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

Receptor impact modelling for the Namoi subregion

Product 2.7 for the Namoi subregion from the Northern Inland Catchments Bioregional Assessment

2018

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

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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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ISBN-PDF 978-1-925315-44-8

Citation

Ickowicz A, Hosack G, Mitchell PJ, Dambacher J, Hayes KR, O'Grady AP, Henderson BL and Herron NF (2018) Receptor impact modelling for the Namoi subregion. Product 2.7 for the Namoi subregion from the Northern Inland Catchments Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NIC/NAM/2.7.

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Cover photograph

Gulligal Lagoon, which is located about halfway between Gunnedah and Boggabri on the western side of the Namoi River, NSW, 2005

Credit: Neal Foster

Australian Government

Department of the Environment and Energy

Bureau of Meteorology

Geoscience Australia

CSIRO

v20180628

Executive summary

This product details the development of qualitative mathematical models and receptor impact models for the Namoi subregion. Receptor impact models enable the Bioregional Assessment team to assess how changes in hydrology due to additional coal resource development may result in changes in ecosystems.

A receptor impact model describes the relationship between:

- one or more hydrological response variables, which represent characteristics of surface water and groundwater that potentially change due to coal resource development (for example, drawdown or annual flow volume) and
- a receptor impact variable, which is a characteristic of the system (for example, projected foliage cover) that, according to the conceptual modelling, is potentially sensitive to changes in the hydrological response variables.

The outputs of the receptor impact models will help identify ecosystem responses to coal resource development and the need for further local-level studies of ecosystems and their response to coal resource development.

Coal resource developments

Receptor impact modelling for the Namoi subregion applies the two potential coal resource development futures considered in the bioregional assessments:

- *baseline coal resource development (baseline)*: a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as at December 2012
  - in the Namoi subregion there are five open-cut coal mines: Boggabri Coal Mine, Rocglen Mine, Sunnyside Mine, Tarrawonga Mine and Werris Creek Mine; and one longwall mine: Narrabri North.
- *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
  - in the Namoi subregion there are ten additional coal resource developments: Boggabri Coal Expansion Project, Caroona Coal Project, Gunnedah Precinct, Maules Creek Project, Narrabri South, Tarrawonga Coal Expansion Project, Vickery Coal Project, Vickery South Coal Project, Watermark and the Narrabri Gas Project. Eight of these additional coal resource developments are modelled for the Namoi subregion, with the remaining two mines, Vickery South Coal Project (open-cut coal mine) and the Gunnedah Precinct (open-cut and underground), not being modelled due to insufficient information. Analysis of the impacts of these two developments will be restricted to commentary in product 3-4 (impact and risk analysis).

The difference in results between CRDP and baseline is the change that is primarily reported in a bioregional assessment. This change is due to additional coal resource development.

Potential hydrological changes have been presented in companion product 2.6.1 (surface water modelling) and companion product 2.6.2 (groundwater modelling) for the Namoi subregion. This product outlines the development and description of the qualitative mathematical models and receptor impact models for the Namoi subregion that will be applied to determining risk to, and potential impacts on, ecosystems in product 3-4 (impact and risk analysis).

Methods

Receptor impact model development is both qualitative and quantitative due to the complexity and uncertainty associated with describing relationships between hydrological change and ecological components of the system. The absence of directly relevant theory and ecological response data of potential impacts due to the hydrological changes that may occur in the future requires expert judgement or elicitation to be used in: i) mapping ecological processes and key components (as signed digraphs); ii) constructing qualitative models that predict – as an increase, decrease or no change – landscape class response to hydrological change; and iii) selection of ecological indicators (receptor impact variables) from the ecological components or processes and the hydrological regimes (hydrological response variables) that support them. The resulting statistical models quantify how changes in hydrological response variables due to coal resource development may potentially impact the receptor impact variables in a short-term (2013 to 2042) and long-term (2073 to 2102) period within a landscape class.

Ecosystems

The Namoi subregion supports a variety of ecosystems and in this bioregional assessment they are classified into 29 landscape classes and allocated to one of six landscape groups: ‘Floodplain or lowland riverine’, ‘Non-floodplain or upland riverine’, ‘Dryland remnant vegetation’, ‘Rainforest’, ‘Human-modified’ and ‘Springs’.

Qualitative mathematical models and receptor impact models use these classifications to investigate how changes in hydrology may affect ecosystems. Results that apply the receptor impact models and the potential impact of hydrological changes spatially are reported in Sections 3.4.3.3, 3.4.4.3 and 3.4.5.3 of the impact and risk analysis in companion product 3-4 for the Namoi subregion.

Two modelling workshops were held to build the qualitative mathematical models and receptor impact models and required input from experts in these landscapes and/or the Namoi subregion. Receptor impact models were developed for landscape classes that experts considered more likely to be at risk from hydrological changes due to additional coal resource development, and for which they had the expertise to inform model development. Commentary on those landscape groups and classes that were not included in the ecosystem modelling is provided in Sections 2.7.3, 2.7.4, 2.7.5, 2.7.6 and 2.7.7.

'Floodplain or lowland riverine' landscape group

The floodplain and lowland riverine landscape classes contain a collection of landscape and ecological elements exposed to inundation or flooding along a river system including: riparian forests, wetlands and grassy woodlands. The floodplain and lowland riverine qualitative model was developed to capture most of the key linkages within and between the riverine and floodplain habitats. This model informed the receptor impact variables (in bold) and hydrological response variables for the following landscape classes:

- Floodplain riparian forests (groundwater-dependent ecosystem (GDE) and non-GDE) landscape classes: change in projected foliage cover in response to change in groundwater drawdown and change in the frequency of overbank flows
- Floodplain wetland (GDE and non-GDE) landscape classes: probability of presence of tadpoles from *Limnodynastes* genus in pools and riffles in response to change in the frequency of overbank flows
- Permanent and temporary lowland streams (GDE and non-GDE) landscape classes: average number of families of aquatic macroinvertebrates in edge habitat in response to changes in cease-to-flow attributes of the surface water regime.

Results from these three separate receptor impact models were used to evaluate the combined impact of changes in one or more of these receptor impact variables across the extent of the 'Floodplain or lowland riverine' landscape group (Section 2.7.3.1.4).

The floodplain riparian forests receptor impact model predicts that, in relation to groundwater changes, the mean of the average percent projected foliage cover will drop from just under 15% with no change in groundwater level to about 10% if levels decrease by 20 m relative to the reference level in 2012 due to additional coal resource development. A change in drawdown over the longer term will have a larger effect on mean projected foliage cover than a change in drawdown over the short term, indicating that potential impacts from changes in hydrology may not be immediate.

In relation to surface water changes, the mean of the average percent foliage cover will increase from just under 12% with no change in the frequency of overbank events to about 18% if the frequency changes to 0.7 (event per year) (relative to the reference level of 0.33 (event per year) in 2012).

The floodplain wetlands receptor impact model supports the experts' elicited hypothesis that an increase in overbank flows will have a positive effect on the probability of presence of tadpoles. The model predicts that the probability of presence of tadpoles is fairly uncertain across the floodplain wetland landscape classes with values between 0.35 to 0.80 under historical conditions, and as the number of overbank flow events increases the probability of presence of tadpoles would increase to between 1 and 0.60.

The lowland riverine receptor impact model supports the experts' elicited hypothesis that an increase in the frequency of zero-flow days due to additional coal resource development will have a negative effect on the number of families of macroinvertebrates. As the number of zero-flow days increases, the number of families would drop steeply, with values of less than 0.5 under intermittent flow conditions.

'Non-floodplain or upland riverine' landscape group

The 'Non-floodplain or upland riverine' landscape group comprises ecosystems that tend to be in elevated portions of the catchment and include a diverse range of aquatic and terrestrial ecosystems. The upland riverine qualitative mathematical model included all upland riverine classes and the adjacent riparian vegetation, and was developed to accommodate the general lack of hydrological and spatial connectivity between the landscape classes across the zone of potential hydrological change. Receptor impact variables (in bold) and hydrological response variables were identified for the following landscape classes:

- Upland riparian forest GDE: change in projected foliage cover in response to changes in groundwater drawdown and overbank flow events
- Permanent and temporary upland streams (GDE and non-GDE) landscape classes: average number of families of aquatic macroinvertebrates in instream pool habitat in response to changes in cease-to-flow attributes of the surface water regime
- Upland riverine landscape classes: probability of presence of tadpoles from *Limnodynastes* genus in pools and riffles in response to changes in cease-to-flow attributes of the surface water regime.

Results from these three separate receptor impact models were used to evaluate the combined impact of changes in one or more of these receptor impact variables across the extent of the 'Non-floodplain or upland riverine' landscape group (Section 2.7.4.1.4).

The upland riparian forest receptor impact model predicts that the mean of the average projected foliage cover will decrease with the maximum difference in additional drawdown relative to the reference level in 2012. However, there is considerable uncertainty in these predictions as there is an 80% chance that the average foliage cover will lie somewhere between approximately 15% and 30% in the short-assessment period, and somewhere between roughly 10% and 30% in the long-assessment period, with a 6-m drop in groundwater level. The model interpretation also indicates that long-term drawdown will have more effect on projected foliage cover than short-term drawdown.

In relation to change in overbank flows, the upland riparian forest model predicts that the mean of the average of projected foliage cover will increase from just under 24% with no change to about 30% if the frequency increases to 0.8 (event per year) (relative to the reference level of 0.33 (event per year) in 2012.

The upland riverine receptor impact model supports the experts' elicited hypothesis that an increase in the frequency of zero-flow days due to additional coal resource development will have a negative effect on the number of families of macroinvertebrates. However, there is substantial variability across the landscape class. Under conditions of constant flow the number of families of macroinvertebrates can range from less than 5 (families) to almost 20. As the number of zero-flow days increases, experts were of the opinion that the number of families would drop quite dramatically to less than 0.5.

The upland riverine receptor impact model predicts that the probability of presence of tadpoles will respond to changes in frequency of zero-flow days due to additional coal resource development. Under conditions of constant flow the probability of presence of tadpoles is predicted to be almost 1 and as the number of zero-flow days increases this may decrease to less than 0.1.

In addition to the upland riverine system, a qualitative model was developed for the non-floodplain wetlands in this landscape group and focused on internally draining lakes in the Namoi assessment extent, with the Lake Goran ecosystem being the primary focus, but also including Yarrie Lake (both defined as 'Non-floodplain wetland' landscape class). A receptor impact model was not developed for this landscape group. Qualitative analyses generally indicate a negative or ambiguous response prediction for most biological variables within the non-permanent wetland ecosystem in response to hydrological changes. Tree and shrub groups were predicted to decline, which leads to negative impacts to habitats for birds, frogs and terrestrial invertebrates. A predicted decrease in wading birds and piscivorous and insectivorous birds leads to a release, or increase, in their prey populations. The potential impact of decreased sheet flow is predicted to lead to a decrease in all forms of aquatic macrophytes and herbivorous birds.

Pilliga (upland and lowland) region

The Pilliga and Pilliga Outwash represent a unique set of ecological systems within the Namoi subregion. It was considered appropriate to develop a set of separate ecological models for the Pilliga to improve the assessment of potential ecological impacts. The zone of potential hydrological change for the Pilliga region included riverine landscape classes (9.8% of upland streams and 13.1% of lowland streams), the 'Grassy woodland GDE' landscape class (8% of the zone), and the non-floodplain wetlands landscape classes (<0.2% of the zone). Key ecological processes in both upland and lowland riverine landscape classes were captured together in the Pilliga riverine qualitative mathematical model. A qualitative model for the 'Grassy woodland GDE' landscape class was also formulated, but no quantitative modelling was developed as it is considered less sensitive to hydrological change given its reduced reliance on groundwater and surface water (see Section 2.7.3).

The riverine classes in the Pilliga region have a unique set of conditions such as: sandy beds, temporary flow with some permanent pools above highly stratified sandstone, and channels that often form shallow and poorly defined ephemeral wetlands. Receptor impact variables (in bold) and hydrological response variables were identified for the following ecosystems:

- Pilliga riverine (upland and lowland): change in projected foliage cover in response to changes in cease-to-flow attributes and groundwater drawdown
- Pilliga riverine (upland and lowland): average number of families of slow-water macroinvertebrates in instream pool habitat in response to changes in cease-to-flow attributes and groundwater drawdown.

The receptor impact modelling for the Pilliga region defines impacts on riverine landscape classes based on changes in these receptors according to defined thresholds (see Table 37 and Table 38).

The Pilliga riverine receptor impact model predicts that percent foliage cover will decrease as groundwater drawdown increases due to additional coal resource development. The mean of the average percent projected foliage cover will decrease from just below 25% with no change in groundwater level, to about 20% if the levels decrease by 150 m relative to the reference level in 2012. In relation to surface water changes due to additional coal resource development, the model predicts that the mean of the average percent projected foliage cover will decrease from just under 25% under constant flow to about 10% if the number of zero-flow days increases to 180 (days per year).

In relation to number of families of aquatic macroinvertebrates, the Pilliga riverine receptor impact model predicts that an increase in zero-flow days and/or cease-to-flow days will have a slightly negative effect but will vary across landscape classes. Under conditions of constant flow, the number of families of macroinvertebrates will range from 15 (families) to 20 and as the number of zero-flow days increases the number of families would decrease with values between 13 and less than 10 for very intermittent flow conditions (zero-flow days of greater than 150).

The model predicts that the number of families of macroinvertebrates will decrease as groundwater drawdown increases due to additional coal resource development. Under conditions of no change in groundwater level, the number of families is predicted to be just under 12, decreasing to about 6 if levels decrease by 55 m relative to the reference level in 2012.

'Rainforest' landscape group

The 'Rainforest' landscape group is distinguished primarily by its vegetation structure and composition and is predominately 'Dry Rainforest' or 'Western Vine Thickets' (both threatened vegetation classes in NSW). 4 km^2 of the 'Rainforest' landscape class and 0.3 km^2 of the 'Rainforest GDE' landscape class are within the zone of potential hydrological change. A qualitative model was developed for this landscape group given the conservation values surrounding the vegetation types common to this group. This model identified groundwater as being critical to supporting many biophysical components of the ecosystem (Section 2.7.6.2). Given the limited resources and the limited extent of this landscape group in the zone, a receptor impact model was not formulated. Thus, potential ecological impacts are not quantified, but can be inferred from modelled changes in groundwater drawdown across this landscape group.

'Springs' landscape group

The 'Springs' landscape group is comprised of two landscape classes: 'Great Artesian Basin (GAB) springs' and 'Non-GAB springs' denoting the hydrological connectivity of the spring to the underlying aquifer. The 'GAB springs' landscape class is associated with sedimentary sequences of the GAB and can be characterised as 'discharge' or 'recharge' springs.

Two of the seven 'GAB springs' in the Namoi assessment extent are located within the zone of potential hydrological change. Given their location on the eastern edge of the Pilliga region, these springs were considered to be 'recharge' springs; that is, their source of water is from localised recharge from nearby sandstone outcrop areas. A qualitative mathematical model was formulated for a typical recharge GAB spring that included the associated terrestrial and aquatic ecosystems. This model identified groundwater drawdown as the critical variable driving ecological function in this system (Section 2.7.7.2). Given the nature of these springs and their limited extent in the zone of potential hydrological change, a receptor impact model was not formulated for this group. Any changes in groundwater drawdown across the extent of these springs can be used to infer potential ecological impacts, however these cannot be quantified.

Limitations and gaps

The limitations and gaps surrounding evaluation of ecosystem responses to changes in surface water and groundwater regimes are discussed. It emphasises that the degree to which ecological modelling can inform impacts across the extent of a particular landscape class is limited by the available expertise, the evidence base that informs the model, and the coverage of hydrological modelling, particularly with respect to the surface water. Some specific limitations include:

- a limited understanding of the nature of groundwater interactions between riverine and terrestrial ecosystems for the Pilliga region; a more complete picture of the hydrological connections among the Pilliga riverine, vegetation and wetland elements is considered a key priority for future work
- a paucity of surface water hydrological response information for the upland riverine reaches and very little coverage of the entire stream network in the Pilliga region
- the degree to which species within the 'Rainforest' landscape group access groundwater given that this habitat occurs in elevated parts of the Namoi subregion.

The receptor impact modelling described in this product culminates with the creation of receptor impact models (functions) that are subsequently applied in product 3-4 (impact and risk analysis) for the Namoi subregion, and result in risk predictions that translate the potential hydrological change to indicators of potential ecosystem change.

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Acknowledgements

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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 is 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, has undertaken 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.

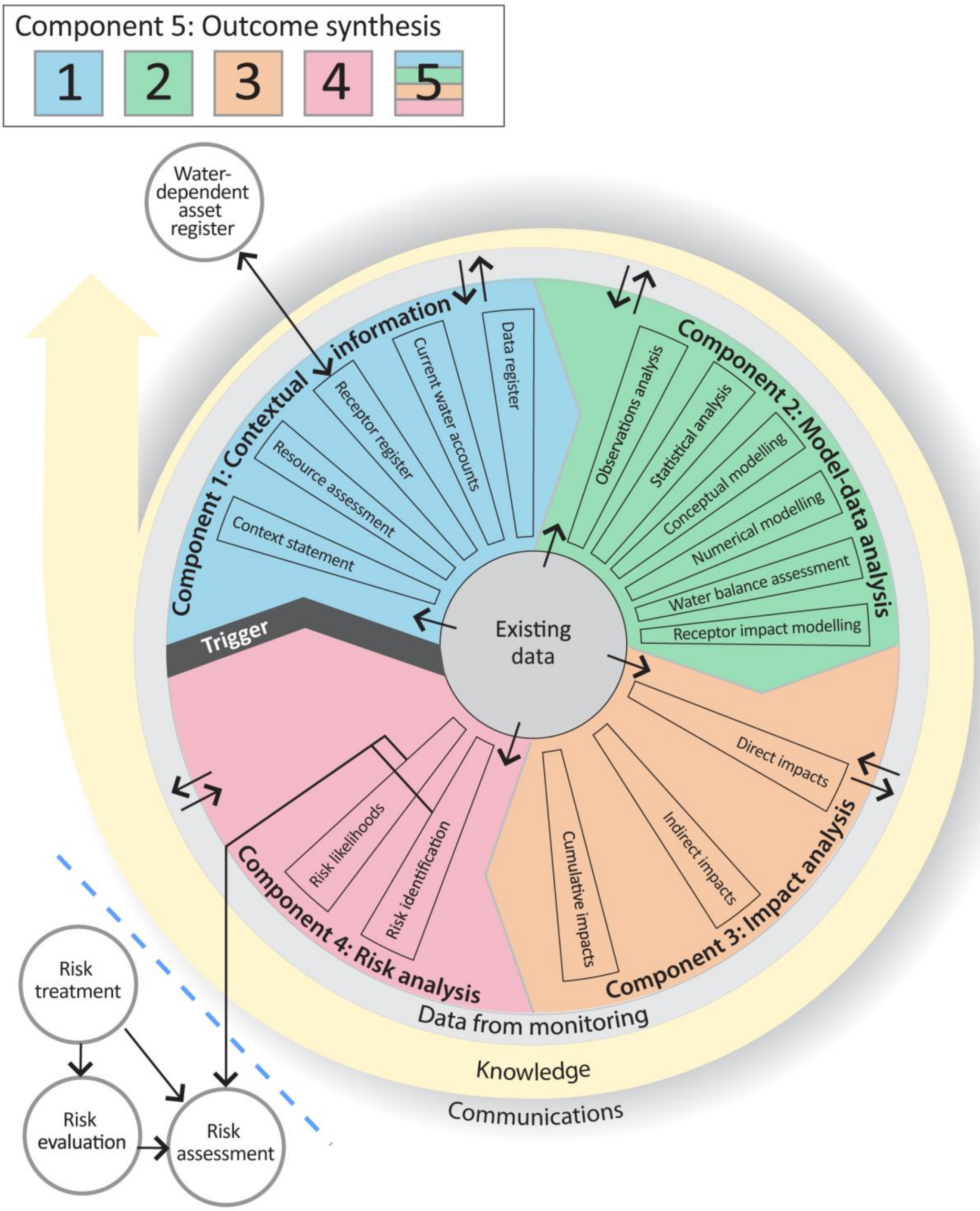

Figure 1 Schematic diagram of the bioregional assessment methodology

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 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), in the first instance, to 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.

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.

Table 1 Methodologies

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

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

Technical products

The outputs of the BAs include a suite of technical products presenting information about the ecology, hydrology, hydrogeology and geology of a 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 information included in the technical products is specified in the BA methodology. 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. The red outlines in both Figure 2 and Table 2 indicate the information included in this technical product.

