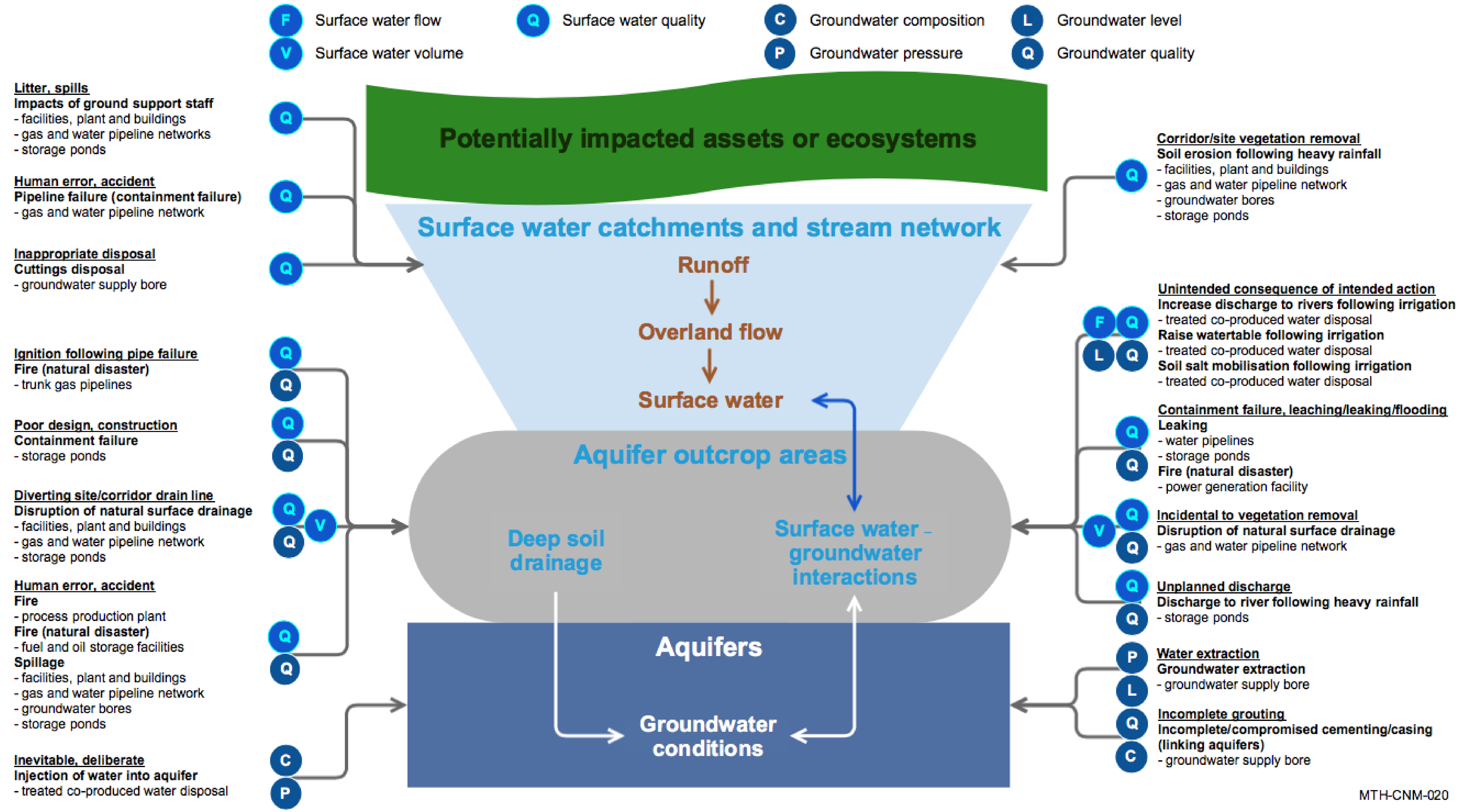

Figure 19 Causal pathways for hazards (impact causes, impact modes and activities) related to the processing facilities component for coal seam gas operations

Impact causes are underlined, impact modes are bold and activities are preceded by hyphens.
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