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.

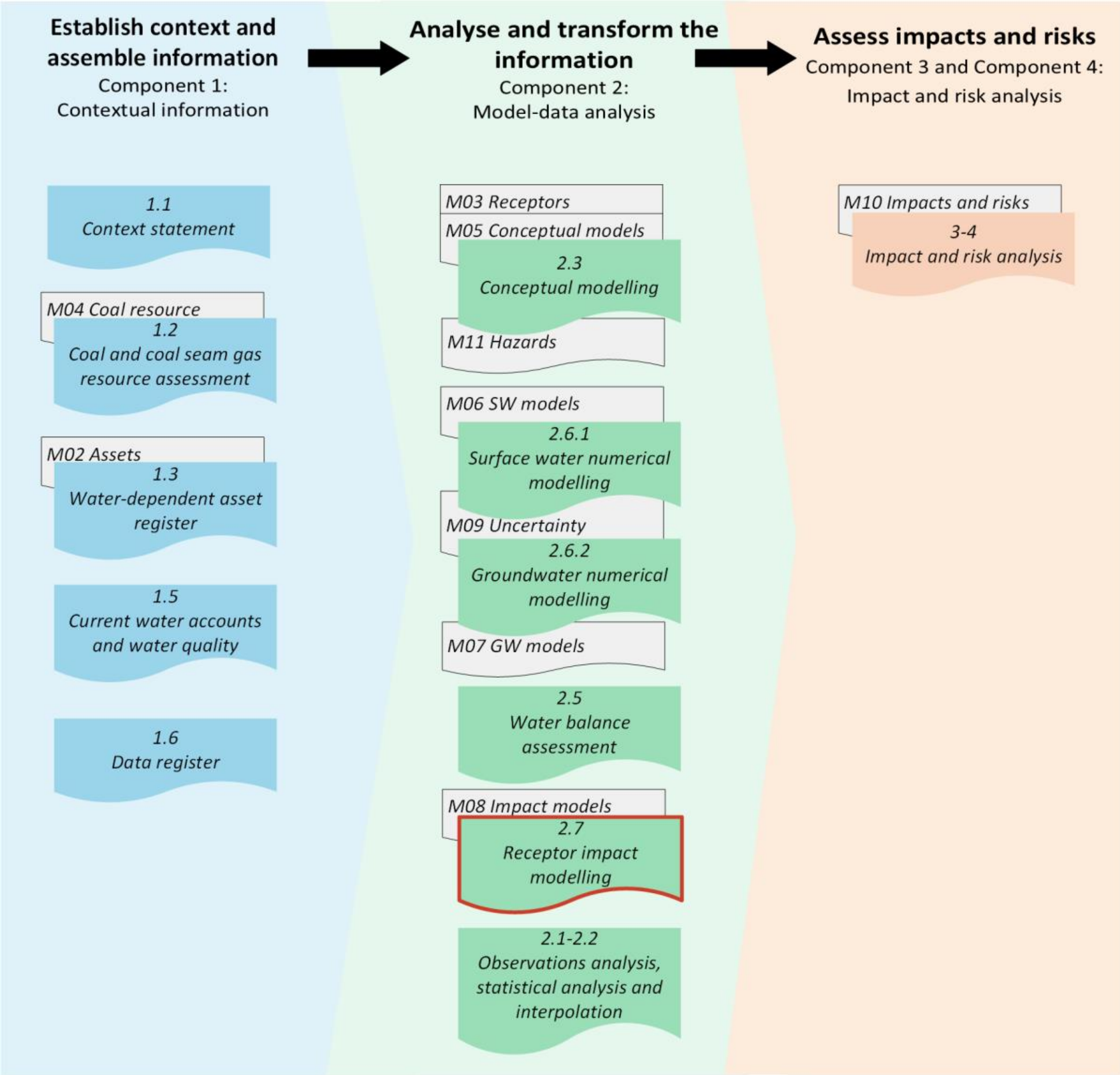

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

In each component (Figure 1) of a bioregional assessment, 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 technical product. The BA methodology (Barrett et al., 2013) specifies the overall approach.

Table 2 Technical products delivered for the Namoi subregion

For each subregion in the Northern Inland Catchments Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' column[a]. Other products – such as datasets, metadata, data visualisation and factsheets – are 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 product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical 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[b]	Type[a]
Component 1: Contextual information for the Namoi subregion	1.1	Context statement	2.5.1.1, 3.2	PDF, HTML
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	PDF, HTML
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.5	Current water accounts and water quality	2.5.1.5	PDF, HTML
	1.6	Data register	2.5.1.6	Register
Component 2: Model-data analysis for the Namoi subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	PDF, HTML
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	PDF, HTML
	2.6.1	Surface water numerical modelling	4.4	PDF, HTML
	2.6.2	Groundwater numerical modelling	4.4	PDF, HTML
	2.7	Receptor impact modelling	2.5.2.6, 4.5	PDF, HTML
Component 3 and Component 4: Impact and risk analysis for the Namoi subregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	PDF, HTML
Component 5: Outcome synthesis for the Namoi subregion	5	Outcome synthesis	2.5.5	PDF, HTML

[a]The types of products are as follows:
- 'PDF' indicates a PDF document that is developed by the Northern Inland Catchments Bioregional Assessment using the structure, standards and format specified by the Programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.

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

About this technical product

The following notes are relevant only for this technical product.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 151.0° East for the Northern Inland Catchments bioregion and two standard parallels of –18.0° and –36.0°.
- Visit http://www.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 product. 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 published date. Where the published date is not available, the last updated date or created date is used. For Bioregional Assessment Derived Datasets, the created date is used.

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 28 June 2018, 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 28 June 2018, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

2.7 Receptor impact modelling for the Namoi subregion

This product presents receptor impact modelling for the Namoi subregion using results from the model-data analysis (Component 2). Receptor impact models translate predicted changes in hydrology into the distribution of ecological outcomes that may arise from those changes. They perform an essential role in quantifying the potential impact on and risk to water-dependent ecosystems and assets due to coal resource development.

A receptor impact model predicts the relationship between:

- one or more hydrological response variables (hydrological characteristics of the system that potentially change due to coal resource development – for example, maximum groundwater drawdown due to additional coal resource development), and
- a 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, annual mean percent canopy cover of woody riparian vegetation).

Receptor impact models in a bioregion or subregion are developed for a landscape class, which is defined for bioregional assessment (BA) purposes as an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Only those landscape classes that fall within the zone of potential hydrological change are candidates for receptor impact models. Receptor impact variables are chosen as indicators of potential ecosystem change for landscape classes to simplify the analysis for a large number of assets and complexity of ecosystems across the subregion. An assessment of potential impact for a water-dependent asset, which is reported in the impact and risk analysis (product 3-4), considers the intersection of that asset with landscape classes, and the predictions of changes in receptor impact variables for those landscape classes, amongst other lines of evidence.

In receptor impact modelling the critical change is the difference between average groundwater and surface water conditions in the reference period (1983 to 2012), and their predicted average conditions under the baseline future and under the coal resource development pathway (CRDP) future.

BAs also consider impact on, and risk to, economic and sociocultural water-dependent assets; however, receptor impact models are not constructed for these assets. Potential impacts on water-dependent economic assets are assessed through availability of groundwater or surface water and against specific management thresholds, such as cease-to-pump flow rates and drawdown depths at which 'make good' provisions might apply. The assessment of potential impacts on sociocultural assets is limited to characterising the hydrological changes that may be experienced by those assets in the impact and risk analysis (product 3-4).

It is important to recognise that receptor impact model interpretation is often presented as statements that are a simple summary of the (often more complicated) relationship between a receptor impact variable and hydrological response variables. They are not impact or risk predictions for the Namoi subregion, which are presented in product 3-4 (impact and risk analysis), and should always be considered alongside other indicators of potential change.

2.7.1 Methods

Summary

This section details the specific application to the Namoi subregion of methods described in companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018).

In bioregional assessments (BAs), receptor impact models are intended to characterise potential ecosystem changes that may result from hydrological changes predicted in response to coal resource development. A receptor impact model is constructed for one or more landscape classes. A landscape class represents ecosystems with similar water dependencies that are expected to respond similarly to changes in groundwater and/or surface water. Only landscape classes that intersect the zone of potential hydrological change are considered to be candidates for receptor impact models. Outside the zone, hydrological changes are considered too unlikely to result in adverse impacts to water-dependent ecosystems.

The potential impacts of coal resource development on ecological assets are initially assessed using qualitative mathematical models. These models are elicited from independent experts and contain key components and processes of the landscape class ecosystems, and the hydrological variables that support them. They are then used to qualitatively predict (reported as increase, decrease or no change) how the landscape class ecosystem will respond to changes in hydrology that may occur as a result of coal resource development.

The receptor impact modelling process continues with selection of receptor impact variables from the ecological components or processes identified in the qualitative mathematical model and hydrological response variables to represent the hydrological regimes that support these components or processes. Thus the landscape classification and qualitative mathematical models form the bases for elicitations to quantify potential changes in receptor impact variables in response to changes in hydrological response variables.

The elicitation allows the BA team to construct a statistical model that predicts how changes in the hydrological response variables due to coal resource development will impact the receptor impact variables. Within a landscape class, this statistical model enables the BA team to quantify the risk to ecological assets of coal resource development using predicted changes in hydrological response variables in a short-term (2013 to 2042) and long-term (2073 to 2102) period.

The receptor impact models predict the distribution function of the receptor impact variables for different futures (baseline and coal resource development pathway) and at specific assessment years (2042 and 2102). The distribution functions are summarised in BAs by a limited series of percentiles (or quantiles), nominally 5% increments between the 5th and 95th percentiles.

2.7.1.1 Background and context

Receptor impact modelling attempts to capture the direct, indirect and cumulative impacts of coal seam gas (CSG) and coal mining development on the ecosystems within the defined landscape classes. The aim of receptor impact modelling is to convert the potentially abstract information about hydrological changes into quantities (risk assessment endpoints) that stakeholders care about and can more readily understand and interpret. In particular, the model outcomes are anticipated to relate more closely to stakeholders' values and beliefs and therefore support community discussion and decision making about acceptable levels of development.

The causal pathways that describe how coal resource development can potentially lead to changes in hydrology are identified in companion product 2.3 for the Namoi subregion (Herr et al., 2018b). The receptor impact models represent the subsequent pathways, which relate changes in hydrological response variables to potential impacts on water-dependent landscape classes and assets within the zone of potential hydrological change.

To better understand the potential impacts of coal resource development on water resources and water-dependent assets such as wetlands and groundwater bores, receptor impact modelling for BAs deals with two potential futures:

- *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. In receptor impact modelling, however, the critical change is the difference between average groundwater and surface water conditions in the reference period (1983 to 2012), and their predicted average conditions under the baseline and the CRDP in the short term (2013 to 2042) and longer term (2073 to 2102).

This product presents the receptor impact modelling for the Namoi subregion. The modelling is described in detail in the companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018). Section 2.7.1.2 of this document describes how this methodology is applied to the Namoi subregion.

The following terms are used throughout the receptor impact model products to describe the modelling process and its results:

- *hydrological response variable* – a hydrological characteristic of the system (for example, drawdown or the annual flow volume) that potentially changes due to coal resource development (see companion submethodology M07 (as listed in Table 1) on groundwater modelling (Crosbie et al., 2016) and companion submethodology M06 (as listed in Table 1) on surface water modelling (Viney, 2016))

- *receptor impact variable* – a characteristic of the system that, according to the conceptual modelling, potentially changes due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums)
- *receptor impact model* – a receptor impact model predicts a relationship between a receptor impact variable (for example, annual mean percent canopy cover of woody riparian vegetation), and one or more hydrological response variables (for example, *dmax*, maximum groundwater drawdown due to additional coal resource development).

2.7.1.2 Receptor impact modelling for ecological water-dependent assets

In BA, receptor impact models for ecological water-dependent assets are conditioned upon, and therefore depend on, *landscape classes*. A landscape class is defined as an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Each bioregion or subregion has multiple landscape classes grouped into landscape groups.

The workflow for ecological receptor impact modelling is outlined in Figure 3. Input from independent external ecology experts contributes to the workflow at three separate stages (2, 3 and 5 in Figure 3), along with output from hydrological modelling (companion product 2.6.1 (Aryal et al., 2018) and companion product 2.6.2 (Janardhanan et al., 2018) for the Namoi subregion) and the expertise of the hydrology modellers. External experts, hydrologists and risk analysts contribute to the selection of hydrological response variables that are ecologically meaningful and also accessible to hydrological modelling. The expert elicitation data are available as a downloadable dataset from data.gov.au.

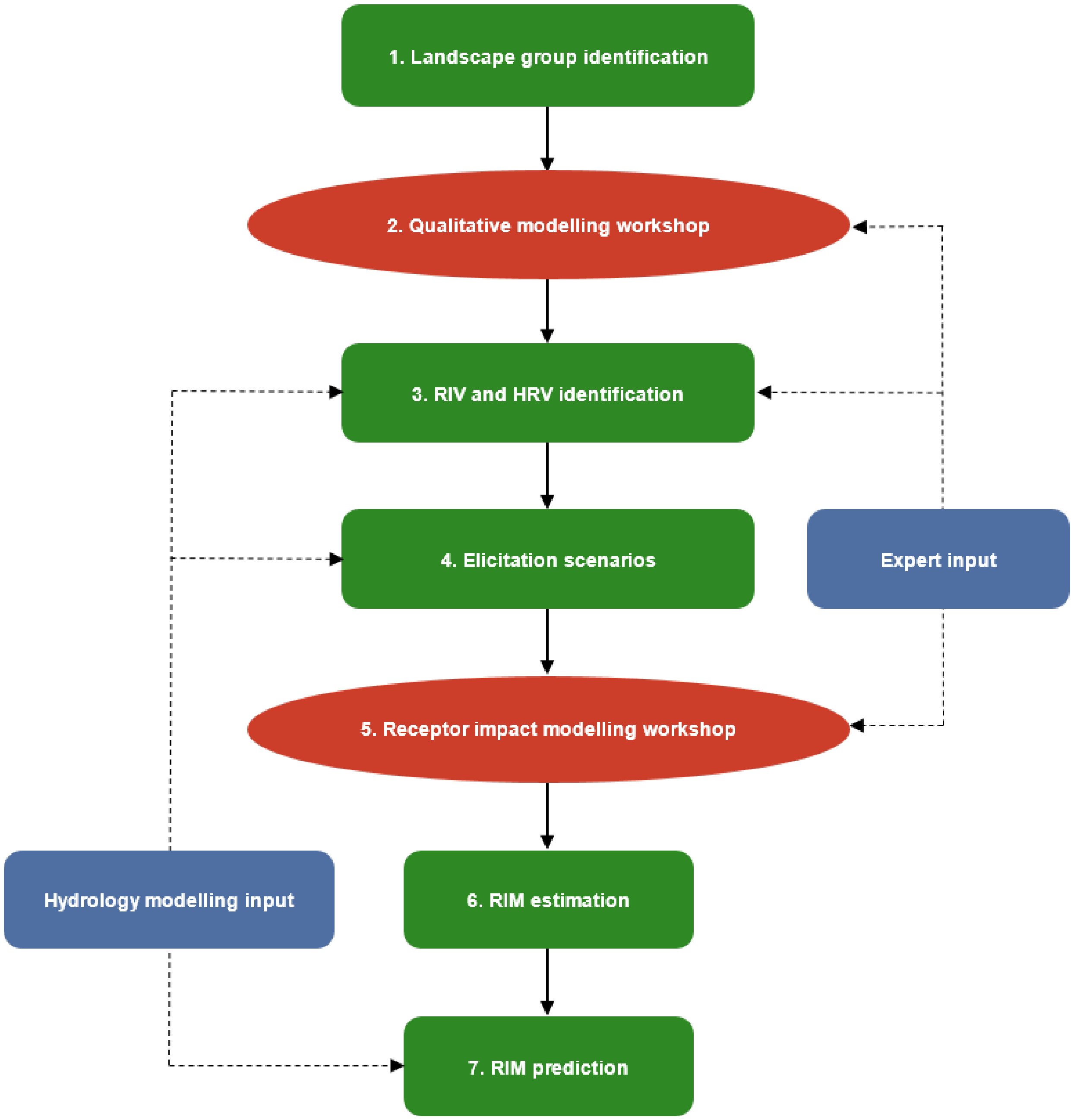

Figure 3 Outline of the ecological receptor impact workflow identifying (by stage) the contributions of external independent ecology experts, groundwater hydrology modelling and surface water hydrology modelling for the Namoi subregion

In this figure the green boxes represent specific stages undertaken by the Assessment team in the overall receptor impact modelling process, the red boxes are the two external workshops and the blue boxes are external expert or modelling inputs. HRV = hydrological response variable, RIM = receptor impact model, RIV = receptor impact variable

The workflow shown in Figure 3 leads to the construction of a receptor impact model that predicts the response of a receptor impact variable to changes in hydrological response variables. The receptor impact models propagate the uncertainty in: (i) the effect of coal resource development on the hydrological response variables under the baseline and CRDP; and, (ii) the uncertainty in the receptor impact variable response to these hydrological changes across a landscape class.

2.7.1.2.1 Identification of landscape classes that are potentially impacted

BAs identify landscape classes (Stage 1 in Figure 3) that could be impacted by coal resource development as those landscape classes that lie wholly or partially within the zone of potential hydrological change. The zone of potential hydrological change is defined as the union of the groundwater and surface water zones of potential hydrological change. The groundwater zone of potential hydrological change is defined as the area with a greater than 5% chance of exceeding 0.2 m of drawdown in the relevant aquifers (see companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018)). In the BA for the Namoi subregion, the relevant aquifer is the regional watertable.

The surface water zone of potential hydrological change is defined in a similar manner. The area contains those river reaches where a change in at least one of nine surface water hydrological response variables exceeds its specified threshold. For the four flux-based hydrological response variables – annual flow (AF), daily flow rate at the 99th percentile (P99), interquartile range (IQR) and daily flow rate at the 1st percentile (P01) – the threshold is a 5% chance of a 1% change in the variable, with an additional threshold specified for P01 (see Table 4 in companion product 3-4 for the Namoi subregion (Herr et al., 2018a)). That is, if 5% or more of model runs show a maximum change in results under CRDP of 1% relative to baseline. For four of the frequency-based hydrological response variables – high-flow days (FD), low-flow days (LFD), length of low-flow spell (LLFS) and zero-flow days (ZFD) – the threshold is a 5% chance of a change of three days per year. For the final frequency-based hydrological response variable (low-flow spells, LFS), the threshold is a 5% chance that the maximum difference in the number of low flow spells between the baseline and CRDP futures is at least two spells per year (companion submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016)).

It is important to recognise that the zone of potential hydrological change identifies those parts of the landscape where there is at least a 5% chance of a small (as defined by hydrological thresholds used) hydrological change attributable to coal resource development. The zone serves only to identify those landscape classes that should be taken to the next step of the receptor impact methodology from those landscape classes that should not, on the grounds that the latter are predicted to experience negligible (or insignificant) exposure to hydrological change due to coal resource development.

2.7.1.2.2 Qualitative mathematical modelling of landscape classes

BAs use qualitative mathematical models to describe landscape class ecosystems, and to predict (qualitatively) how coal resource development will directly and indirectly affect these ecosystems. Qualitative mathematical models were constructed in dedicated workshops, attended by experts familiar with these landscapes and/or the Namoi subregion (Table 3; Stage 2 in Figure 3). In the workshop, ecological and hydrological experts were asked to describe how the key species and/or functional groups within the landscape class ecosystem interact with each other, and to identify the principal physical processes that mediate or otherwise influence these interactions. During this process the experts were also asked to identify how key hydrological processes support the ecological components and processes of the landscape class. The experts' responses were formally translated into qualitative mathematical models which enable the BA team to identify critical relationships and variables that will become the focus of the quantitative receptor impact models.

Table 3 List of organisations with experts participating in the Namoi subregion qualitative mathematical modelling (QMM) and receptor impact modelling (RIM) workshops

Organisation	Number of experts
Consultant ecologist	3
Department of the Environment and Energy	1
Eco Logical Australia	3
Macquarie University	3
NSW Department of Primary Industries	2
NSW Office of Environment and Heritage	1
University of New England	2
University of Newcastle	1

Qualitative modelling proceeds from the construction and analysis of sign-directed graphs, or signed digraphs, which are depictions of the variables and interactions of a system. These digraphs are only concerned with the sign (+, –, 0) of the direct effects that link variables. For instance, the signed digraph in Figure 4 depicts a straight-chain system with a basal resource (R), consumer (C) and predator (P). There are two predator-prey relationships, where the predator receives a positive direct effect (i.e. nutrition, shown as a link ending in an arrow (→)), and the prey receives a negative direct effect (i.e. mortality, shown as a link ending in a filled circle (─•)). The signed digraph also depicts self-effects, such as density-dependent growth, as links that start and end in the same variable. In the example in Figure 4 these self-effects are negative.

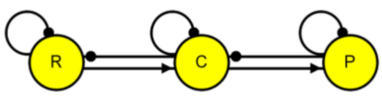

Figure 4 Signed digraph depicting a straight-chain system with a basal resource (R), consumer (C) and predator (P)

The structure of a signed digraph provides a basis to predict the stability of the system that it portrays, and also allows the analyst to predict the direction of change of all the model's variables (i.e. increase, decrease, no change) following a sustained change to one (or more) of its variables. The signed digraph in Figure 4, for example, is stable because: (i) it only has negative feedback cycles, (ii) the paths leading from the predators to their prey and back to the predator are negative feedback cycles of length two, and (iii) there are no positive (destabilising) cycles in the system. This model therefore predicts that if this system were to experience a sudden disturbance it would be expected to return relatively quickly to its previous state or equilibrium.

The predicted direction of change of the variables within a signed digraph to a sustained change in one or more of its variables is determined by the balance of positive and negative effects through all paths in the model that are perturbed. Consider, for example, a pressure to the system depicted in Figure 4 that somehow supplements the food available to the predator P causing it to increase its reproductive capacity. The predicted response of C is determined by the sign of the link leading from P to C, which is negative (denoted as P ─• C). The predicted response of R will be positive because there are two negative links in the path from P to R (P ─• C ─• R), and their sign product is positive (i.e. – x – = +).

In the system depicted in Figure 4, the response of the model variables (P, C, R) to a sustained pressure will always be unambiguous – the predictions are said to be completely sign determined. This occurs in this model because there are no multiple pathways between variables with opposite signs.

By way of contrast, the signed digraph depicted in Figure 5 is more complex because it includes an additional consumer and a predator that feeds on more than one trophic level. This added complexity creates multiple pathways with opposite signs between P and R.

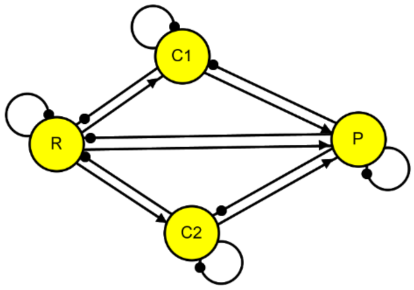

Figure 5 Signed digraph depicting a more complex system containing an additional consumer and a predator that feeds on more than one tropic level

Here the predicted response of R due to an increase in P will be ambiguous, because there are now three paths leading from P to R, two positive (P ─• C1 ─• R, P ─• C2 ─• R) and one negative (P ─• R). The abundance of the resource may therefore increase or decrease. This ambiguity can be approached in two ways. One is to apply knowledge of the relative strength of the links connecting P to R. If P was only a minor consumer of R then the R would be predicted to increase. Alternatively, if R was the main prey of P, and C1 and C2 amounted to only a minor portion of P's diet, then R would be predicted to decrease in abundance.

In many cases, however, there is insufficient knowledge of the strength of the links involved in a response prediction. In these instances, Dambacher et al. (2003) and Hosack et al. (2008) described a statistical approach that estimates the probability of sign determinacy for each response prediction. In the Figure 5 example, with two positively signed paths and one negatively signed path, there is a net of one positive path (i.e. it is considered that a negatively signed path cancels a positively signed path) out of a total of three paths. According to this approach, in the system depicted in Figure 5, R is predicted to increase 77% of the time because of the ratio of the net to the total number of paths.

The ratio of the net to the total number of paths in a response prediction has been determined to be a robust means of assigning probability of sign determinacy to response predictions. These probabilities of sign determinacy can then be used to assess cumulative impacts that result from a perturbation to the system.

2.7.1.2.3 Choice of hydrological response variables and receptor impact variables

In BAs, qualitative mathematical models are used to represent how ecosystems will respond qualitatively (increase, decrease, no change) to changes in the hydrological variables that support them. The models also provide a basis for identifying receptor impact variables and hydrological response variables that are the subject of the quantitative receptor impact models (Stage 3 in Figure 3).

The qualitative mathematical models identify a suite of ecologically important water requirements that support the landscape class ecosystem. These variables are sometimes expressed as hydrological regimes, for example an overbank flow regime premised on an average recurrence interval of once every three years. The hydrological components in these models are linked to the hazard analysis (companion submethodology M11 (as listed in Table 1) for hazard analysis (Ford et al., 2016)) and provide the mechanism via which the coal resource development can adversely affect groundwater and surface water dependent ecosystems.

Hydrological response variables are derived from the numerical surface water and groundwater model results to represent these ecologically important water requirements. The surface water hydrological response variables in the receptor impact models are defined in terms of mean annual values for two 30-year periods: 2013 to 2042 and 2073 to 2102 (e.g. mean number of zero-flow days per year between 2013 and 2042). The hydrological response variables are generalised for the assessment extent and thus serve as indicators of change in ecologically important flows, rather than accurate characterisation of flow regimes at local scales. They differ from the hydrological response variables defined in companion product 2.6.1 for surface water modelling in the Namoi subregion (Aryal et al., 2018), which represent the maximum difference between the CRDP and baseline simulations over the 90-year simulation period (e.g. the maximum difference in zero-flow days per year between 2013 and 2102).

Receptor impact variables are selected according to the following criteria:

- *Is it directly affected by changes in hydrology?* These variables typically have a lower trophic level.
- *Is it representative of the broader landscape class?* Variables (or nodes) within the qualitative model that other components of that ecosystem or landscape class depend on will speak more broadly to potential impacts.
- *Is it something that expertise available can provide opinion on?* There is a need to be pragmatic and make a choice of receptor impact variable that plays to the strengths of the experts available.
- *Is it something that is potentially measurable?* This may be important for validation of the impact and risk analysis.
- *Will the choices of receptor impact variable for a landscape class resonate with the community?* This speaks to the communication value of the receptor impact variable.

Receptor impact variables are chosen as indicators about the response of a landscape class. Changes in the receptor impact variables (e.g. foliage cover, taxa richness) imply changes to the ecology of the landscape class. A decrease in projected cover of woody riparian vegetation implies a reduction in the abundance and/or health of trees along river banks. A receptor impact variable may coincide with an ecological asset. For example, the abundance of a species listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), whose modelled 'Habitat (potential species distribution)' is an asset, might be selected as an indicator of overall ecosystem condition if experts thought its abundance were highly sensitive to hydrological change. Alternatively, a receptor impact variable that is not an asset, but which is highly sensitive to hydrological change, may be a useful indicator of the overall response of a given asset or landscape class.

The goal of the receptor impact modelling workshop (Stage 5 in Figure 3) is to predict how a given receptor impact variable will respond at future time points to changes in the values of hydrological response variables, whilst acknowledging that this response may be influenced by the status and condition of the receptor impact variable in the reference year (2012). Response variables to represent changes in water quality that might be expected to accompany changes in the relative contributions of surface runoff and groundwater to streamflow are not included in the models or the elicitations.

The elicitation generates subjective probability distributions for the expected value of the receptor impact variable under a set of hydrological scenarios that represent possible combinations of changes to hydrological response variables. These scenarios are the elicitation equivalent of a sampling design for an experiment where the aim is to maximise the information gain and minimise the cost. The same design principles therefore apply (Stage 4 in Figure 3).

It is essential to have an efficient design to collect the expert information, given the large number of receptor impact models, landscape classes, and bioregions and subregions to address within the operational constraints of the programme. The design must also respect, as much as possible, the predicted hydrological regimes as summarised by hydrological modelling outputs. Without this information, design points may present hydrological scenarios that are unrealistically beyond bounds suggested by the landscape class definition. Alternatively, insufficiently wide bounds on hydrological regimes lead to an over-extrapolation problem when receptor impact model predictions are made conditional on hydrological simulations at the risk-estimation stage (Stage 6 in Figure 3). The design must further respect the feasibility of the design space, which may be constrained by mathematical relationships between related hydrological response variables. The design must accommodate the requirement to predict to past and future assessment years. The design must also allow for the estimation of potentially important interactions and nonlinear impacts of hydrological response variables on the receptor impact variable.

2.7.1.2.4 Construction and estimation of receptor impact models

BAs address the question ‘How might selected receptor impact variables change under various scenarios of change for the hydrological response variables?’ through formal elicitation of expert opinion. This is a difficult question to tackle and presents a challenging elicitation task. BAs implement a number of processes that are designed to help meet this challenge: (i) persons invited to the receptor impact modelling workshops are selected based on the relevance of their domain expertise; (ii) all experts are provided with pre-workshop documents that outline the approach, the expectations on the group and the landscape classes and descriptions, and subsequently the finalised qualitative models; and (iii) experts are given some training on subjective probability, common heuristics and biases, together with a practice elicitation.

The elicitation proper follows a five-step procedure (described in detail in companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)) that initially elicits fractiles, fits and plots a probability density function to these fractiles, and then checks with the experts if fractiles predicted by the fitted density are sufficiently close to their elicited values. This process is re-iterated until the experts confirm that the elicited and fitted fractiles, and the fitted lower (10th) and upper (90th) fractiles, provide an adequate summary of their opinions for the elicitation scenario concerned.

The experts' responses to the elicitations are treated as data inputs into a Bayesian generalised linear model (Stage 6 in Figure 3; see submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). The model estimation procedure allows for a wide variety of possible model structures that can accommodate quadratic responses of receptor impact variables to changes in hydrological response variables, and interactive (synergistic or antagonist) effects between hydrological response variables. The procedure uses a common model selection criterion (the Bayesian Information Criterion) to select the model that most parsimoniously fits the experts' response to the elicitation scenarios.

2.7.1.2.5 Receptor impact model prediction

This stage (Stage 7 in Figure 3) applies the receptor impact model methodology to predict the response of the receptor impact variables. The general framework allows for the receptor impact model to be applied either at single or multiple receptor locations (assessment units). The receptor impact model can therefore be applied at multiple receptor locations that are representative of a landscape class within a bioregion or subregion. The primary endpoint considered, however, is predicting receptor impact variable response to the BA future across an entire landscape class, which is accomplished by including all locations (assessment units) that represent the hydrological characteristics of the landscape class. The uncertainty from the hydrology modelling is propagated through the receptor impact model at each location to give the predicted distribution of the receptor impact variable at different time points for the two futures considered by BA (baseline and CRDP). The uncertainties are then aggregated to give the response across the entire landscape class. Companion submethodology M09 (as listed in Table 1; Peeters et al., 2016) provides further details on how uncertainty is propagated through the hydrological models. Integrating across these receptors produces the overall predicted response of the receptor impact variable for the landscape class given the choice of the BA future. These landscape class results are summarised in product 3-4 (impacts and risks) for the Namoi subregion (Herr et al., 2018a). The results do not replace the need for detailed site or project specific studies, nor should they be used to pre-empt the results of detailed studies that may be required under state and Commonwealth legislation. Detailed site studies may give differing results due to the scale of modelling used.

2.7.1.2.6 Receptor impact modelling assumptions and implications

The receptor impact modelling methodology (companion submethodology M08 (as listed in Table 1; Hosack et al., 2018)) and its implementation was affected by design choices that have been made within BA. Some of these broader choices are described in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018). Table 4 summarises some of the assumptions made for the receptor impact modelling, the implications of those assumptions for the results, and how those implications are acknowledged through the BA products.

Table 4 Summary of the receptor impact modelling assumptions, their potential implications, and their acknowledgement through BA products

Assumptions of receptor impact modelling	Implications	Acknowledgement
Discretisation of continuous landscape surface	Provided a defined spatial scope for experts to address. Connections between landscape classes broken. Changes in one landscape class may have implications for adjacent landscape classes	Identify potential connections between landscape classes where possible in the impact and risk product. Some qualitative mathematical models do include links to nearby landscape classes
Data underpinning landscape classes is sufficient and correct	Landscape class definition required data input from pre-existing data sources. Prioritisation for qualitative mathematical models and receptor impact models may be affected. Minimal effect on model development for receptor impact models	Acknowledge issues with data in the impact and risk product (also done in the conceptual modelling product). In companion product 3-4 for the Namoi subregion (Herr et al., 2018a) acknowledge that mapped results reflect the mapped inputs
Areas of landscape classes are constant over modelling period	Provides a defined spatial scope for expert assessment of change. BA is about identifying existing areas that are at risk from coal resource development as opposed to predicting the changes in areal extent or transition to different landscape classes. Some potential for changes in the area of the landscape class to affect its sensitivity to hydrological change but would need to be assessed on an asset-by-asset basis	Acknowledge in Methods
Other developments and users of water (e.g. agriculture) are constant over time	Provided a defined context for experts to consider. BA is about identifying existing areas that are at risk from coal resource development as opposed to predicting the changes due to other developments or the relative attribution	Acknowledge in Methods
Landscape characteristics other than hydrological variables are not represented in quantitative receptor impact models	Limits hydrological response variables used in receptor impact models to those that may be derived from hydrological models developed by BA. The absence of water quality variables is a noted limitation. Loss of within-landscape class predictive performance from the receptor impact models	Identify as knowledge gap when the hydrological response variables used in the model represent a subset of the key dependencies. Acknowledge importance of local (vs regional) analyses where the concern is over particular parts of a landscape class
Experts available adequately represent the state of knowledge for relevant landscape classes	Experts provided domain expertise and experience that informed both model structure and also provided quantifiable predictions of receptor impact variable response to novel hydrological scenarios. Expert availability affected the quality/utility of the qualitative mathematical model; identification of receptor impact variables that reflect expertise of those in the room	Acknowledge that the receptor impact variable is an 'indicator' of the potential ecosystem response. Identify as knowledge gap where part of the landscape class is not represented

Assumptions of receptor impact modelling	Implications	Acknowledgement
The simplification of complex systems is appropriate for the task	Provided formal approach to model identification and selection of candidate receptor impact variables. Not all components and relationships are represented by receptor impact models	Acknowledge that one or two receptor impact variables can underestimate complex ecosystem function. Make assumptions clear. High-level interpretation of results. Emphasise importance of interpreting the hydrological change
A common set of modelled hydrological response variables is appropriate across different landscape classes	Limits hydrological response variables used in receptor impact models to those that may be derived from hydrological models developed by BA. Enables some simplification of complex systems. Loss of local specificity in predictions of receptor impact variables	The need for local-scale information is identified (in multiple places)
Receptor impact variables are good indicators of ecosystem response	The qualitative models informed the selection of receptor impact variables within the additional constraints imposed by expert availability given project timelines. Focus of the quantified relationships within the landscape class	The need for local-scale information is identified (in multiple places)
Extrapolation of predictions beyond elicitation scenarios	The ranges of hydrological scenarios to be considered at the expert elicitation sessions were informed by preliminary hydrological modelling output and hydrological expert advice within BA. However, final model results sometimes extended beyond this preliminary range due to necessary changes in underlying hydrological modelling assumptions and assimilation of data. Extrapolation beyond the range of hydrological response variables considered by the expert elicitation increases uncertainty in receptor impact variable predictions	Identify as a limitation for the appropriate landscape class in the impact and risk product where this occurs
Qualitative mathematical models focus on impacts of long-term sustained hydrological changes (press perturbations) to ecosystems. The quantitative receptor impact models can and do account for pulse perturbations and associated responses, where experts were free to include direct and indirect effects as well as pulse and press perturbations within their assessments	Qualitative models may not accurately represent impacts of shorter-term hydrological changes (pulse perturbations) on ecosystems and landscape classes	Describe rationale for the focus on press perturbations in companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018). Note that many potential pulse perturbations are caused by accidents and managed by site-based processes. Identify as a limitation / knowledge gap. Note that quantitative receptor impact models do account for pulse perturbations

BA = bioregional assessment

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2.7.2 Prioritising landscape classes for receptor impact modelling

Summary

The purpose of this section is to provide the rationale for the choice of landscape groups that have been selected for the impact and risk analysis, and to describe the modelling undertaken for each of these groups. The landscape classification for the assessment extent of the Namoi subregion identified 29 landscape classes that were aggregated into 6 broad landscape groups.

The zone of potential hydrological change developed for the Namoi subregion was used to: (i) identify ecological landscape classes that intersect it and are potentially impacted by the modelled hydrological changes due to additional coal resource development, and (ii) rule out landscape classes that do not intersect the zone and are therefore considered *very unlikely* (less than 5% chance) to be impacted by changes in hydrology. Qualitative and/or receptor impact models are only needed for those ecological landscape classes that are potentially impacted.

A total of 21 landscape classes, comprising 4 landscape groups that intersect the 7014 km^2 zone of potential hydrological change, are considered dependent on groundwater or surface water regimes. These landscape groups, therefore, are potentially impacted due to additional coal resource development and are considered further in this product and through the remainder of the impact and risk analysis of the bioregional assessment (BA) for the Namoi subregion. The landscape groups are ‘Floodplain or lowland riverine’, ‘Non-floodplain or upland riverine’, ‘Springs’ and ‘Rainforest’.

The Pilliga and Pilliga Outwash Interim Biogeographic Regionalisation of Australia (IBRA) subregions, or simply termed the ‘Pilliga region’ here, represent a unique set of landscapes within the Namoi subregion. Based on agreement with experts in this region, separate modelling was undertaken for the Pilliga that included riverine landscape classes (upland and lowland) and the ‘Grassy woodland groundwater-dependent ecosystem (GDE)’ landscape class that is mostly contained within this region.

The next four sections in this product (Section 2.7.3 to Section 2.7.6, inclusive) focus on the four landscape groups that are considered during subsequent stages of the BA for the Namoi subregion. The purpose of the current section is to provide the rationale for the choice of landscape groups that have been selected for the impact and risk analysis, and to describe the modelling undertaken for each of these groups.

2.7.2.1 Potentially impacted landscape classes

The landscape classification for the assessment extent of the Namoi subregion identified 29 landscape classes that were aggregated into 6 broad landscape groups (see Section 2.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018b)). Once the zone of potential hydrological change was developed for the Namoi subregion (as outlined in companion product 3-4 for the Namoi subregion (Herr et al., 2018a)) it was used to: (i) identify ecological landscape classes that intersect it and are potentially impacted by the modelled hydrological changes due to additional coal resource development, and (ii) rule out landscape classes that do not intersect the zone and are therefore considered *very unlikely* (less than 5% chance) to be impacted by changes in hydrology. Qualitative and/or receptor impact models are only needed for those ecological landscape classes that are potentially impacted.

There are two landscape groups that are automatically ruled out of this component of BA regardless of their extent within the zone of potential hydrological change. Firstly, the 'Dryland remnant vegetation' landscape group is ruled out from potential impacts because it comprises vegetation communities that are deemed to be reliant on incident rainfall and local runoff and do not include features in the landscape that have potential hydrological connectivity to surface water or groundwater features (for further information, see Section 2.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018b)). Secondly, the 'Human-modified' landscape group (comprising six landscape classes) is excluded from this analysis because it primarily comprises agricultural and urban landscapes that are highly modified by human activity, and contains a set of ecohydrological attributes distinct from the other landscape groups (for further information, see Section 2.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018b)). Attributes of the water-dependency of some aspects of these landscapes are considered elsewhere (see Section 3.5 of companion product 3-4 for the Namoi subregion (Herr et al., 2018a)), that is, the potential impact of coal resource development on economic assets such as groundwater bores.

None of the 15 springs of the 'Non-GAB springs' landscape class found in the assessment extent are located within the zone of potential hydrological change. Therefore, this landscape class can be ruled out as it is *very unlikely* to be impacted due to additional coal resource development.

The remaining 21 landscape classes, comprising 4 landscape groups that intersect the 7014 km^2 zone of potential hydrological change, are considered dependent on groundwater or surface water regimes. These landscape groups, therefore, are potentially impacted due to additional coal resource development and are considered further in this product and through the remainder of the impact and risk analysis of the BA for the Namoi subregion (i.e. as presented in companion product 3-4 (Herr et al., 2018a)). The landscape groups are 'Floodplain or lowland riverine', 'Non-floodplain or upland riverine', 'Springs' and 'Rainforest'.