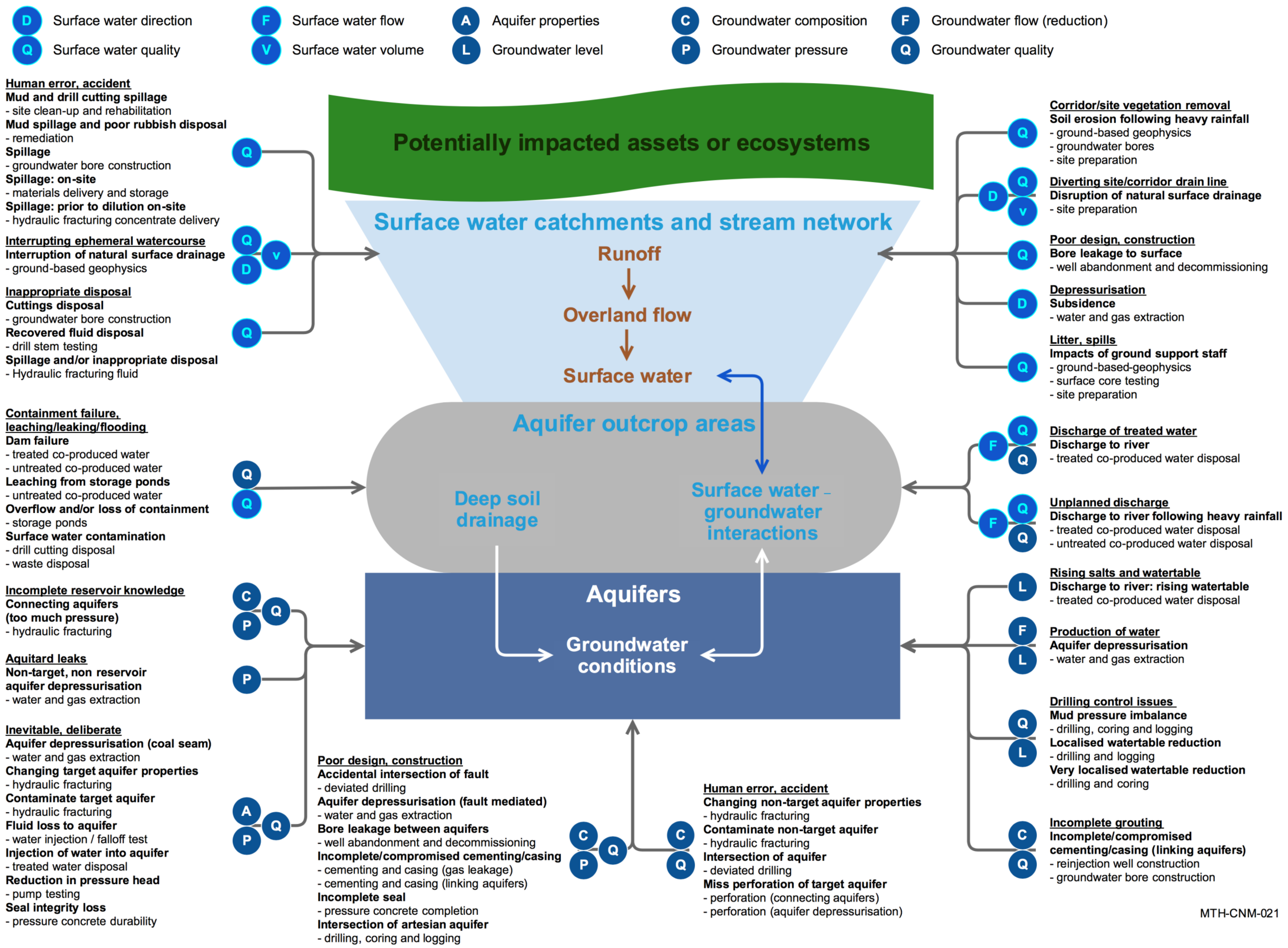

Figure 20 Causal pathways for hazards (impact causes, impact modes and activities) related to the wells component for coal seam gas operations

Impact causes are underlined, impact modes are bold and activities are bullet points.
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

Appendix B Names and descriptions of causal pathway groups and causal pathways

For the purposes of bioregional assessments, causal pathways are 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 causal pathways are initiated by an activity associated with the coal resource development (as identified from the Impact Modes and Effects Analysis).

Causal pathways commonly overlap or link. For example, the depressurisation of coal seams to extract coal seam gas (CSG) will also produce water that needs to be managed or disposed of through surface water or groundwater systems.

A consistent set of names for causal pathways need to be used across all Assessments.

Causal pathways are classified into four groups, as follows. Each of these groups consists of between three to five causal pathways, as shown in Table 7 to Table 10.

The specified names for each group and causal pathway should be used consistently in reporting causal pathways for all subregions and bioregions.

B.1 'Subsurface depressurisation and dewatering' causal pathway group

This group of causal pathways arises when coal mines and CSG operations intentionally dewater and depressurise subsurface hydrostratigraphic units (such as coal seams and aquifers) to permit coal resource extraction. Pumping groundwater to enable coal resource extraction modifies pre-existing groundwater gradients, for example, changes groundwater levels, pressures or compositions of aquifers. A number of activities may affect the pressure gradients that control the direction and rate of groundwater transmission within different hydrostratigraphic layers, for example: pumping of the watertable to lower the groundwater level to enable open-cut coal mining; pumping of the target coal resource layer to allow underground mining; or depressurising a water-saturated target coal seam to induce desorption and subsequent extraction of CSG. Groundwater level or pressure is most commonly altered, but other gradients can also be changed via this process, such as temperature, density or chemical composition (water quality). This causal pathway group also includes conventional groundwater extraction from aquifers, which may be undertaken to supply water resources to support development and production activities associated with coal mining or CSG operations. However, the scale of these effects is typically much less than those associated with mine dewatering or CSG extraction.

B.2 'Subsurface physical flow paths' causal pathway group

This group of causal pathways involves physical modification of the rock mass or geological architecture by creating new physical paths that water may potentially infiltrate and flow along. Just because a new physical path is created does not necessarily mean that water will start flowing along it in preference to how it flowed before – it will still follow the path of least resistance, and be governed by pressure gradients. This causal pathway group can, however, potentially lead to direct hydraulic connection between the targeted coal resource layers and other hydrostratigraphic units (such as regional aquifers), by creating new zones of deformation in the rock mass. This may occur when the integrity of wells drilled for groundwater or gas extraction is compromised, or may occur due to hydraulic fracturing of coal seams. The cracking that occurs in the rock mass above underground longwall panels may also subsequently cause enhanced hydraulic connection, and potentially impact adjacent aquifers or aquitards in some circumstances. Propagation of these underground mining effects to the surface may also cause subsidence (as outlined in the surface water drainage causal pathway group below).

B.3 'Surface water drainage' causal pathway group

This group of causal pathways involves the physical disruption and disturbance of surface topography and near-surface materials (vegetation, topsoil, weathered rock). Such landscape changes can alter parameters such as the direction, volume and quality of surface flow over the landscape within the mine lease, and may reduce runoff to the stream network. Land surface subsidence caused by underground coal mining is an important example of this group. Surface disturbance can also lead to enhanced soil erosion rates, which can then affect surface water quality, for example, through increased stream sediment loads. This group of causal pathways typically starts with activities associated with development of the mine site area, coal seam gas well network and related infrastructure. It can include activities such as diverting water around operations areas with drains or walls, realigning part of a stream network to permit mining to occur, or clearing vegetation and soil to construct a drilling pad.

B.4 'Operational water management' causal pathway group

This group of causal pathways involves the modification of water management systems to facilitate sourcing, storing, using and disposing water at the coal resource development site. This is not a causal pathway of the natural hydrological system as such (as the other three are), but is associated with human-made water management rules, regulations and existing plans.

Table 7 Causal pathways in the 'Subsurface depressurisation and dewatering' causal pathway group

Causal pathway	Relevance[a] (open-cut coal mine, underground coal mine, coal seam gas operation)	Comments
Groundwater pumping enabling coal seam gas extraction	Coal seam gas operation	Intentional depressurisation of coal seams to reduce hydrostatic pressure and enable production of coal seam gas (and co-produced water)
Groundwater pumping enabling underground coal mining	Underground coal mine	Intentional dewatering of coal resource layers to reduce groundwater pressures below level of base of mining
Groundwater pumping enabling open-cut coal mining	Open-cut coal mine	Intentional dewatering to lower the watertable level so that open-cut mining operations may occur
Unplanned groundwater changes in non-target aquifers	Coal seam gas operation Underground coal mine Open-cut coal mine	Groundwater extraction for resource development may unintentionally affect groundwater variables and parameters such as pressure, flow paths and water quality in non-target layers, in situations where direct hydraulic connections exist. Such hydraulic connections may occur preferentially via geological structures such as faults, or more diffusely where direct stratigraphic contact exists between layers.
Groundwater pumping of target aquifer	Open-cut coal mine Underground coal mine Coal seam gas operation	Intentional extraction undertaken to supply water from a target aquifer, which is required for on-site development and production usage in the coal resource development operations (see also the 'operational water management' causal pathway group).

[a]Mine and coal seam gas operations are listed in relative order of importance.