When developing ecological models for the Namoi subregion it was deemed necessary to develop a separate model for defining potential ecological impacts for the Pilliga and Pilliga Outwash IBRA subregions (SEWPaC, 2012). The Pilliga and Pilliga Outwash IBRA subregions, or simply termed the 'Pilliga region' here, represent a unique set of landscapes within the Namoi subregion. By comparison to the other landscapes across the Namoi subregion, the Pilliga region has many unique attributes in terms of its ecology, geomorphology, underlying hydrogeology, soils and ecohydrology. Consistent with the structuring of the ecological models, outlined further in this product (see Section 2.7.5), the potential hydrological changes and ecosystem impacts are presented for both a separate Pilliga region of the zone of potential hydrological change and the remaining 'non-Pilliga' areas or reporting regions for the relevant landscape classes (see Section 3.3.2.2 of companion product 3-4 for the Namoi subregion (Herr et al., 2018a) for details on reporting regions).

2.7.2.1.1 'Floodplain or lowland riverine' landscape group

The zone of potential hydrological change contains all four riverine landscape classes within the 'Floodplain or lowland riverine' landscape group and includes 61% of the entire extent of this group within the assessment extent (Table 5). Among these four riverine classes, the largest contribution is from the 'Temporary lowland stream' (2062.2 km) and 'Permanent lowland stream' (979.6 km) landscape classes (Table 5). All six of the non-riverine classes occur within the zone of potential hydrological change (Table 5). The largest non-riverine class by area is the 'Floodplain grassy woodland GDE' (421.7 km^2) and 'Floodplain grassy woodland' (121.3 km^2) (Table 5). Almost half of all the 'Floodplain riparian forest GDE' in the assessment extent (148.7 km^2) is included in the zone of potential hydrological change (Table 5). Most of the areas classified as 'Floodplain wetland' and 'Floodplain wetland GDE' in the assessment extent (30.1 $km^2$and 151.8 km^2 respectively) form part of the zone of potential hydrological change (Table 5).

A single signed digraph model was created for the 'Floodplain or lowland riverine' landscape group that captured most of the key linkages within and between the riverine and floodplain habitats. From this model, key hydrological response variables were selected for a subset of the landscape classes. Given the expertise and resources available at the qualitative modelling workshop for the Namoi subregion, it was decided that receptor impact models be developed for a subset of landscape classes of this group (Table 5). There are two landscape classes in the 'Floodplain or lowland riverine' landscape group (non-Pilliga region) where groundwater drawdown was assigned as a hydrological response variable: 'Floodplain riparian forest' and 'Floodplain riparian forest GDE'. The corresponding receptor impact variable for riparian forests was identified as change in projected foliage cover. The frequency of overbank flows was identified as being an important driver of the riparian ecosystem ('Floodplain riparian forest' and 'Floodplain riparian forest GDE' landscape classes) as well as the off-channel water bodies or floodplain wetlands ('Floodplain wetland' and 'Floodplain wetland GDE' landscape classes). The experts at the qualitative modelling workshop considered the presence of tadpoles from the *Limnodynastes* genus as the key receptor impact variable for floodplain wetlands. The cease-to-flow attributes of the surface water regime were considered as critical hydrological response variables for the riverine landscape classes and were assigned: annual number of zero-flow days and annual maximum zero-flow spells. Assemblages of macroinvertebrates in the edge habitat were deemed to be appropriate receptor impact variables for gauging impacts on these cease-to-flow attributes of the flow regime.

Receptor impact models were not constructed for the 'Floodplain grassy woodland' and 'Floodplain grassy woodland GDE' landscape classes. While these classes occupy a large proportion of this landscape group within the zone of potential hydrological change, they are considered less sensitive to hydrological change given their reduced reliance on groundwater and surface water (see Section 2.7.3 for more details).

Table 5 Extent of all landscape classes in the assessment extent and zone of potential hydrological change for the Namoi subregion

Landscape class names as shown in companion product 2.3 for the Namoi subregion (Herr et al., 2018b). The relevant reporting region, qualitative model and receptor impact model is given for each landscape class.

Landscape group	Landscape class	Extent[a] in assessment extent[b]		Extent in the zone		Reporting region	Qualitative model	Receptor impact model
Floodplain or lowland riverine	Floodplain riparian forest (km^2)	1.5	na	0.2	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain or lowland riverine	1. Floodplain riparian forests – projected foliage cover
	Floodplain riparian forest GDE (km^2)	148.7	na	72	na			
	Floodplain wetland (km^2)	30.1	na	21.6	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain or lowland riverine	2. Floodplain wetland (GDE and non-GDE) – probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*) in pools and riffles
	Floodplain wetland GDE (km^2)	151.8	na	88	na			
	Permanent lowland stream (km^2/km)	17.3	1,688.6	na	979.6	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain or lowland riverine	3. Permanent and temporary lowland streams (GDE and non-GDE) – average number of families of aquatic macroinvertebrate in edge habitat
	Permanent lowland stream GDE (km^2/km)	na	456.8	na	240.8			
	Temporary lowland stream (km^2/km)	1.5	8,053.3	na	2062.2			
	Temporary lowland stream GDE (km^2/km)	8.3	509.3	na	84.3			
	Floodplain grassy woodland (km^2)	400.2	na	121.3	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain or lowland riverine	No
	Floodplain grassy woodland GDE (km^2)	1,445.4	na	421.7	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain or lowland riverine	No
	Permanent lowland stream (km^2/km)	17.3	1,688.6	na	14.3	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine – projected foliage cover

Landscape group	Landscape class	Extent[a] in assessment extent[b]		Extent in the zone		Reporting region	Qualitative model	Receptor impact model
	Permanent lowland stream GDE (km^2/km)	na	456.8	na	<0.1			2. Pilliga riverine – average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools
	Temporary lowland stream (km^2/km)	1.5	8,053.3	na	624.6			
	Temporary lowland stream GDE (km^2/km)	8.3	509.3	2.4	86.9			
	Floodplain riparian forest (km^2)	1.5	na	<0.1	na	Pilliga and Pilliga Outwash	No	No
	Floodplain riparian forest GDE (km^2)	148.7	na	0.2	na			
	Floodplain wetland (km^2)	30.1	na	0.5	na			
	Floodplain wetland GDE (km^2)	151.8	na	1.6	na			
	Floodplain grassy woodland (km^2)	400.2	na	2.9	na			
	Floodplain grassy woodland GDE (km^2)	1,445.4	na	0.2	na			
	Total area	**2,204.8**	**na**	**752.2**	**na**			
	Total length	**na**	**10,708**	**na**	**4092.7**			
Non-floodplain or upland riverine	Upland riparian forest GDE (km^2)	87.4	na	2.9	na	Upper Namoi, Mid Namoi, Lower Namoi	Upland riverine	1. Upland riparian forest – projected foliage cover
	Permanent upland stream (km^2/km)	0.1	1,646.1	na	92.6	Upper Namoi, Mid Namoi, Lower Namoi	Upland riverine	1. Permanent and temporary upland streams (GDE and non-GDE) – average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools
	Permanent upland stream GDE (km^2/km)	1.1	227.4	0.1	14.2			
	Temporary upland stream (km^2/km)	na	16,512.8	na	745.1			

Landscape group	Landscape class	Extent[a] in assessment extent[b]		Extent in the zone		Reporting region	Qualitative model	Receptor impact model
	Temporary upland stream GDE (km^2/km)	0.1	464	na	34.7			2. Upland riverine – probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*)
	Permanent upland stream (km^2/km)	na	1,646.1	na	<0.1	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine – projected foliage cover
	Permanent upland stream GDE (km^2/km)	na	227.4	na	<0.1			
	Temporary upland stream (km^2/km)	na	16,512.8	na	530.4			
	Temporary upland stream GDE (km^2/km)	na	464	na	11.5			
	Grassy woodland GDE (km^2)	3,247.6	na	561.7	na	Pilliga	Grassy woodland GDE	No
				72.8	na	Upper Namoi, Mid Namoi, Lower Namoi		
	Non-floodplain wetland (km^2)	130.3	na	13.1	na	All	Non-floodplain wetland (GDE and non-GDE)	No
	Non-floodplain wetland GDE (km^2)	23.5	na	8.1	na			
	Total area	**3,490.1**	**na**	**663**	**na**			
	Total length	**na**	**18,850.3**	**na**	**1428.5**			

Landscape group	Landscape class	Extent[a] in assessment extent[b]		Extent in the zone		Reporting region	Qualitative model	Receptor impact model
Rainforest	Rainforest (km^2)	na	153.1	na	4.0	All	Rainforests (GDE and non-GDE)	No
	Rainforest GDE (km^2)	na	43.5	na	0.3			
	Total area	**na**	**196.6**	**na**	**4.3**			
Springs	GAB springs (number)	7	na	2	na	All	GAB springs	No
	Non-GAB springs (number)	15	na	0	na			
	Total number	**22**	na	**2**	na			
Dryland remnant vegetation	Grassy woodland (km^2)	8,623.7	na	1177.5	na	All	Not considered	Not considered
	Total area	**8,623.7**	na	**1177.5**	na			
Human-modified	Conservation and natural environments (km^2)	400.7	na	111.2	na	All	Not considered	Not considered
	Intensive uses (km^2)	276	na	91.5	na			
	Production from dryland agriculture and plantations (km^2)	16,075.3	na	2814.5	na			
	Production from irrigated agriculture and plantations (km^2)	1,854.1	na	594.2	na			
	Production from relatively natural environments (km^2)	2,356.2	na	739	na			
	Water (km^2)	182.1	na	66.5	na			
	Total area	**21,144.4**	**na**	**4416.9**	**na**			

[a]Extent of each landscape class is either an area of vegetation (km^2), length of stream network (km) or number of springs (number).
[b]Values for the extent in assessment extent are the same regardless of reporting region.
GAB = Great Artesian Basin; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

2.7.2.1.2 'Non-floodplain or upland riverine' landscape group

For the areas outside the Pilliga region in the zone of potential hydrological change (i.e. Upper Namoi, Mid Namoi and Lower Namoi reporting regions), the most common riverine landscape class within the 'Non-floodplain or upland riverine' landscape group in the zone of potential hydrological change is classified as 'Temporary upland stream' (745.1 km) reflecting the intermittent or ephemeral nature of many of the stream segments (Table 5). The remainder of the stream network is classified as 'Permanent upland stream' (92.6 km), 'Temporary upland stream GDE' (34.7 km) and 'Permanent upland stream GDE' (14.2 km) (Table 5). Most non-riverine landscapes in the 'Non-floodplain or upland riverine' landscape group in the zone of potential hydrological change are in the 'Grassy woodland GDE' landscape class (72.8 km^2). The 'Upland riparian forest GDE' landscape class makes up a very small area of the zone of potential hydrological change (2.9 km^2) along with a small area of 'Non-floodplain wetland' (13.1 km^2) and 'Non-floodplain wetland GDE' landscape classes (8.1 km^2) (Table 5).

Three different components of this landscape group were considered for the qualitative modelling given the general lack of hydrological and spatial connectivity between the landscape classes across the zone of potential hydrological change. The level of fragmentation and lack of spatial overlap between the 'Upland riparian forest GDE', 'Grassy woodland GDE' and the 'Non-floodplain wetland'/'Non-floodplain wetland GDE' landscape classes suggested limited potential for hydrological and ecological connectivity. The upland riverine qualitative model included all upland riverine landscape classes and the adjacent riparian vegetation ('Upland riparian forest GDE') landscape class. Three receptor impact models were formulated based on this qualitative model: upland riverine (two separate models) and upland riparian forest (Table 5). Cease-to-flow attributes (zero-flow days and zero-flow spells) of the surface water regime were assigned as hydrological response variables for the upland riverine model. The corresponding receptor impact variables included changes in macroinvertebrate assemblages and the probability of the presence of tadpoles from the *Limnodynastes* genus (Table 5). For upland riparian forest, groundwater drawdown and overbank flow events were considered the key hydrological response variables. The potential ecosystem impacts on this landscape class were quantified using projected foliage cover (Table 5).

In addition to the upland riverine system, a qualitative model was developed for the non-floodplain wetlands in this landscape group (Table 5). However, no elicitation or quantitative modelling was conducted because these wetland systems were considered a low priority given their unknown levels of groundwater dependence. A qualitative model was also developed for the 'Grassy Woodland GDE' landscape class and this is discussed below in Section 2.7.2.1.4.

2.7.2.1.3 Pilliga riverine landscape classes

The Pilliga region within the zone of potential hydrological change contains both upland and lowland riverine reaches. 'Temporary upland stream' (530.4 km) and 'Temporary lowland stream' (624.6 km) landscape classes make up the majority of the riverine networks, reflecting the highly ephemeral and/or intermittent nature of the drainage network (Table 5). A small fraction of the 'Permanent lowland stream' landscape class (14.3 km) intersects with the Pilliga region in the zone of potential hydrological change (Table 5).

Given the unique characteristics of the Pilliga's stream network (i.e. low relief, intermittent flow patterns), a qualitative model, in consultation with the local experts, was developed for both upland and lowland riverine classes – Pilliga riverine (Table 5). This meant that both lowland and upland riverine landscape classes share a similar model that encompasses both the riverine and riparian systems. From this model, key hydrological response variables were identified: groundwater drawdown, change in annual zero-flow days and maximum zero-flow spells. The receptor impact modelling workshop used two different receptor impact variables to indicate potential ecological impacts in this system: projected foliage cover of riparian trees and number of families of aquatic macroinvertebrates. A qualitative model for the 'Grassy woodland GDE' landscape class was also formulated, but no quantitative modelling was developed.

2.7.2.1.4 'Grassy woodland GDE' landscape class

The 'Grassy woodland GDE' landscape class makes up most of the non-riverine landscapes in the Pilliga region (561.7 km^2) and a small portion (72.8 km^2) of the total 634.5 km^2 of this landscape class across the entire zone of potential hydrological change is located outside of the Pilliga region (Table 5). This landscape class includes a collection of different vegetation communities and habitats, however, given the concentration of this landscape class in the Pilliga region of the zone of potential hydrological change, a qualitative model was developed by the workshop participants with a focus on the ecology of this region (Table 5). Given the limitations on resources at the receptor impact modelling workshop and the uncertainty surrounding the nature of groundwater dependency of vegetation in the Pilliga region, a receptor impact model was not formulated for this landscape class.

2.7.2.1.5 'Rainforest' landscape group

The 'Rainforest' landscape group occupies a limited area within the zone of potential hydrological change, with the 'Rainforest' landscape class intersecting 4.0 km^2 of the zone and the 'Rainforest GDE' landscape class intersecting 0.3 km^2 (Table 5). A qualitative model was developed for this landscape group that emphasises the relationship of key ecological components and groundwater dynamics. Given the limited extent of this landscape class within the landscape group and the large degree of uncertainty associated with its groundwater dependency it was decided not to formulate a quantitative receptor impact model for this group.

2.7.2.1.6 'Springs' landscape group

Two springs are known to occur within the zone of potential hydrological change, which are classified as 'GAB springs' based on their association with underlying sandstone formations. These two springs are located on the eastern edge of the Pilliga Basin and are thought to be primarily recharge springs, given their location on the eastern fringes of the Great Artesian Basin (GAB) (Fensham and Fairfax, 2003). A qualitative model was formulated for a typical recharge GAB spring (Table 5). However, it was decided by experts that given the nature of the flow paths associated with these springs, impacts from additional resource development would be difficult to quantify and it was not pursued further.

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2.7.3 'Floodplain or lowland riverine' landscape group

Summary

The 'Floodplain or lowland riverine' landscape group occupies a land area of approximately 6% of the Namoi subregion assessment extent and makes up around a quarter of the entire length of the stream network across the assessment extent. There are four lowland riverine landscape classes that capture differences in surface water (temporary/permanent) and groundwater (groundwater-dependent ecosystem (GDE)/non-GDE) regimes across the assessment extent. The floodplain landscape classes contain a collection of landscape and ecological elements exposed to inundation or flooding along a river system including riparian forests, wetlands and grassy woodlands.

The zone of potential hydrological change for the Namoi subregion contains all four of the riverine landscape classes, with the largest by length being the 'Temporary lowland stream' (2062.2 km) and 'Permanent lowland stream' (979.6 km) classes. All six of the non-riverine landscape classes occur within the zone of potential hydrological change with the largest classes by area being 'Floodplain grassy woodland GDE' (421.7 km^2 or 6% of the zone) and 'Floodplain grassy woodland' (121.3 km^2 or 1.7% of the zone). There is approximately 1% of 'Floodplain riparian forest GDE' and 1.6% of 'Floodplain wetland' and 'Floodplain wetland GDE' landscape classes within the zone of potential hydrological change. An overview of those aspects of riverine, groundwater and floodplain ecohydrology relevant to the Namoi subregion is presented to provide context to the ecological modelling presented thereafter.

A qualitative model was developed for this landscape group that captured some of the key linkages within and between the riverine and floodplain habitats. From this model, key hydrological response variables were selected for a subset of the landscape classes. There are two landscape classes in the 'Floodplain or lowland riverine' landscape group (non-Pilliga region) where groundwater drawdown was assigned as a hydrological response variable: 'Floodplain riparian forest' and 'Floodplain riparian forest GDE'. The corresponding receptor impact variable for riparian forests was identified as change in projected foliage cover. The frequency of overbank flows was identified as being an important driver of the riparian ecosystem ('Floodplain riparian forest' and 'Floodplain riparian forest GDE' landscape classes) as well as the off-channel water bodies or floodplain wetlands ('Floodplain wetland' and 'Floodplain wetland GDE' landscape classes). The experts at the quantitative modelling workshop considered the presence of tadpoles from the *Limnodynastes* genus as the appropriate receptor impact variable for floodplain wetlands.

The cease-to-flow attributes of the surface water regime were considered as critical hydrological response variables for the lowland riverine landscape classes and were assigned: annual number of zero-flow days (averaged over 30 years) and annual maximum zero-flow spells. Assemblages of macroinvertebrates in the edge habitat were deemed to be appropriate receptor impact variables for gauging impacts on these cease-to-flow attributes of the flow regime.

2.7.3.1 'Floodplain or lowland riverine' landscape group

2.7.3.1.1 Description

The 'Floodplain or lowland riverine' landscape group occupies a land area of approximately 6% of the assessment extent and makes up around a quarter of the entire length of the stream network across the assessment extent. The landscape classification used by the bioregional assessment (BA) team defined four 'lowland' riverine classes based on topographical and geomorphological features (i.e. lowland), water regime (i.e. permanent or temporary) and the likelihood of intersecting with known surface expression GDEs (see Section 2.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018) for further details). The classification also captures a range of non-riverine features such as wetlands and vegetation types across the riparian–floodplain transition.

Floodplains can be defined broadly as a collection of landscape and ecological elements exposed to inundation or flooding along a river system (Rogers, 2011). The floodplain landscapes of the Namoi subregion assessment extent are predominantly lowland–dryland systems incorporating a range of wetland types such as riparian forests, marshes, billabongs, tree swamps, anabranches and overflows (Rogers, 2011). Riparian forest landscape classes are located within or directly adjacent to the stream channel and are inundated when the channel is full. They are generally classified as being dependent on groundwater in the alluvium. Floodplain grassy woodlands occupy the floodplain further away from the stream channel and are flooded intermittently and may or may not rely on groundwater. Off-channel water bodies or wetlands are interspersed along the floodplain and are typically inundated during overbank flow events (see Section 2.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018) for further details). Figure 6 is an example of the distribution of landscapes along typical floodplain areas, such as along the Namoi River.

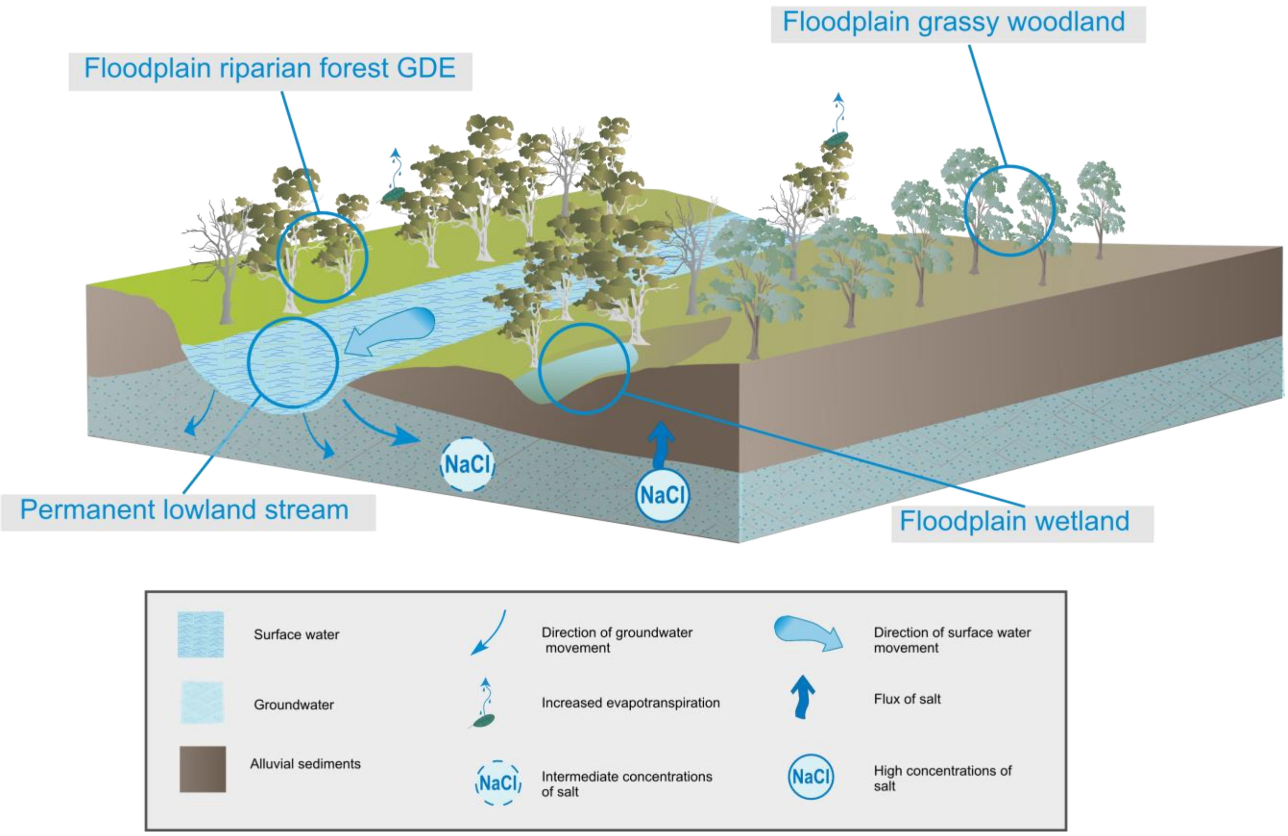

Figure 6 Pictorial conceptual model of a landscape typical of the 'Floodplain or lowland riverine' landscape group within the zone of potential hydrological change of the Namoi subregion

The model depicts a river system that is losing water to the underlying alluvial aquifer. Some of the hydrological processes relevant to this landscape are also shown.
GDE = groundwater-dependent ecosystem
Source: Symbols courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

The Namoi subregion zone of potential hydrological change contains all four riverine landscape classes within this group, with the largest by length being the 'Temporary lowland stream' (2062.2 km) and 'Permanent lowland stream' (979.6 km) landscape classes (Table 6, Figure 7). All six of the non-riverine landscape classes occur within the zone of potential hydrological change (Table 6). The largest landscape classes by area are 'Floodplain grassy woodland GDE' (421.7 km^2 or 6% of the zone) and 'Floodplain grassy woodland' (121.3 km^2 or 1.7% of the zone) (Table 6).

Table 6 Areas and/or lengths of the 'Floodplain or lowland riverine' landscape classes within the entire Namoi subregion assessment extent and the non-Pilliga region of the zone of potential hydrological change

Landscape class	Area in assessment extent (km^2)	Area in the zone of potential hydrological change (km^2)	Percentage of total area in the zone of potential hydrological change (%)	Length in assessment extent (km)	Length in the zone of potential hydrological change (km)	Percentage of total length in the zone of potential hydrological change (%)
Floodplain grassy woodland	400.2	121.3	1.7%	na	na	na
Floodplain grassy woodland GDE	1,445.4	421.7	6%	na	na	na
Floodplain riparian forest	1.5	0.2	<0.1%	na	na	na
Floodplain riparian forest GDE	148.7	72	1%	na	na	na
Floodplain wetland	30.1	21.6	0.3%	na	na	na
Floodplain wetland GDE	151.8	88	1.3%	na	na	na
Permanent lowland stream	17.3	13.4	0.2%	1,688.6	979.6	17.7%
Permanent lowland stream GDE	0	0	0%	456.8	240.8	4.4%
Temporary lowland stream	1.5	1.5	<0.1%	8,053.3	2062.2	37.4%
Temporary lowland stream GDE	8.3	4.7	<0.1%	509.3	84.3	1.5%
Total – 'Floodplain or lowland riverine' landscape classes	**2,204.8**	**744.4**	**10.6%**	**10,708**	**3366.9**	**61%**
Total – all landscape classes	**35,659.6**	**7013.9**	**100%**	**29,558.3**	**5521.2**	**100%**

na = not applicable
GDE = groundwater-dependent ecosystem

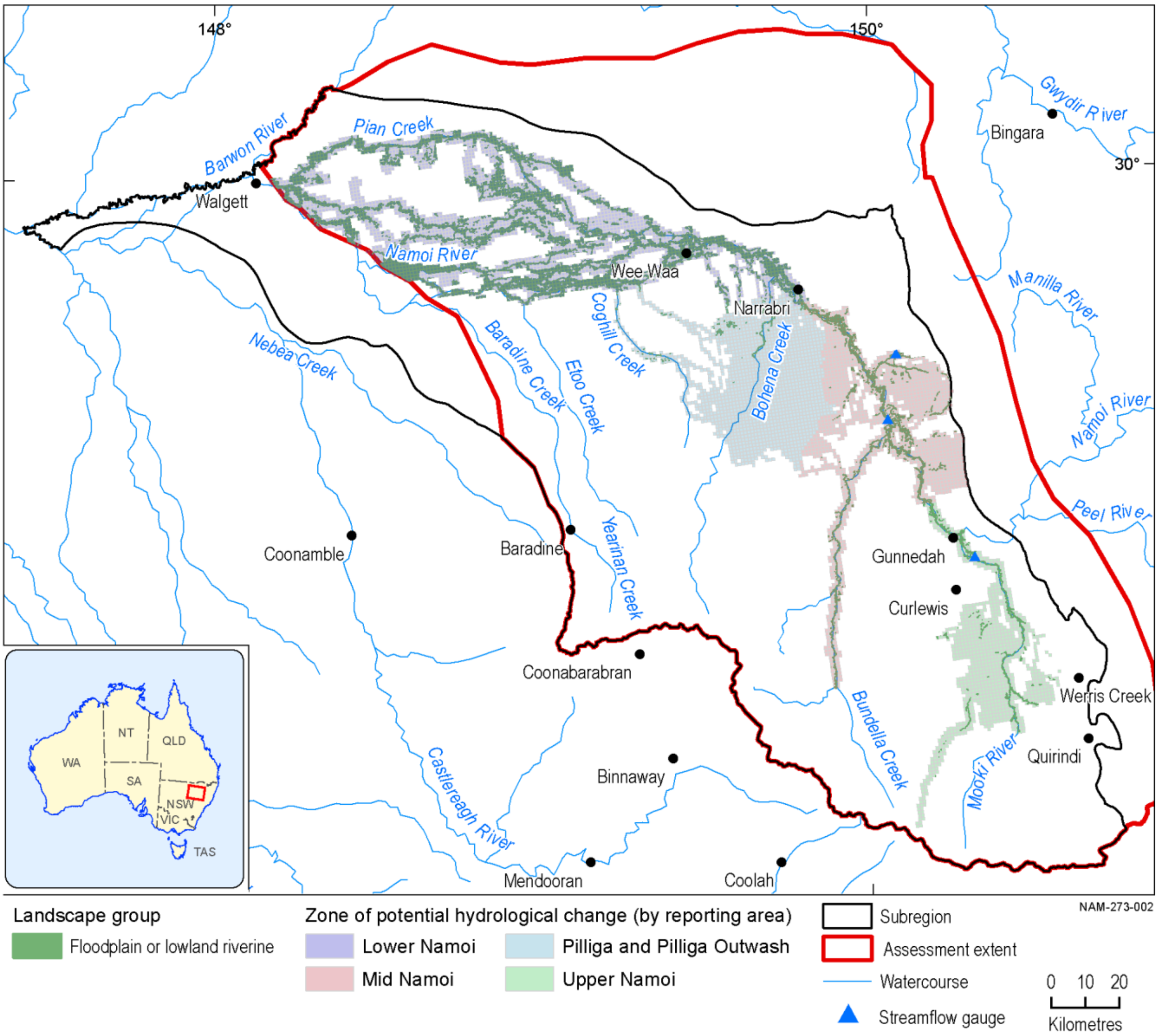

Figure 7 Location of the 'Floodplain or lowland riverine' landscape group within the zone of potential hydrological change in the Namoi assessment extent

Data: Bioregional Assessment Programme (Dataset 2, Dataset 4); Bureau of Meteorology (Dataset 3)

Riverine environment

Lowland streams in the assessment extent include the Namoi River and its tributaries and are low-gradient channels typically incised into alluvium with silt or sandy beds (Figure 8). There are limited riffles and fast-water habitat in these streams, and in those stream reaches with more temporary water regimes, habitat is mostly in pools. In streams such as Maules Creek, the channel is incised into sands and sandy gravels with some riffles and cobble-bottomed stretches.

Figure 8 Namoi River 20 km north of Gunnedah on the Liverpool Plains

Credit: Bioregional Assessment Programme, Patrick Mitchell (CSIRO), January 2016

Lowland stream systems in the Namoi subregion encompass a range of flow regimes (Table 7). Riverine landscape classes classified as ‘permanent’ have surface flows greater than 80% of the time and are mostly found along the Namoi River and the lower reaches of Mooki Creek and the Peel River. Streams classified as ‘temporary’ have surface flows less than 80% of the time and cover a large collection of small tributaries to the Namoi River on the Liverpool Plains and Castlereagh-Barwon regions (Bioregional Assessment Programme, Dataset 1). These landscape classes broadly relate to the classification of Kennard et al. (2010). The ‘permanent’ streams correspond to the ‘stable baseflow’ classes (Classes 1, 2 and 3) (Kennard et al., 2010) and have flow at least 80% of the year, and a baseflow index of 0.15 to 0.40. The riverine landscape classes classified as ‘temporary’ correspond broadly to the ‘unpredictable baseflow’ and ‘intermittent’ classes (Classes 4 and 5 to 8) (Kennard et al., 2010). Rarely to highly intermittent streams are characterised by streams that cease flowing more often than perennial streams and have a lower (0.10 to 0.35) baseflow contribution (Kennard et al., 2010). Highly intermittent or ephemeral streams are characterised by small baseflow contributions (<0.15) and large numbers of zero-flow days (>50) (Kennard et al., 2010).

Table 7 Maximum, median, 10th, 25th, 75th and 90th percentile flows (ML/d) for the three streamflow gauging stations along lowland streams in the Namoi assessment extent

Gauge #	Gauge name (latitude and longitude)	Landscape class	Maximum	10th	25th	Median	75th	90th
419012	Namoi River – Boggabri (–30.67S, 150.06E)	Permanent lowland stream	314,402	18	127	410	1302	2733
419051	Maules Creek (–30.49S, 150.08E)	Permanent lowland stream	30,239	1	3	8	16	45
419084	Mooki River – Ruvigne (–31.04S, 150.33E)	Temporary lowland stream	132,556	0	0	1	19	122

Water resource development along the Namoi River has affected the water regime of the riverine and floodplain environments and their ecological character. For example, there has been an increase in the average and maximum period between flooding of off-channel water bodies (e.g. palustrine wetlands) (CSIRO, 2007) of 27% and 50%, respectively. These changes in frequency have been accompanied by a reduction in annual flooding volume (28% less) (CSIRO, 2007). Despite these changes, the hydrologic condition based on the Hydrology Index score (HI) was deemed to be good across most of the catchment (OEH, 2010). However, the fish condition in terms of both 'nativeness' (the proportion of the fish assemblage that is native versus introduced) and 'expectedness' (the proportion of species collected during sampling that were expected to have occurred in each basin zone before European colonisation) was reported as being poor in the NSW *State of the Catchments 2010* report in the Namoi region (OEH, 2010). Macroinvertebrate condition was poor to moderate. The pressures from alien fish species, changes in water temperature from dam releases (Lake Keepit), artificial barriers to movement and other land use and climate change effects were seen as important for these results.

The following section provides a summary of the current state of knowledge of the linkages between surface water and groundwater hydrological regimes in lowland streams and floodplains to ecological function and composition. It helps to inform the discussion on the nature of the ecological modelling and choice of hydrological response variables associated with this landscape group as discussed in subsequent sections of this report.

Surface water flow regimes are defined by the timing, frequency, duration, magnitude, discharge volume and rates of the rise and fall of flow events (Boulton et al., 2014; Poff et al., 2010). Connectivity between the floodplain and stream channel riverine environments arises from longitudinal, lateral and vertical exchange of water. This connectivity can be described by surface water hydrological response variables that span the flow regime captured by the flow duration curve. Ecologically important components of the surface water regime can be broadly summarised (Dollar, 2004) as cease-to-flow periods, periods of low flows and base flows (or those intermediate of low flows and freshes), freshes, and periods of high flow (including overbench and overbank flows). These are illustrated in Figure 9.

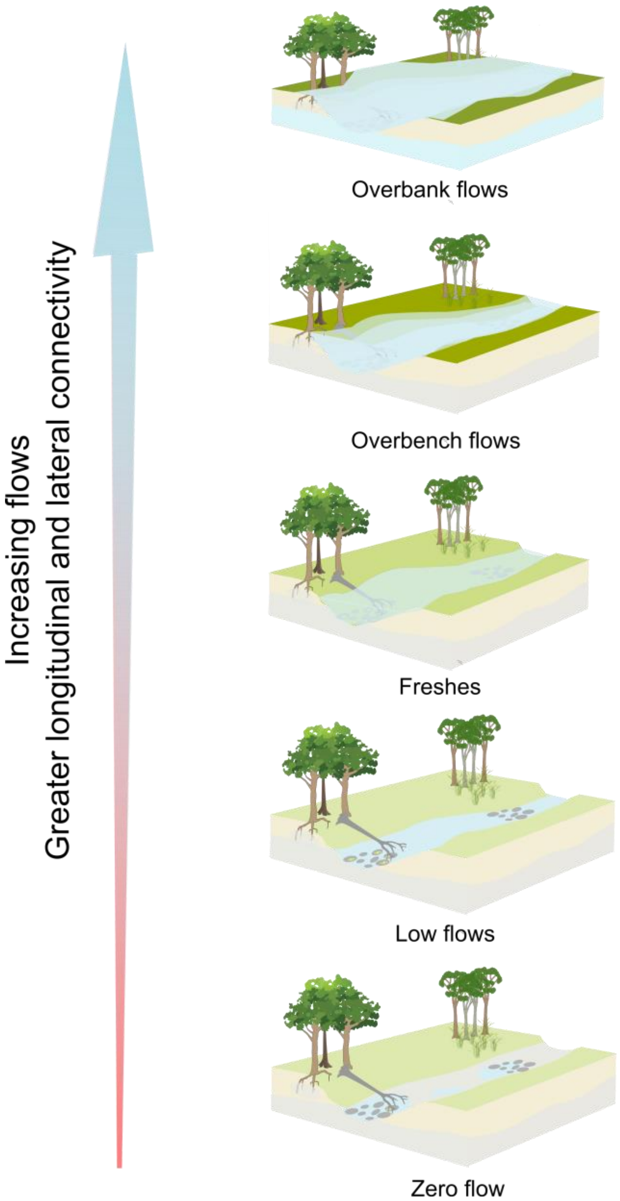

Figure 9 The spectrum of flow types in a river or stream segment

Source: Symbols courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

Larger pulses of river flow increase lateral connectivity within the streambed and provide access to new habitats, including river benches (Robson et al., 2009) (Figure 9). An increase in localised velocity profiles, especially around snags and along river banks creates new habitat for fish and stimulates downstream drift in macroinvertebrates (Boulton et al., 2014). Greater exchange in surface water and groundwater through the hyporheic zone also tends to occur, promoting improved water quality of the alluvial aquifers and increasing recharge to groundwater.

Connectivity between the river channel and the floodplain is essential for ecosystem health and is dependent on the timing, duration and frequency of overbank flows (Watts et al., 2009). These flows are capable of inundating the adjacent floodplain and filling off-channel water bodies and provide opportunities for the migration and exchange of riparian and floodplain biota and nutrients (Boulton et al., 2014). The presence of off-channel water bodies is a distinguishing feature of lowland systems compared to upland streams in the Namoi subregion assessment extent. Overbank flows also modify channel and floodplain geomorphology. Overbank flooding leads to deposition of nutrients and sediments on floodplains (Watts et al., 2009) and provides important wetland habitat for fish (NSW DPI, 2014) and frogs (Watts et al., 2009). Floodplain vegetation growth and life cycles are highly dependent on the depth, duration, frequency and timing of inundation (Roberts and Marston, 2011; Rogers, 2011). For example, regeneration of river red gum (*Eucalyptus camaldulensis*) is intimately linked to patterns of inundation along the riparian and floodplain zones, with regular flooding events required for seedling establishment (Roberts and Marston, 2011). The understorey composition in these forests is also closely linked to the flooding regime, with more regularly flooded sites having a sedge (*Carex, Eleocharis* spp.) dominated community and sites flooded less frequently containing native grasses (Bren and Gibbs, 1986). Overbank flooding maintains the health of floodplain vegetation through provision of freshwater, leaching of soil salinity and regeneration of floodplain species (Doble et al., 2012; Roberts and Marston, 2011). However, there is considerable uncertainty associated with the degree of connection between floodplains and alluvial aquifers at local and regional scales.

Freshes or pulse flows, characterised by moderate increases in streamflow, increase within-stream flow variability and play an important role in the regulation of water quality through the input of freshwater and flushing of deeper pools (Robson et al., 2009). Two main types of pulse flows are identified by the review of Watts et al. (2009): small and large pulses. Small pulses exceed baseflow and inundate some or all of the streambed (Figure 9) for time periods ranging from hours to days. Large pulses can reach flows up to bankfull stage and typically occur over periods of days to weeks (Figure 9). Flow pulses reset several key processes in the stream environment through active bedload transport, maintaining channel dimensions and scouring streambeds and banks (Watts et al., 2009). Larger stream pulses can represent important spawning triggers (King et al., 2009; NSW DPI, 2014) or inundate benches, anabranches and snags increasing habitat availability (Watts et al., 2009).

Mackay et al. (2014) outline 35 metrics that address the magnitude, frequency, duration and timing of low flows. Dominant low-flow metrics for ephemeral streams based on the analysis of Mackay et al. (2014) include:

- number of zero-flow days
- low-flow discharge (where the probability of exceedance is greater than 75% or 90%)
- coefficient of variation in these metrics
- variation in the seasonality of minimum flows.

Low flows and the cessation of flow play a critical role in maintaining longitudinal connectivity and linking of instream habitats. Cease-to-flow events dry out shallow habitats and can create chains of pools, isolated pools or completely dry riverbeds, depending on riverbed morphology (Robson et al., 2009). Rolls et al. (2012) propose four key principles outlining the mechanistic links between the flow-related attributes at the low end of the hydrograph and the attendant ecosystem processes. Low-flow and zero-flow attributes affect the composition, abundance and structure of aquatic biota by influencing the:

- physical extent of the habitat

- habitat conditions of water quality
- sources and exchange of material and energy
- restriction of habitat diversity and connectivity.

The ecologically relevant low-flow attributes are related to antecedent conditions, duration, magnitude, timing and seasonality, rate of change, and frequency that operate within a temporal hierarchy of the flow regime (Rolls et al., 2012).