Table 8 Causal pathways in the 'Subsurface physical flow paths' causal pathway group

Causal pathway	Relevance (open-cut coal mine, underground coal mine, coal seam gas operation)	Comments
Failure of well integrity	Coal seam gas operation Underground coal mine Open-cut coal mine	May create a direct fluid pathway between target formation and overlying aquifers, between the target formation and the surface, or between non-target formations. Additional to coal seam gas wells (main operation where this occurs), it can also include other types of boreholes, such as those drilled for coal exploration or groundwater extraction (though these generally have much smaller impacts compared to CSG extraction).
Hydraulic fracturing	Coal seam gas operation	Intentional activity undertaken to change properties of target coal seams (such as permeability) to enhance gas production. Will create additional lateral flow paths within the coal seam. Depending on in situ rock properties and stress regime, poorly managed hydraulic fracturing can also potentially create fracture pathways linking target coal seams with adjacent hydrostratigraphic units which, in some cases, may be aquifers. There is potential for affecting groundwater flow gradients and changing various water quality parameters, for example, through injecting hydraulic fracturing fluids.
Subsurface fracturing above underground longwall panels	Underground coal mine	Impacts most severe in fracture zone immediately above goaf, but may extend nearer to surface in the constrained deformation zone and laterally away from goaf into rib areas. Effects that propagate to the surface may result in subsidence (see Table 9).
Extracting overburden to access coal	Open-cut coal mine	May permanently alter hydraulic properties of near-surface aquifers, in cases where overburden is used to backfill mining pits. Impacts unlikely until dewatering has ceased and groundwater levels recover.

[a]Mine and coal seam gas operations are listed in relative order of importance.

Table 9 Causal pathways in the 'Surface water drainage' causal pathway group

Causal pathway	Relevance (open-cut coal mine, underground coal mine, coal seam gas operation)	Comments
Intercepting surface water runoff	Open-cut coal mine Underground coal mine Coal seam gas operation	Includes building diversion walls and drains to manage surface water flows around mining pits, operational areas and surface infrastructure
Altering surface water system	Open-cut coal mine Coal seam gas operation Underground coal mine	Diverting or realigning the pre-development surface water drainage, thereby changing the course and nature of the affected river and stream. Also includes other activities that can disrupt surface topography or structure, which may subsequently lead to enhanced erosion and impacts on surface water quality.
Subsidence of land surface	Underground coal mine Coal seam gas operation	Creates artificial topographic lows where surface water may pool and thereby reduce overall volume of inflow to surface water systems. Subsidence may also alter surface slopes which can then affect flow paths and rates of flow to stream network. The magnitude of ground surface subsidence caused by coal seam gas operations is generally significantly less than that caused by underground mining.

[a]Mine and coal seam gas operations are listed in relative order of importance.

Table 10 Causal pathways in the 'Operational water management' causal pathway group

Causal pathway	Relevance (open-cut coal mine, underground coal mine, coal seam gas operation)	Comments
Sourcing water for on-site operations	Open-cut coal mine Underground coal mine	Mining operations may require supplementary water for on-site activities, which may need to be extracted from a nearby river or pumped from groundwater bores. These activities may contribute to reduction in surface water flows, or groundwater drawdown in target aquifers.
Storing extracted water	Coal seam gas operation Open-cut coal mine Underground coal mine	Storing water in large holding dams and ponds may create a point source for leakage (unintentional outflow) which may reach surface water or groundwater systems. Some post-mining rehabilitation plans may involve creating a permanent artificial lake, which may act as groundwater sink.
Discharging extracted water into surface water system	Open-cut coal mine Underground coal mine Coal seam gas operation	This may be a regulated activity governed by specific conditions and rules, or (less commonly) may be unregulated, for example, due to severe flood inundation or dam engineering failure. May increase surface water flow volumes, or affect water quality.
Processing and using extracted water	Coal seam gas operation Open-cut coal mine Underground coal mine	Main impacts may relate to offsite use of co-produced coal seam gas water, for example, for irrigation of crops. Mine water may be reused on-site for various purposes, for example dust suppression, but will mostly be retained within area of operations.
Reinjecting co-produced water into aquifer	Coal seam gas operation	Potential water management option for some coal seam gas operations. Not all sites are amenable to this option, but if managed correctly can have beneficial impacts to reinjection aquifers, for example, by increasing groundwater pressures.

[a]Mine and coal seam gas operations are listed in relative order of importance.

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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

aquitard: a saturated geological unit that is less permeable than an aquifer, and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer.

artesian aquifer: an aquifer that has enough natural pressure to allow water in a bore to rise to the ground surface

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.