The response of aquatic biota to declines in streamflow can be linear while longitudinal connectivity is maintained; but if flow ceases, a more severe threshold response is likely, corresponding to an abrupt loss of specific habitat, change in physicochemical conditions and ecosystem fragmentation (Boulton, 2003). The concept of ‘ramped’ and ‘stepped’ changes in biota in response to declining flows was proposed for macroinvertebrate assemblages by Boulton (2003). The drying river system moves through several discharge thresholds, involving firstly the isolation of riparian habitat, the cessation of flow and the eventual disappearance of surface water (Boulton, 2003). Flow intermittence, the temporary loss of surface water (Datry et al., 2014), prevents the transport of nutrients, biota and organic material downstream, and creates pool environments along the river channel, the quality of which may vary considerably depending on geomorphic condition, health of the extant riparian vegetation, length of the dry period and input of organic matter (Bond and Cottingham, 2008). Extended periods of no flow or an increase in the frequency of no-flow periods is likely to increase the levels of stress in the system through deteriorating water quality (e.g. increases in turbidity, reduced dissolved oxygen and increased temperatures), crowding of biota and reduced hydrological connectivity (Bond and Cottingham, 2008; Marsh et al., 2012) . These no-flow periods can affect seasonal habitat for some species and remove important refugia for other species (Dollar, 2004). Diversity of macroinvertebrates is closely linked to river drying, with the largest drops in species richness occurring in the early stages of drying (Leigh and Datry, 2017). The decline in taxon richness often results in invertebrate communities becoming dominated by ubiquitous taxa (Datry et al., 2014). Chessman et al. (2012) reported that macroinvertebrate assemblages in riffle habitats with fast, flowing water were dominated by aerophilic and rheophilic species, while riffle habitats exposed to severe flow reductions or cessation were dominated by thermophilic species. Marsh et al. (2012) also concluded that communities in streams that are usually perennial but cease to flow for short periods (weeks) will mostly recover the following season but that the community will decline if cease-to-flow periods recur over consecutive years. Alterations to flow intermittence has potentially cascading effects on adjacent ecosystems such as riparian and hyporheic zones (Datry et al., 2007; McCluney and Sabo, 2012).

Mackay et al. (2012) detail a low-flow classification based on 35 low-flow metrics calculated for 830 stream gauge records. Their work concluded that four low-flow metrics provided meaningful biological information in most situations:

- P90, the flow exceeded 90% of the time
- baseflow index
- average number of zero-flow or cease-to-flow days per year

- specific mean annual minimum flow (the average of the annual minimum flow divided by the catchment area).

Their recommendations include the caveat that these are general guidelines and the broad generalisations associated with refining this subset should only be used as a general guide to ecological conditions (Mackay et al., 2012).

Groundwater and river system interactions

While the interconnections between groundwater and river systems are poorly understood in many catchments globally (Ivkovic, 2009), the Namoi river basin has had several detailed studies that have investigated these relations. In general, the contribution of groundwater to baseflow has declined in the lower sections of the Namoi River because of groundwater abstraction from the surrounding alluvium (Giambastiani et al., 2012). The decrease in hydraulic head in recent decades has reversed the flow of groundwater, shifting the once 'gaining' condition of the river to a 'losing' one (CSIRO, 2007; Giambastiani et al., 2012). These trends in surface water – groundwater interactions may have significant implications for the riverine environment, particularly during low-flow periods. This section focuses on ecohydrological processes relevant to the ecological outcomes and complements the discussion of surface and groundwater interactions in Section 2.1.5 in the companion product 2.1-2.2 for the Namoi subregion (Aryal et al., 2018).

Andersen and Acworth (2009) studied the nature of surface water and groundwater exchange along a section of the Namoi River and a zone of perennial pools along Maules Creek (see Figure 10). This study detected zones of groundwater discharge along Maules Creek (reaches classified as 'Temporary lowland stream' or 'Permanent lowland stream' under the BA landscape classification; Bioregional Assessment Programme, Dataset 1) that flow between pools in the streambed sediments (sand and coarse gravel) (Andersen and Acworth, 2009). Further downstream, stream water appears to be recharging the aquifer when it comes into contact with highly permeable paleochannels (Andersen and Acworth, 2009). In a recent report concerning the assessment of ecohydrological responses to coal seam gas and coal mining (Andersen et al., 2016), much of Maules Creek (excluding the most downstream ~2 km) was characterised as predominantly a 'losing transition' stream with intermittent surface flow (Brunner et al., 2009). This definition implies that the capillary fringe of the watertable remains in contact with the stream and that floodplain and riparian vegetation can access this groundwater. However, lowering of the watertable can make this groundwater unavailable to vegetation (Andersen et al., 2016).

Figure 10 Riffle habitat along Maules Creek (‘Temporary lowland stream’ landscape class, ~15 km upstream from its junction with the Namoi River)

Credit: Bioregional Assessment Programme, Patrick Mitchell (CSIRO), January 2016

Stygofauna live in groundwater systems and are particularly sensitive to groundwater environmental disturbance because they are adapted to near steady-state environmental conditions and have very narrow spatial distributions (Hose et al., 2015). The shallow aquifers of the Namoi River and Peel River alluvium support diverse invertebrate and microbial assemblages (Korbel et al., 2013; Tomlinson, 2008). The most important factors influencing the community composition of stygofauna in the region were land use, soil type and carbon availability (Korbel et al., 2013). The microbial assemblages were more affected by ionic water quality and season of sampling (Korbel et al., 2013). Studies of stygofauna in the nearby Gwydir River alluvial aquifer concluded that human impacts on streamflow and aquifer conditions had a large influence on stygofauna community structure, with those bores exhibiting minimal riverine influence having higher richness and abundance (Menció et al., 2014). Experimental studies of drawdown in the Peel Valley alluvium found different responses among stygofauna to changes in the watertable, with copepods showing vertical movement to changing water availability in contrast to amphipods that did not increase their movement (Tomlinson, 2008).

Floodplain environment

The floodplain environment extends from the riparian zone adjacent to the stream channel back across the alluvial plain that receives flood waters at various intervals. The riparian environment is represented by the 'Floodplain riparian forest' and 'Floodplain riparian forest GDE' landscape classes and is dominated by tree species such as river red gum (*Eucalyptus camaldulensis*) and river sheoak (*Casuarina cunninghamiana*) (Benson et al., 2010). These are represented by the 'Eastern Riverine Forests' and 'Inland Riverine Forests' classes in the Keith vegetation classification system (Keith, 2004).

Adjacent to the riparian zone is the floodplain environment, representing the transition between the frequently flooded river channel and the upland environment. Landscape classes occurring in the floodplain environment include 'Floodplain grassy woodland' and 'Floodplain grassy woodland GDE'. This floodplain environment contains woodlands and various types of off-channel water bodies or wetlands with varying degrees of groundwater dependency (Holloway et al., 2013). The back plain environment tends to be dominated by woodland species such as poplar box (*Eucalyptus populnea*), black box (*E. largiflorens*), coolibah (*E. coolabah*), river coobah (*Acacia stenophylla*) and other *Eucalyptus* spp., shrubs and grasses (most commonly plains grass – *Austrostipa aristiglumis)* (Eco Logical, 2009). Off-channel water bodies are also interspersed along the floodplain and include the 'Floodplain wetland' and 'Floodplain wetland GDE' landscape classes. These tend to be palustrine wetlands, typically described as swamps, bogs, marshes and prairies (Aquatic Ecosystems Task Group, 2012). Flooding frequency, duration and depth tend to be reduced for the floodplain wetland landscape classes that tend to have a temporary water regime. Several listed ecological communities are found in the floodplain landscape group areas including the 'Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions', listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Alluvial aquifers form in deposited sediments such as gravel, sand, silt and/or clay within paleochannels, stream channels and the adjacent floodplain. Water is stored and transmitted to varying degrees through inter-granular voids, meaning that aquifers are generally unconfined, shallow and have localised flow systems (DSITIA, 2012). Groundwater expressed at the surface supports ecosystems occupying drainage lines, riverine water bodies, and lacustrine and palustrine wetlands. The riparian forests along much of the lowland streams in the assessment extent were mapped as being groundwater dependent under the NSW DPI GDE mapping approach (NSW Office of Water, Dataset 5). This is consistent with observations of *E. camaldulensis* that show clear dependency on groundwater (Kath et al., 2014; Thorburn and Walker, 1994). Groundwater uptake in the dominant tree species of floodplain woodland environments along the Liverpool Plains (i.e. 'Floodplain woodland' landscape class) such as *E. populnea* has not been as intensely studied. One study of *E. populnea* inferred likely groundwater uptake by comparing the water status of these trees compared to co-occurring shrubs and grasses (Anderson and Hodgkinson, 1997). Other woodland species, more widespread on the Castlereagh-Barwon floodplain, such as black box, have been studied in detail (Jolly and Walker, 1996), where groundwater uptake on the Chowilla anabranch region was closely related to groundwater salinity (Thorburn et al., 1993). When floodplain soils are flooded or receive significant rainfall, *E. largiflorens* switches its water uptake to shallower soil water sources, emphasising its ability to take advantage of the most energetically available soil water (Jolly and Walker, 1996). A study of water use by *E. populnea* in the Namoi Valley made similar findings in regard to water use patterns (Kalaitzis et al., 2000).

The nature of groundwater dependency in these floodplain tree species will determine how these species respond to potential drawdown of the watertable. Previous research has revealed links between groundwater depth and tree condition, but the nature of the response in terms of being ‘ramped’ (i.e. linear changes in condition in response to drawdown) versus ‘stepped’ (i.e. tree condition rapidly changes across critical thresholds) is not clearly defined for most floodplain species. *Eucalyptus* spp. are capable of exploiting large soil volumes, and rooting depths of some species such as *E. marginata* are capable of achieving depths of greater than 20 m (Dell et al., 1983). It is likely that roots are capable of tracking available soil water from deep alluvial aquifers where shallow sources are limited (Thorburn et al., 1993). Kath et al. (2014) used data from two dominant floodplain species, river red gum and poplar box, at 118 sites in the Condamine river basin to present evidence for a critical drawdown threshold in the range from 12.1 to 22.6 m for river red gum and 12.6 to 26.6 m for poplar box, beyond which canopy condition declined abruptly. Another study in a water-limited riparian environment found that transpiration decreased in response to a 9-m decline in groundwater levels, but that changes to foliage density were more influenced by variability between seasons and site conditions (Pfautsch et al., 2015). Tree water uptake of groundwater when growing over deeper watertables is generally less than where the watertable is shallower (e.g. O'Grady et al., 2006; Zencich et al., 2002). The rate of drawdown can also be critical to vegetation survival. Plant roots can remain in contact with a declining watertable if the rate of decline does not exceed the potential root growth rate; 3 to 15 mm/day for arid shrub and grass species (Naumburg et al., 2005).

Floodplain wetlands or off-channel water bodies are perhaps most affected by water resource development along Australia’s intensively managed river basins (Kingsford, 2000). These ecosystems are sustained by flood sequences that drive booms in their productivity (Leigh et al., 2010) and therefore any reduction in flows, particularly overbank flow events, will diminish the source of water and nutrients for these habitats. Despite being important sites of high biodiversity and providing key habitat for waterbirds (Kingsford, 1995), native fish (Closs et al., 2005), invertebrate species (Boulton and Lloyd, 1991) and microbes (Boon et al., 1996), their ecohydrological interactions are not as well understood as the riverine system (Kingsford, 2000). Flooding events provide water and organic matter that trigger a cascade of biological processes driven by the activity of microbes (Boon et al., 1996), zooplankton (Boulton and Lloyd, 1992) and plants (Bunn and Boon, 1993). Colonisers such as fish larvae and insects are brought into the wetland habitats when water conditions are suitable. Frogs (burrowing and non-burrowing) utilise the open-water habitats and produce tadpoles in the newly established water bodies (Jansen and Healey, 2003; Ocock et al., 2014). Waterbirds attracted to the abundant food sources move in to the temporary wetland habitats from more permanent water bodies elsewhere (Kingsford, 1995). Lignum (*Muehlenbeckia florulenta*) is an important element in these off-channel water bodies and can quickly respond to flooding or heavy rainfall through rapid leaf growth and/or flowering (Capon et al., 2009). The germination of aquatic macrophytes may also occur in response to inundation (Britton and Brock, 1994). Fringing floodplain trees also respond to flooding events through increased growth and recruitment with some species such as *E. camaldulensis* requiring a flooding sequence to ensure seedling survival (Roberts and Marston, 2011).

2.7.3.1.2 Qualitative mathematical model

A model for the floodplain or lowland riverine ecosystem (Figure 11) was developed based on the model for the 'Non-floodplain or upland riverine' (non-Pilliga) landscape classes (see Section 2.7.4.1.2) with additional components and processes associated with the floodplain system. The low-gradient stream channels in this floodplain landscape class lack significant amounts of fast-water habitats; therefore fast-water habitat variables, such as associated populations of fast-water invertebrates, tadpoles and native fishes (which are part of the model in Section 2.7.4.1.2) are omitted from the model here.

The major feature of the floodplain is the existence of off-channel water bodies, which are filled by connections to overbank floods and groundwater. These water bodies provide habitat for plankton (Boon et al., 1996), macrophytes (Bunn and Boon, 1993) and populations of fish (Closs et al., 2005), off-channel frogs (Ocock et al., 2014), and still-water invertebrates such as shrimps and snails (Boulton and Lloyd, 1991). Slow-water native fishes and some waterbird species are major predators of the off-channel frogs. Floodplain grasses, shrubs and trees provide inputs of coarse particulate organic matter to the stream system, and habitat for mammals, reptiles, frogs and birds (Bunn and Boon, 1993).

The volume of overbank flow (VOBF) determines the magnitude of flood events. VOBF was defined as the maximum daily streamflow during, or cumulative volume of, an overbank event. These flood events facilitate the transport of organic matter from the floodplain into the stream channel. Hypoxic blackwater events (so-called because high concentrations of dissolved organic matter leached from inundated detritus darkens the water) occur when the first flush of a flood event coincides with a peak in accumulated floodplain organic matter (Whitworth et al., 2012). Blackwater events severely lower pH and dissolved oxygen in floodwaters, adversely affecting many fish and aquatic invertebrates such as crayfish (Hladyz et al., 2011; McCarthy et al., 2014). The inundation period of the floodplain is an important determinant of populations of long-lived tadpoles, the composition of and emergence from the microinvertebrate 'egg bank' (Jenkins and Boulton, 2007), and the proportions of families of aquatic invertebrate communities (e.g. the richness of Ephemeroptera, Plecoptera and Trichoptera relative to Odonata, Coleoptera and Hemiptera; EPT/OCH ratio). Flood events can increase the relative dominance of hyporheic fauna over phreatic fauna (obligate stygobites) in aquifers alongside stream channels.

Riparian trees in this landscape (e.g. river red gum) access groundwater in the alluvium and are heavily dependent on overbank flows for their recruitment success (Roberts and Marston, 2011). Floodplain trees (i.e. trees outside of the riparian zone on top of river terraces such as black box) were described as being dependent on groundwater for their growth and survival, but their recruitment was not dependent on any specific overbank flow regime. A hydrologic flow regime (HR2) related to overbank flood flows was considered to be key in maintaining the soil moisture of floodplain soils for riparian trees.

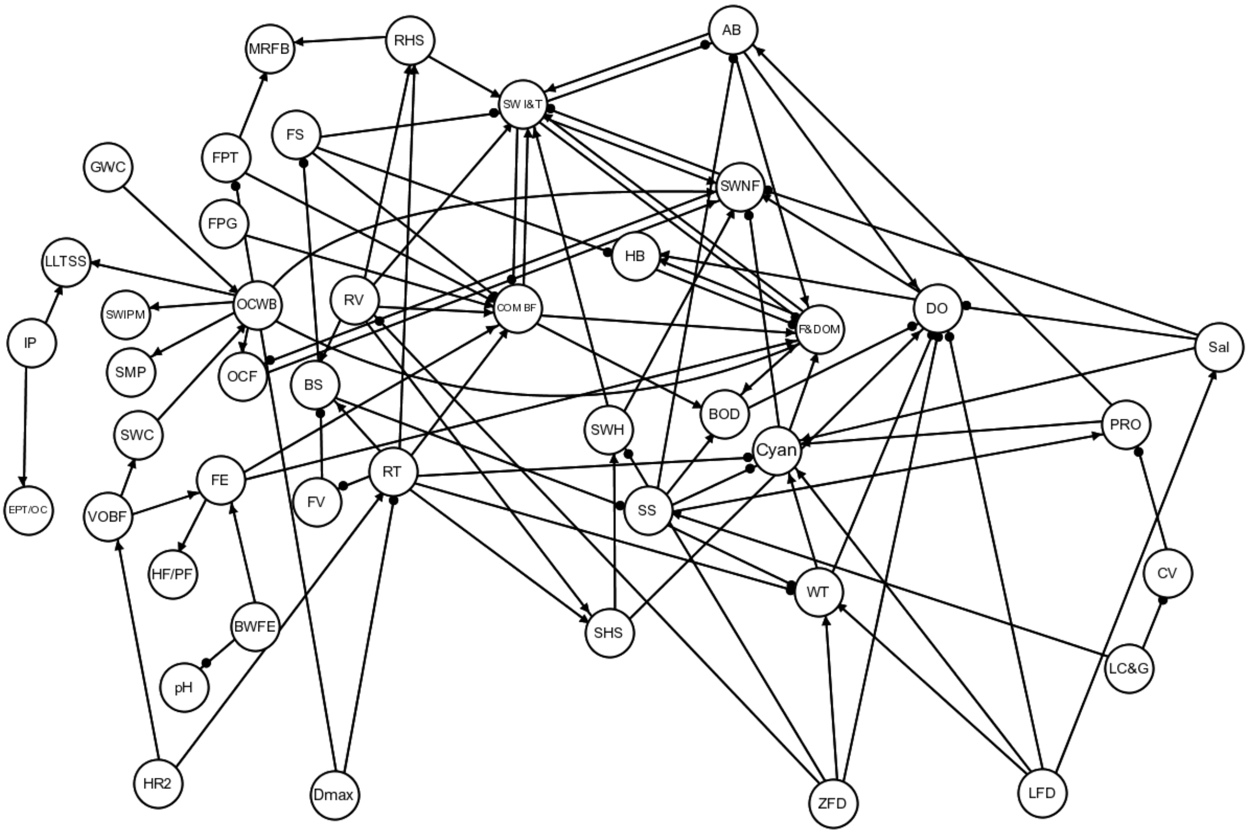

Figure 11 Signed digraph model of the 'Floodplain or lowland riverine' landscape group

Model variables are: algal bloom (AB), biological oxygen demand (BOD), bank stability (BS), blackwater flood event (BWFE), cyanobacteria (Cyan), coarse particulate organic matter and biofilm (COM BF), catchment vegetation (CV), dissolved oxygen (DO), Ephemeroptera, Plecoptera and Trichoptera richness relative to Odonata, Coleoptera and Hemiptera richness (EPT/OC), fine particulate and dissolved organic matter (F&DOM), flood event (FE), floodplain grasses (FPG), floodplain trees (FPT), fine sediments (FS), flood velocity (FV), groundwater connectivity (GWC), hyporheic biota (HB), hyporheic fauna relative to phreatic fauna (HF/PF), inundation period (IP), land clearing and grazing (LC&G), long-lived tadpoles, shrimps, crayfish, Odonata and snails (LLTSS), mammals, reptiles, frogs and birds (MRFB), off-channel frogs (OCF), off-channel water body (OCWB), acidity or basicity of water (pH), phosphorous runoff (PRO), riparian habitat structure (RHS), riparian trees (RT), riparian vegetation (e.g. sedges & rushes) (RV), salinity (Sal), stream habitat structure (SHS), submerged macrophytes (SMP), suspended sediment (SS), slow-water invertebrates and tadpoles (SW I&T), surface water connectivity (SWC), slow-water habitat (SWH), still-water invertebrates, plankton and macrophytes (SWIPM), slow-water native fishes (SWNF), volume of overbank flow (VOBF), water temperature (WT), maximum difference in drawdown (Dmax), low-flow days (LFD), zero-flow days (ZFD), hydrological regime 2 (HR2).
Data: Bioregional Assessment Programme (Dataset 6)

Surface water and groundwater modelling predict significant potential impacts to hydrological regime 2, low-flow days, zero-flow days, and maximum depth to groundwater level. Combinations of these impacts were considered in seven scenarios (Table 8).

Table 8 Summary of the (cumulative) impact scenarios (CISs) for the 'Floodplain or lowland riverine' landscape group

CIS	HR2	LFD	ZFD	Dmax
C1	–	0	0	+
C2	–	+	0	0
C3	–	+	+	0
C4	0	+	0	+
C5	0	+	+	+
C6	–	+	0	+
C7	–	+	+	+

Pressure scenarios are determined by combinations of no-change (0), increase (+) or a decrease (–) in the following signed digraph variables: hydrological regime 2 (HR2), low-flow days (LFD), zero-flow days (ZFD), and maximum difference in drawdown (Dmax).
Data: Bioregional Assessment Programme (Dataset 6)

Qualitative analyses of the signed digraph model (Figure 11) generally indicate a negative, neutral (zero) or ambiguous response prediction for biological variables within the floodplain or lowland riverine ecosystem (Table 9). The only biological variables that were predicted to respond positively to any of the cumulative impact scenarios was cyanobacteria (to six of the seven cumulative impact scenarios), algal blooms (to the first and seventh scenarios), and also off-channel frogs (OCF), the latter of which can be attributed, in part, to a predicted decline in their native fish predators. Riparian trees were predicted to decrease across all of the seven cumulative impact scenarios, while riparian vegetation (sedges and rushes) was predicted to decrease only in response to an increase in zero-flow days. Hyporheic fauna were predicted to decrease in proportion to phreatic fauna in cumulative impact scenarios that included a decrease in hydrological regime 2. Note that some variables in the signed digraph were isolated from any impacts due to the four scenarios, as there was no interaction pathway leading to them from the input variables of HR2, LFD, ZFD or Dmax (e.g., EPT/OC, pH, GWC). In all cases their predicted response was zero or no change, but for brevity these zero predictions were not included in Table 9 below.

Physical and habitat variables were also predicted to change in the cumulative impact scenarios, and with a decrease in riparian trees there as an associated increase in flood velocity, decline in bank stability and increase in fine sediments. Fine particulate and dissolved organic matter was generally predicted to increase, and coarse particulate organic matter and biofilm to decrease.

Table 9 Predicted response of the signed digraph variables in the floodplain or lowland riverine ecosystem to (cumulative) changes in hydrological response variables

Signed digraph variable (full name)	Signed digraph variable (shortened form)	C1	C2	C3	C4	C5	C6	C7
Slow-water invertebrates and tadpoles	SW I&T	(–)	?	?	?	?	(–)	(–)
Fine particulate and dissolved organic matter	F&DOM	?	?	(+)	(+)	(+)	(+)	(+)
Coarse particulate organic matter and biofilm	COM BF	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Fine sediments	FS	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Bank stability	BS	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Stream habitat structure	SHS	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Flood velocity	FV	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Riparian trees	RT	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Riparian vegetation (e.g. sedges and rushes)	RV	0	0	(–)	0	(–)	0	(–)
Biological oxygen demand	BOD	?	?	?	?	(+)	?	(+)
Algal bloom	AB	(+)	?	?	?	?	?	(+)
Hyporheic biota	HB	?	(–)	(–)	(–)	(–)	(–)	(–)
Riparian habitat structure	RHS	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Mammals, reptiles, frogs and birds	MRFB	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Slow-water native fishes	SWNF	(–)	(–)	–	(–)	(–)	(–)	–
Dissolved oxygen	DO	?	(–)	(–)	(–)	(–)	?	(–)
Water temperature	WT	(–)	?	?	?	?	?	?
Salinity	Sal	0	(+)	(+)	(+)	(+)	(+)	(+)
Phosphorous runoff	PRO	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Cyanobacteria	Cyan	?	(+)	(+)	(+)	(+)	(+)	(+)
Slow-water habitat	SWH	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Off-channel water body	OCWB	(–)	(–)	(–)	0	0	(–)	(–)
Off-channel frogs	OCF	?	(+)	(+)	(+)	(+)	(+)	(+)
Still-water invertebrates, plankton and macrophytes	SWIPM	(–)	(–)	(–)	0	0	(–)	(–)
Submerged macrophytes	SMP	(–)	(–)	(–)	0	0	(–)	(–)
Surface water connectivity	SWC	(–)	(–)	(–)	0	0	(–)	(–)
Floodplain trees	FPT	(–)	0	0	(–)	(–)	(–)	(–)
Flood event	FE	(–)	(–)	(–)	0	0	(–)	(–)
Volume of overbank flow	VOBF	(–)	(–)	(–)	0	0	(–)	(–)

Signed digraph variable (full name)	Signed digraph variable (shortened form)	C1	C2	C3	C4	C5	C6	C7
Long-lived tadpoles, shrimps, crayfish, Odonata and snails	LLTSS	(–)	(–)	(–)	0	0	(–)	(–)
Hyporheic fauna relative to phreatic fauna	HF/PF	(–)	(–)	(–)	0	0	(–)	(–)
Suspended sediment	SS	(+)	(+)	(+)	(+)	(+)	(+)	(+)

Qualitative model predictions that are completely determined are shown without parentheses. Predictions that are ambiguous but with a high probability (0.80 or greater) of sign determinancy are shown with parentheses. Predictions with a low probability (less than 0.80) of sign determinancy are denoted by a question mark. Zero denotes completely determined predictions of no change.
Data: Bioregional Assessment Programme (Dataset 6)

2.7.3.1.3 Choice of hydrological response variables and receptor impact variables

In BAs, the potential ecological impacts of coal resource development are assessed in two simulation periods – 2013 to 2042 and 2073 to 2102. These are labelled as the short- and long-assessment years, respectively. Potential ecological changes are quantified in BAs by predicting the state of a select number of receptor impact variables in the two simulation periods. These predictions are made conditional on the values of certain groundwater and surface water statistics that summarise the outputs of numerical model predictions in that landscape class in an interval of time that precedes the assessment year. In all cases these predictions also allow for the possibility that changes in the future may depend on the state of the receptor impact variable in the reference year 2012, and consequently this is also quantified by conditioning on the predicted hydrological conditions in a reference interval that precedes 2012 (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)).

For surface water and groundwater variables in the Namoi subregion, the reference assessment interval is defined as the 30 years preceding and including 2012 (i.e. 1983 to 2012). For surface water variables in the Namoi subregion, the short-assessment interval is defined as the 30 years preceding the short-assessment year (i.e. 2013 to 2042), and the long-assessment interval is defined as the 30 years that precede the long-assessment year (i.e. 2073 to 2102). For groundwater, maximum drawdown (metres) and time to maximum drawdown are considered across the full 90-year window (i.e. 2013 to 2102).

In BAs, choices of receptor impact variables must balance the project's time and resource constraints with the objectives of the assessment and the expectations of the community (companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018)). This choice is guided by selection criteria that acknowledge the potential for complex direct and indirect effects within perturbed ecosystems, and the need to keep the expert elicitation of receptor impact models tractable and achievable (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)).

For a subset of landscape classes within the 'Floodplain or lowland riverine' group, the qualitative modelling workshop identified five hydrological response variables as key drivers of the surface water and groundwater regimes that were thought to (i) be instrumental in maintaining and shaping the ecosystem, and (ii) have the potential to change due to coal resource development. All of the ecological components and processes represented in the qualitative model are potential receptor impact variables and all of these are predicted to vary as the hydrological factors vary either individually or in combination (Table 10).

Following advice received from participants during (and after) the qualitative modelling workshop, and guided by the availability of experts for the receptor impact modelling workshop, the scope of the BA numerical modelling and the receptor impact variable selection criteria, the receptor impact models focused on the following relationships:

1. the response of the floodplain riparian trees to changes in hydrological regime 2 (EventsR3.0) and maximum groundwater drawdown (dmaxRef)
2. the response of tadpoles from the *Limnodynastes* genus to changes in hydrological regime 2 (EventsR3.0)
3. the response of aquatic macroinvertebrates to changes in the cease-to-flow components of the surface water regime (ZQD and ZME).

The hydrological factors identified by the participants in the qualitative modelling workshops have been interpreted as a set of hydrological response variables. The hydrological response variables are summary statistics that: (i) reflect these hydrological factors, and (ii) can be extracted from BA's numerical surface water and groundwater models during the reference, short- and long-assessment intervals defined previously. The hydrological factors and associated hydrological response variables for the relevant classes in the 'Floodplain or lowland riverine' landscape group are summarised in Table 10. The precise definition of each receptor impact variable, typically a species or group of species represented by a qualitative model node, was determined during the receptor impact modelling workshop.

Using this interpretation of the hydrological response variables, and the receptor impact variable definitions derived during the receptor impact modelling workshop, the relationships identified in the qualitative modelling workshop were formalised into three receptor impact models (Table 11).

Table 10 Summary of the hydrological response variables used in the receptor impact models for the floodplain or lowland riverine landscape classes, together with the signed digraph variables that they correspond to

Signed digraph variable	Hydrological response variable	Definition
GW	dmaxRef	Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012)
GW	tmaxRef	The year that the maximum difference in drawdown relative to the reference period (1983 to 2012) (dmaxRef) occurs
HR2	EventsR3.0	The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.
ZFD	ZQD	The number of zero-flow days per year, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.
ZFD	ZME	The maximum length of spells (in days per year) with zero flow, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

Table 11 Summary of the three receptor impact models developed for the floodplain or lowland riverine landscape classes in the Namoi subregion

Relationship being modelled	Receptor impact variable (with associated sample units)	Hydrological response variable
Response of the floodplain riparian forests to changes in hydrological regime 2 and groundwater	Annual mean projected foliage cover of forests dominated by river red gum (*E. camaldulensis*)	EventsR3.0 dmaxRef tmaxRef
Response of tadpoles to changes in hydrological regime 2	Probability of presence of tadpoles from *Limnodynastes* genus (species *dumerilii*, *salmini*, *interioris* and *terraereginae*), sampled using standard 30 cm dip net	EventsR3.0
Response of aquatic macroinvertebrates to changes in zero-flow regime	Average number of families of aquatic macroinvertebrates in edge habitat sampled using the NSW AUSRIVAS method for edges	ZQD ZME

Hydrological response variables are as defined in Table 10.

2.7.3.1.4 Receptor impact models

Floodplain riparian forests

Table 12 summarises the elicitation design matrix for the projected foliage cover of riparian trees in the 'Floodplain riparian forest' and 'Floodplain riparian forest GDE' landscape classes. The design point identifiers are simply index variables that identify the row of the elicitation design matrix. They are included here to maintain an auditable path between analysis and reporting.

The first design point provides for an estimate of the uncertainty in mean projected foliage cover across the landscape class in the reference year 2012 (Yref). The remaining design points represent hydrological scenarios that span the uncertainty in the values of the hydrological response variables in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years.

Table 12 Elicitation design matrix for annual mean projected foliage cover of river red gum in the 'Floodplain or lowland riverine' landscape group in the Namoi subregion zone of potential hydrological change

Identifier	EventsR3.0	dmaxRef	Yref	Year	tmaxRef
1	0.33	0.00	na	2012	0
26	0.38	20.20	0.07	2042	2103
28	0.10	0.20	0.22	2042	2001
48	0.67	0.20	0.22	2042	2103
15	0.67	4.46	0.07	2042	2052
36	0.67	20.20	0.22	2042	2001
52	0.10	20.20	0.22	2042	2103
86	0.38	4.46	0.22	2102	2001
61	0.10	20.20	0.07	2102	2001
73	0.10	0.20	0.07	2102	2103
57	0.67	0.20	0.07	2102	2001
92	0.38	0.20	0.22	2102	2052
108	0.67	20.20	0.22	2102	2103

Receptor impact modelling elicitation design matrix for annual mean projected foliage cover, over a 100 m x 100 m transect in floodplain riparian forests. Design points for Yref in the future (short- and long-assessment periods) were calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers) are either default values or values determined by groundwater and surface water modelling. Hydrological response variables are as defined in Table 10. na = not applicable
Data: Bioregional Assessment Programme (Dataset 6)

Design point identifiers 15 through to 108 (as listed in Table 12) represent combinations of the three hydrological response variables (dmaxRef, tmaxRef, EventsR3.0), together with high and low values of Yref (see companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). The high and low values for Yref were calculated during the receptor impact modelling workshop following the experts' response to the first design point, and then automatically included within the design for the elicitations at the subsequent design points.

The receptor impact modelling methodology allows for a very flexible class of statistical models to be fitted to the values of the receptor impact variables elicited from the experts at each of the design points (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). The model fitted to the elicited values of mean foliage projected cover for the floodplain riparian forest landscape classes is summarised in Figure 12 and Table 13. The fitted model takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \sum_{j=1}^{3} \beta_{h_j} x_{h_j} \quad (1)$$

where x_0 is an intercept term (a vector of ones), x_f is a binary indicator variable scored 1 for the case of an assessment in the short- or long-assessment year, x_l is a binary indicator variable scored 1 for the case of an assessment in the long-assessment year, x_r is a continuous variable that represents the value of the receptor impact variable in the reference year (Yref, set to zero for the case of an assessment in the reference year), $x_{h_j}, j = 1 \ldots 3$ are the (continuous or integer) values of the three hydrological response variables (dmaxRef, tmaxRef and EventsR3.0), η is the linear predictor, *h* is an invertible link function and *y* is the expected response (Hosack et al., 2018). Note that the modelling framework provides for more complex models, including quadratic value of, and in interactions between, the hydrological response variables but in this instance the simple linear model (Equation 1) was identified as the most parsimonious representation of the experts’ responses.

The model estimation procedure adopts a Bayesian approach. The model coefficients $(\beta_0, \beta_f, \beta_l, \beta_r, \beta_{h_j})$ are assumed to follow a multivariate normal distribution. The Bayesian estimation procedure quantifies how compatible different values of the parameters of this distribution are with the data (the elicited expert opinion) under the model. The (marginal) mean and 80% central credible intervals[1] of the three hydrological response variable coefficients are summarised in partial regression plots in Figure 12, whilst Table 13 summarises the same information for all seven model coefficients.

The model indicates that the experts’ opinion provides strong evidence for Yref having a positive effect on average projected foliage cover (Figure 12, Table 13). This suggests that given a set of hydrological response variable values in the future, a site with a higher projected foliage cover at the 2012 reference point is more likely to have a higher projected foliage cover in the future than a site with a lower projected foliage cover value at this time point. This reflects the lag in the response of projected foliage cover to changes in hydrological response variables that would be expected of mature trees with long life spans.

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[1] A central credible interval is the region in the centre of a posterior or prior distribution that contains a specified amount of the probability of the distribution, such that there is equal probability above and below the interval. Hence, an 80% central credible interval is defined as the range of values with posterior (or prior) probability (1 – 0.8)/2 above and below the interval.

The model also indicates that the experts’ opinion provides strong evidence for dmaxRef having a negative effect on average percent projected foliage cover (Figure 12). This suggests that percent projected foliage cover will decrease as groundwater drawdown increases due to coal resource development. The model predicts that (holding all other hydrological response variables constant at the midpoint of their elicitation range) the mean of the average percent projected foliage cover will drop from just under 15% without any change in groundwater level, to about 10% if the levels decrease by 20 m relative to the reference level in 2012 (Figure 12). There is, however, considerable uncertainty in these predictions, with an 80% chance that the projected foliage cover will lie somewhere between approximately 5% and 30% on the short-assessment period, and somewhere between roughly 2% and 20% in the long-assessment period. In relation to dmaxRef, Yrs2tmax is also found significant (Figure 12). The interpretation is that long-term drawdown will cause a larger decrease in projected foliage cover than short-term drawdown.

The model indicates that the experts’ opinion provides strong evidence for EventsR3.0 having a positive effect on average percent projected foliage cover (Figure 12). The model predicts that (holding all other hydrological response variables constant at the midpoint of their elicitation range) the mean of the average percent foliage cover will increase from just under 12% without any change in overbank events frequency, to about 18% if the frequency increases to 0.7 (relative to the reference level of 0.33 in 2012).

Finally, the model also indicates some diverging influence between short-term and long-term influence (Figure 12). For the short-assessment period, experts believe in a relative increase of projected foliage cover, while they expect a decrease in the long-term assessment. An interpretation is that the effects of changes in hydrology are not immediate on projected foliage cover, and a worsening of the conditions starting today will only be observed by 2102.

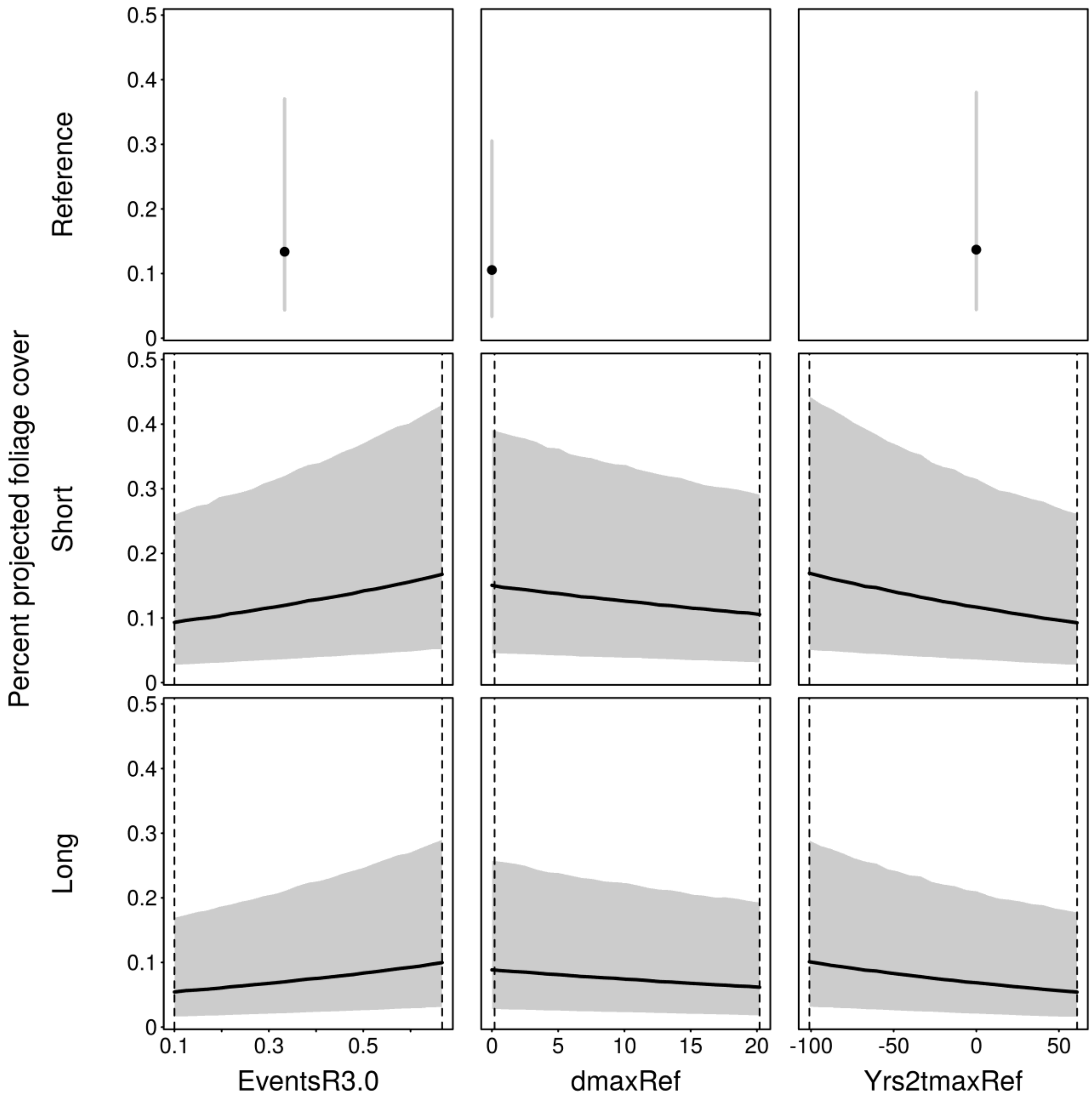

Figure 12 (Top row) Predicted mean (black dot) and 80% central credible interval (grey line) of annual mean projected foliage cover, over a 100 m x 100 m transect in floodplain riparian forest landscape classes under reference hydrological conditions. (Middle and bottom rows) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of each hydrological response variable on annual mean projected foliage cover, holding all other hydrological response variables constant at the midpoint of their elicitation range (during risk estimation all vary hydrological response variables simultaneously)

Dashed vertical lines show hydrological response variable range used in the elicitation. EventsR3.0 and dmaxRef are as defined in Table 10. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102). The numbers on the y-axis range from 0 to 1 as the receptor impact model was constructed using the proportion for the statistical modelling. They should be interpreted as a percent foliage cover ranging from 0 to 100%.
Data: Bioregional Assessment Programme (Dataset 6)

Table 13 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for annual mean projected foliage cover in floodplain riparian forest landscape classes

	Mean	q10	q90
(Intercept)	–2.38	–3.56	–1.19
future1	1.99	0.711	3.28
long1	–0.531	–0.94	–0.123
Yref	0.98	0.656	1.3
EventsR3.0	1.1	0.486	1.72
dmaxRef	–0.0188	–0.0368	–0.000716
Yrs2tmaxRef	–0.00397	–0.00735	–0.000586

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). Yref quantifies the value of the receptor impact variable during the reference period. Hydrological response variables EventsR3.0 and dmaxRef are as defined in Table 10. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102).
Data: Bioregional Assessment Programme (Dataset 6)

Floodplain wetlands

Table 14 summarises the elicitation matrix for the probability of the presence of tadpoles for the floodplain wetland landscape classes. The first design point – design point identifier 1 – addresses the predicted variability (across the landscape class in the reference interval) in overbank flows (EventsR3.0), capturing the lowest and highest predicted values together with two intermediate values (Table 14). This design point provides for an estimate of the uncertainty in probability of presence of tadpoles across the floodplain wetland landscape classes in the reference year 2012 (Yref; Table 14).