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

Clarence-Moreton bioregion: The Clarence-Moreton bioregion is located in north-east NSW and south-east Queensland and adjoins the Northern Inland Catchments bioregion. Along with the towns of Casino, Lismore and Grafton, it contains the outskirts of the Queensland cities of Brisbane, Ipswich, Logan and Toowoomba. The bioregion contains large river systems (including the Clarence, Richmond and Logan-Albert rivers) and extensive wetlands, some of which are nationally important. Many of these wetlands are home to water-dependent plants and animals that are listed as rare or threatened under Queensland and Commonwealth legislation. The bioregion contains numerous national parks and forest reserves and includes sites of international importance for bird conservation. A large area of the bioregion is used for dryland farming and plantations and as grazing land for livestock. Irrigated agriculture takes up a comparatively small area. Groundwater is extracted for various uses but most commonly for livestock and agricultural purposes. The largest water reservoir in this bioregion is Lake Wivenhoe on the Brisbane River, which supplies Brisbane and its surrounds. The NSW part of the bioregion has smaller dams located in the upper Richmond river basin.

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

confined aquifer: an aquifer saturated with confining layers of low-permeability rock or sediment both above and below it. It is under pressure so that when the aquifer is penetrated by a bore, the water will rise above the top of the aquifer.

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

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).

detection score: for the purposes of Impact Modes and Effects Analysis (IMEA), 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

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

discharge: water that moves from a groundwater body to the ground surface or surface water body (e.g. a river or lake)

diversion: see extraction

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 (ACRD). 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

geological formation: stratigraphic unit with distinct rock types, which is able to mapped at surface or in the subsurface, and which formed at a specific period of geological time

Gloucester subregion: The Gloucester subregion covers an area of about 348 km^2. The Gloucester subregion is defined by the geological Gloucester Basin. It is located just north of the Hunter Valley in NSW, approximately 85 km north-north-east of Newcastle and relative to regional centres is 60 km south-west of Taree and 55 km west of Forster.

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 recharge: replenishment of groundwater by natural infiltration of surface water (precipitation, runoff), or artificially via infiltration lakes or injection

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)

hazard priority number: for the purposes of Impact Modes and Effects Analysis (IMEA), one of two ranking systems that indicate the relative importance of a hazard. It is the sum of severity score, likelihood score and detection score.

hazard score: for the purposes of Impact Modes and Effects Analysis (IMEA), one of two ranking systems that indicate the relative importance of a hazard. It is the sum of the severity score and likelihood score.

Hunter subregion: Along the coast, the Hunter subregion extends north from the northern edge of Broken Bay on the New South Wales Central Coast to just north of Newcastle. The subregion is bordered in the west and north–west by the Great Dividing Range and in the north by the towns of Scone and Muswellbrook. The Hunter River is the major river in the subregion, rising in the Barrington Tops and Liverpool Ranges and draining south‑west to Lake Glenbawn before heading east where it enters the Tasman Sea at Newcastle. The subregion also includes smaller catchments along the central coast, including the Macquarie and Tuggerah lakes catchments.

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

inflow: surface water runoff and deep drainage to groundwater (groundwater recharge) and transfers into the water system (both surface water and groundwater) for a defined area

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.

life-cycle stage: one of five stages of operations in coal resource development considered as part of the Impact Modes and Effects Analysis (IMEA). For coal seam gas (CSG) operations these are exploration and appraisal, construction, production, work-over and decommissioning. For coal mines these are exploration and appraisal, development, production, closure and rehabilitation. Each life-cycle stage is further divided into components, which are further divided into activities.

likelihood: probability that something might happen

likelihood score: for the purposes of Impact Modes and Effects Analysis (IMEA), 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

material: pertinent or relevant

permeability: the measure of the ability of a rock, soil or sediment to yield or transmit a fluid. The magnitude of permeability depends largely on the porosity and the interconnectivity of pores and spaces in the ground.

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)

recharge: see groundwater recharge

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.

severity: magnitude of an impact

severity score: for the purposes of Impact Modes and Effects Analysis (IMEA), 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

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.

stratigraphy: stratified (layered) rocks

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)

subsidence: localised lowering of the land surface. It occurs when underground voids or cavities collapse, or when soil or geological formations (including coal seams, sandstone and other sedimentary strata) compact due to reduction in moisture content and pressure within the ground.

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

transparency: a key requirement for the Bioregional Assessment Programme, achieved by providing the methods and unencumbered models, data and software to the public so that experts outside of the Assessment team can understand how a bioregional assessment was undertaken and update it using different models, data or software 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.

unconfined aquifer: an aquifer whose upper water surface (watertable) is at atmospheric pressure and does not have a confining layer of low-permeability rock or sediment above it

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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