Table 14 Elicitation design matrix for probability of the presence of tadpoles from *Limnodynastes* genus (*dumerilii*, *salmini*, *interioris* and *terraereginae*) in pools and riffles in the 'Floodplain or lowland riverine' landscape group in the Namoi subregion zone of potential hydrological change

Identifier	EventsR3.0	Yref	Year
1	0.33	na	2012
2	0.38	0.5	2042
6	0.67	0.8	2042
10	0.10	0.8	2102
9	0.67	0.5	2102
11	0.38	0.8	2102
61	0.10	0.5	2042
7	0.17	0.5	2042

Receptor impact modelling elicitation design matrix for probability of presence of tadpoles in pools and riffles habitat in floodplain wetlands, sampled using standard 30 cm dip net. Design points for Yref in the future (short- and long-assessment periods) were calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers) are either default values or values determined by groundwater and surface water modelling. Hydrological response variable EventsR3.0 is as defined in Table 10. na = not applicable
Data: Bioregional Assessment Programme (Dataset 6)

Design points 2 to 61 inclusive (as listed in Table 14) represent scenarios that span the uncertainty in the predicted values of overbank flood events in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years, combined with high and low values of Yref. Again, the high and low values for Yref were calculated during the receptor impact modelling workshop.

The fitted model for probability of the presence of tadpoles takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \beta_{h_1} x_{h_1} + \beta_{h_2} x_{h_2} \quad (2)$$

where the terms x_0, x_f, x_l and x_r are as before and x_{h_1} is the value of EventsR3.0 (x_{h_2} relates to the quadratic term). The (marginal) mean and 80% central credible interval of the coefficient for this hydrological response variable are summarised in the partial regression plots in Figure 13, whilst Table 15 summarises the same information for all five model coefficients.

The hydrological response variable in the tadpole model varies during the reference interval and the future interval. The model indicates that the experts' elicited information supports the hypothesis that an increase in EventsR3.0 will have a positive effect on the probability of the presence of tadpoles (with a quadratic term suggesting a plateau past a number of overbank flood events, then a decrease). The model suggests that the probability of tadpoles is fairly uncertain across the floodplain wetland landscape classes with values between 0.35 to 0.80 under historical conditions (EventsR3.0 = 0.33), holding all other covariates at their mid-values. As the number of overbank flow events increases, however, experts were of the opinion that the probability of tadpoles would increase with values 1 and 0.60 falling within the 80% credible interval under highly flooded conditions (EventsR3.0 >0.6 day) (Figure 13).

There was very little evidence in the elicited data to suggest that this effect would be substantially different in the future assessment years. Again, this is indicated by the almost identical partial regression plots in the reference, short- and long-assessment years (Figure 13), and the relatively large negative 10th and positive 90th percentiles for the long and future coefficients in Table 15. The model does, however, suggest that the experts' uncertainty increased for predictions in the future assessment years relative to the reference year.

The best-fitting model in this case is unable to eliminate the possibility that the probability of tadpoles in the reference years has no influence on the probability of tadpoles in the future years. This is indicated by the fact that the model automatically dropped this variable from the model. This suggestion is consistent with the hypothesis that there is likely to be very little lag in the response of this short-lived group to changes in the hydrological response variables.

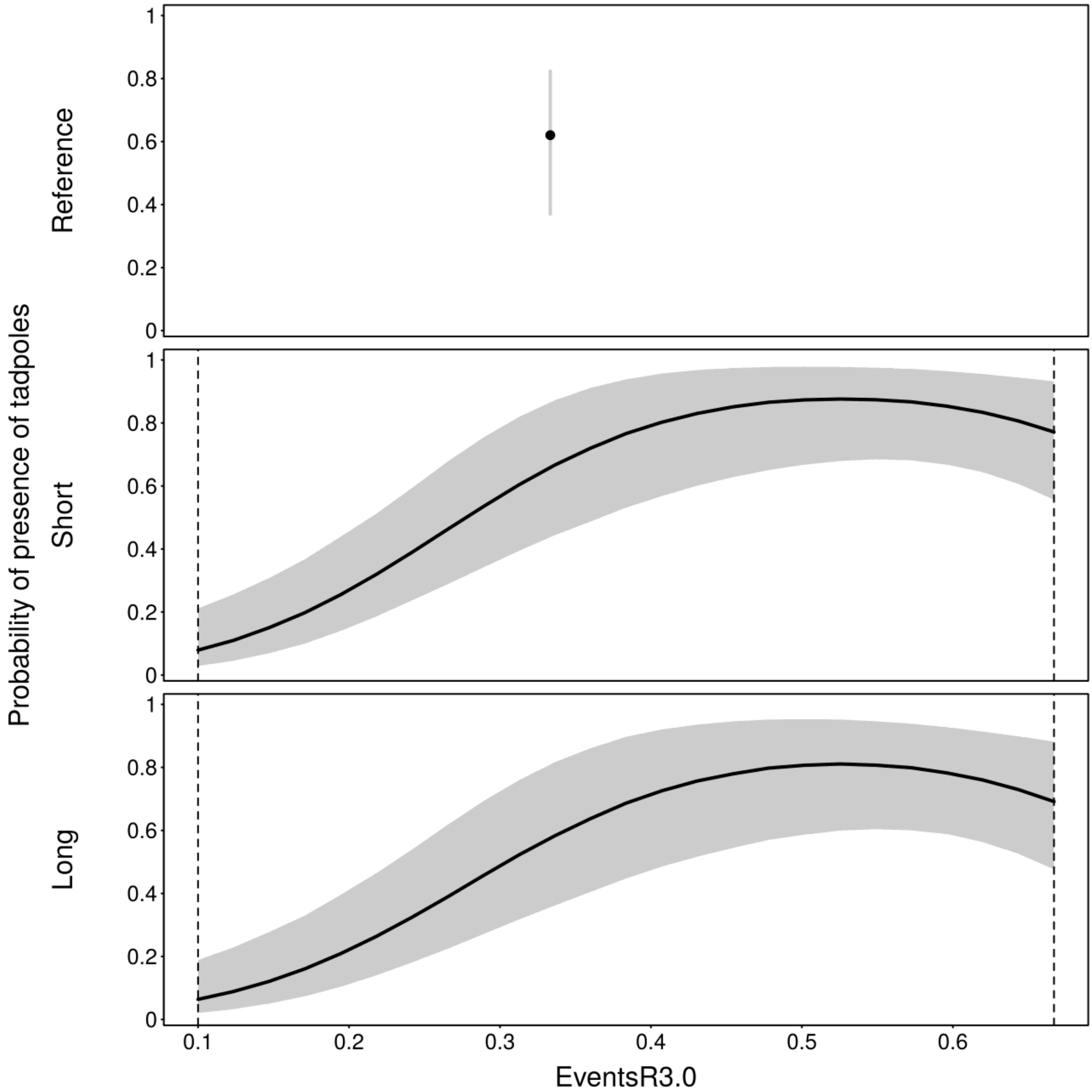

Figure 13 (Top row) Predicted mean (black dot) and 80% central credible interval (grey line) of probability of the presence of tadpoles in pools and riffle habitat in floodplain wetland landscape classes under reference hydrological conditions. (Middle and bottom panels) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of hydrological response variable EventsR3.0 on probability of the presence of tadpoles in pools and riffle habitat in floodplain wetlands

Dashed vertical lines show hydrological response variable range used in the elicitation. EventsR3.0 is as defined in Table 10.
Data: Bioregional Assessment Programme (Dataset 6)

Table 15 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for probability of the presence of tadpoles in pools and riffle habitat in floodplain wetlands

	Mean	q10	q90
(Intercept)	−4.17	−6.3	−2.03
future1	−0.0208	−1.04	1.0
long1	−0.228	−0.921	0.464
EventsR3.0	18.7	9.33	28.1
I(EventsR3.0^2)	−17.7	−28.4	−7.13

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). Yref quantifies the value of the receptor impact variable during the reference period. EventsR3.0 is as defined in Table 10. I(EventsR3.0^2) quantifies the quadratic effect of EventsR3.0.
Data: Bioregional Assessment Programme (Dataset 6)

Lowland riverine landscape classes

Table 16 summarises the elicitation matrix for the average number of families of aquatic macroinvertebrates in edge habitat sampled using the NSW AUSRIVAS method or referred to here as simply the average number of families of aquatic macroinvertebrates. The first six design points – design points 1 to 7 as shown in the table – address the predicted variability (across the lowland riverine landscape class in the reference interval) in ZQD (zero-flow days (averaged over 30 years) subsequently referred to in this section as 'zero-flow days') and ZME (maximum length of spells with zero flow, averaged over a 30-year period), capturing the lowest and highest predicted values together with two intermediate values. These design points provide for an estimate of the uncertainty in aquatic macroinvertebrate family abundance across the landscape classes in the reference year 2012 (Yref).

Design points 10 to 27 inclusive (as listed in Table 16) represent scenarios that span the uncertainty in the predicted values of ZQD and ZME in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years, combined with high and low values of Yref. Again, the high and low values for Yref were calculated during the receptor impact modelling workshop.

The fitted model for number of families of macroinvertebrates takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \beta_{h_1} x_{h_1} + \beta_{h_2} x_{h_2} \quad (3)$$

where the terms x_0, x_f, x_l and x_r are as before and x_{h_1} is the integer value of ZQD and x_{h_2} is the integer value of ZME. The (marginal) mean and 80% central credible interval of the coefficient for these hydrological response variables are summarised in the partial regression plots in Figure 14, whilst Table 17 summarises the same information for all six model coefficients.

Table 16 Elicitation design matrix for average number of families of aquatic macroinvertebrate in edge habitat sampled using the NSW AUSRIVAS method for edges in the ‘Floodplain or lowland riverine’ landscape group in the Namoi subregion zone of potential hydrological change

Identifier	ZQD	ZME	Yref	Year
4	164.85	79.13	na	2012
5	327.44	8.72	na	2012
3	164.85	39.57	na	2012
2	164.84	0.82	na	2012
7	329.70	79.13	na	2012
1	0.00	0.00	na	2012
14	347.00	153.00	11.0	2042
10	339.51	13.32	11.0	2042
8	0.00	0.00	11.0	2042
11	173.00	67.10	11.0	2042
26	173.00	153.00	4.9	2042
27	173.00	153.00	11.0	2102
16	172.99	0.90	4.9	2102
19	347.00	67.10	4.9	2102

Receptor impact model elicitation design matrix for average number of families of aquatic macroinvertebrate in edge habitat in permanent and temporary lowland streams. Design points for Yref in the future (short- and long-assessment periods) were calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers) are either default values or values determined by groundwater and surface water modelling. Hydrological response variables ZQD and ZME are as defined in Table 10. na = not applicable
Data: Bioregional Assessment Programme (Dataset 6)

The hydrological response variable in the macroinvertebrates model varies during the reference interval and the future interval. The model indicates that the experts’ elicited information strongly supports the hypothesis that an increase in ZQD and/or ZME will have a negative effect on the number of families of macroinvertebrates. The model suggests that it can vary substantially across the landscape class from less than 5 to almost 20 when ZQD >0, holding all other covariates at their mid-values. As the number of zero-flow days increases, however, experts were of the opinion that the number of families would drop quite dramatically with values less than 0.5 falling within the 80% credible interval under very intermittent flow conditions (ZFD >300 days) (Figure 14).

There was very little evidence in the elicited data to suggest that this effect would be substantially different in the future assessment years. Again, this is indicated by the almost identical partial regression plots in the reference, short- and long-assessment years (Figure 14), and the relatively large negative 10th and positive 90th percentiles for the long and future coefficients in Table 17. The model does, however, suggest that the experts’ uncertainty increased for predictions in the future assessment years relative to the reference year.

The best-fitting model is unable to eliminate the possibility that the average number of families of macroinvertebrates in the reference years has no influence on its number in the future years. This is indicated by the fact that the model automatically dropped this variable from the model. This suggestion is consistent with the hypothesis that there is likely to be very little lag in the response of this measure of aquatic macroinvertebrate family richness in response to changes in the hydrological response variables.

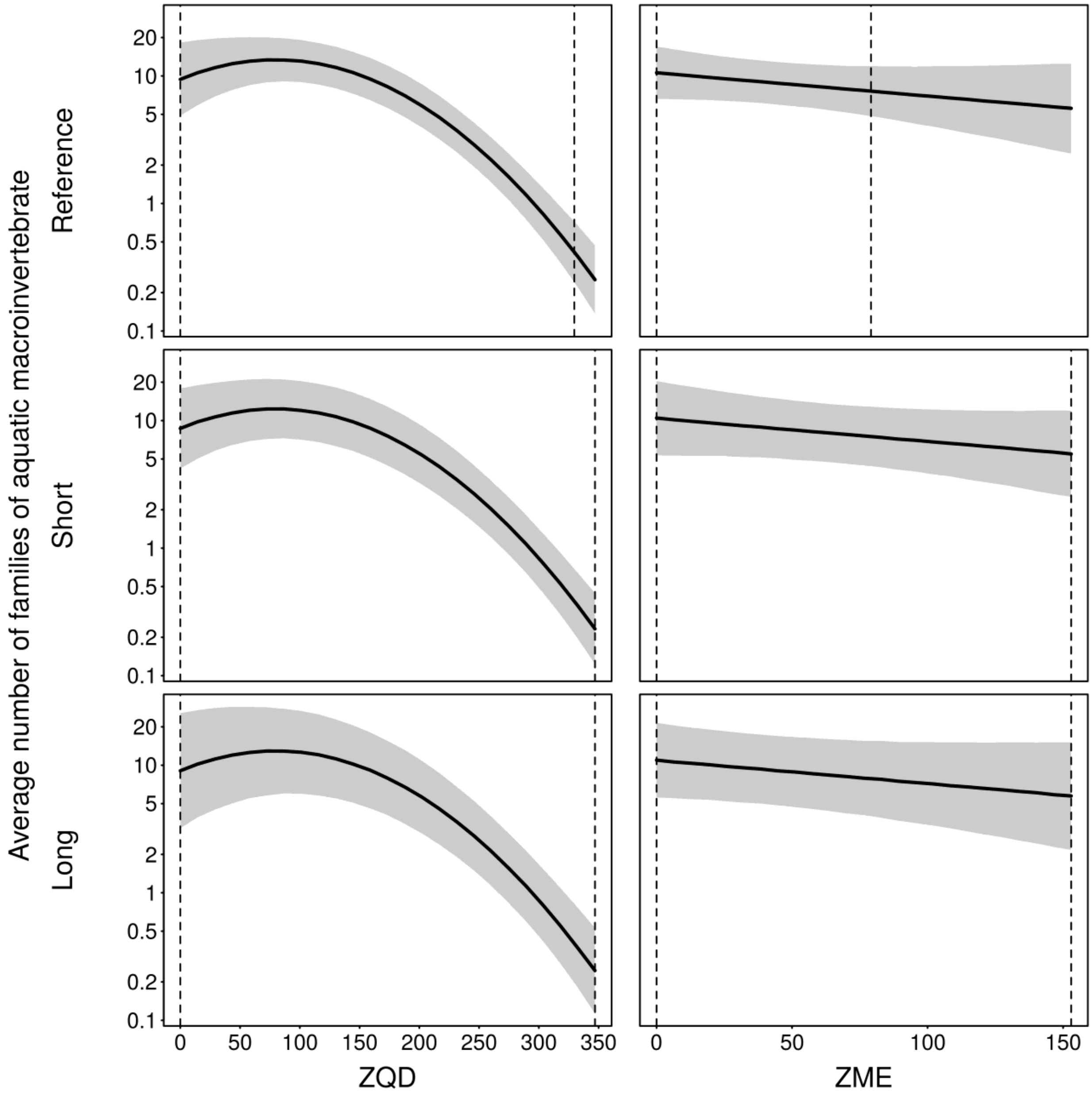

Figure 14 (Top row) Predicted mean (black dot) and 80% central credible interval (grey polygon) of average number of families of aquatic macroinvertebrate in edge habitat in lowland riverine landscape classes under reference hydrological conditions. (Middle and bottom rows) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of each hydrological response variable on average number of families of aquatic macroinvertebrate in edge habitat in lowland riverine landscape classes, holding all other hydrological response variables constant at the midpoint of their elicitation range (during risk estimation all hydrological response variables vary simultaneously)

Dashed vertical lines show hydrological response variable range used in the elicitation. ZQD and ZME are as defined in Table 10.
Data: Bioregional Assessment Programme (Dataset 6)

Table 17 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for average number of families of aquatic macroinvertebrates in edge habitat in lowland riverine landscape classes

	Mean	q10	q90
(Intercept)	2.41	1.83	2.99
future1	0.0724	–0.495	0.64
long1	0.0462	–0.734	0.826
ZQD	0.00884	0.00188	0.0158
ZME	–0.00419	–0.0107	0.00233
I(ZQD^2)	–5.55e-05	–7.36e-05	–3.75e-05

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). ZQD and ZMA are as defined in Table 10. I(ZQD^2) quantifies the quadratic effect of ZQD.
Data: Bioregional Assessment Programme (Dataset 6)

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2.7.4 'Non-floodplain or upland riverine' landscape group

Summary

The 'Non-floodplain or upland riverine' landscape group comprises ecosystems that tend to be in elevated portions of the catchment and includes a diverse range of aquatic and terrestrial ecosystems. The upland riverine landscape classes make up approximately 64% of riverine classes in the Namoi assessment extent, while the upland terrestrial landscape classes make up approximately 10% of this extent.

The majority of the riverine classes within the 'Non-floodplain or upland riverine' group in the zone of potential hydrological change are classified as 'Temporary upland stream' (745.1 km), reflecting the intermittent or ephemeral nature of many of the stream segments. The remainder of the stream network is classified as 'Permanent upland stream' (92.6 km), 'Temporary upland stream groundwater-dependent ecosystem (GDE)' (34.7 km) and 'Permanent upland stream GDE' (14.2 km). The majority of the non-riverine landscape in the 'Non-floodplain or upland riverine' landscape group in the zone of potential hydrological change is classified as 'Grassy woodland GDE' (72.8 km^2). This landscape class represents a relatively diverse set of vegetation communities that occupy several different landforms with groundwater contributions from potentially different flow paths and hydrogeology. The 'Upland riparian GDE' class makes up a very small area of the zone of potential hydrological change (2.9 km^2) along with a small area of 'Non-floodplain wetland' (13.1 km^2) and 'Non-floodplain wetland GDE' (8.1 km^2) landscape classes.

Three different components of the 'Non-floodplain or upland riverine' landscape group were considered for the qualitative modelling. The upland riverine model included all upland riverine classes and the adjacent riparian vegetation ('Upland riparian forest GDE' landscape class). Three receptor impact models were formulated based on this qualitative model: upland riverine (two separate models) and upland riparian forest. Cease-to-flow attributes of the surface water regime were assigned as hydrological response variables for the upland riverine model and the receptor impact variables included changes in macroinvertebrate assemblages and the probability of the presence of tadpoles. For upland riparian forest, groundwater drawdown and overbank flow events were considered the key hydrological response variables. The potential ecosystem impacts on this landscape class were quantified using projected foliage cover. In addition to the upland riverine system, a qualitative model was developed for the non-floodplain wetlands in this landscape group.

Receptor impact modelling indicates that foliage cover during the reference period is an important predictor of foliage cover in the future, and that the experts' opinion provides strong evidence for maximum additional drawdown having a negative effect, and the number of events having a positive effect on average projected foliage cover. Receptor impact modelling also strongly supports the hypothesis that an increase in the mean number of zero-flow days and/or the mean maximum length of zero-flow spells will have a negative effect on probability of the presence of tadpoles and on the number of families of macroinvertebrates, despite the experts being quite uncertain about average values.

2.7.4.1 Non-floodplain or upland riverine

2.7.4.1.1 Description

This section describes and presents ecological modelling for the 'Non-floodplain or upland riverine' landscape group for the non-Pilliga regions in the zone of potential hydrological change of the Namoi subregion. This landscape group encompasses the riverine habitat, adjacent riparian areas and remnant patches of vegetation across different positions in the landscape classed as 'Grassy woodland GDE' (Figure 15). The upland environment includes the following riverine classes:

- 'Permanent upland stream'
- 'Permanent upland stream GDE'
- 'Temporary upland stream'
- 'Temporary upland stream GDE'.

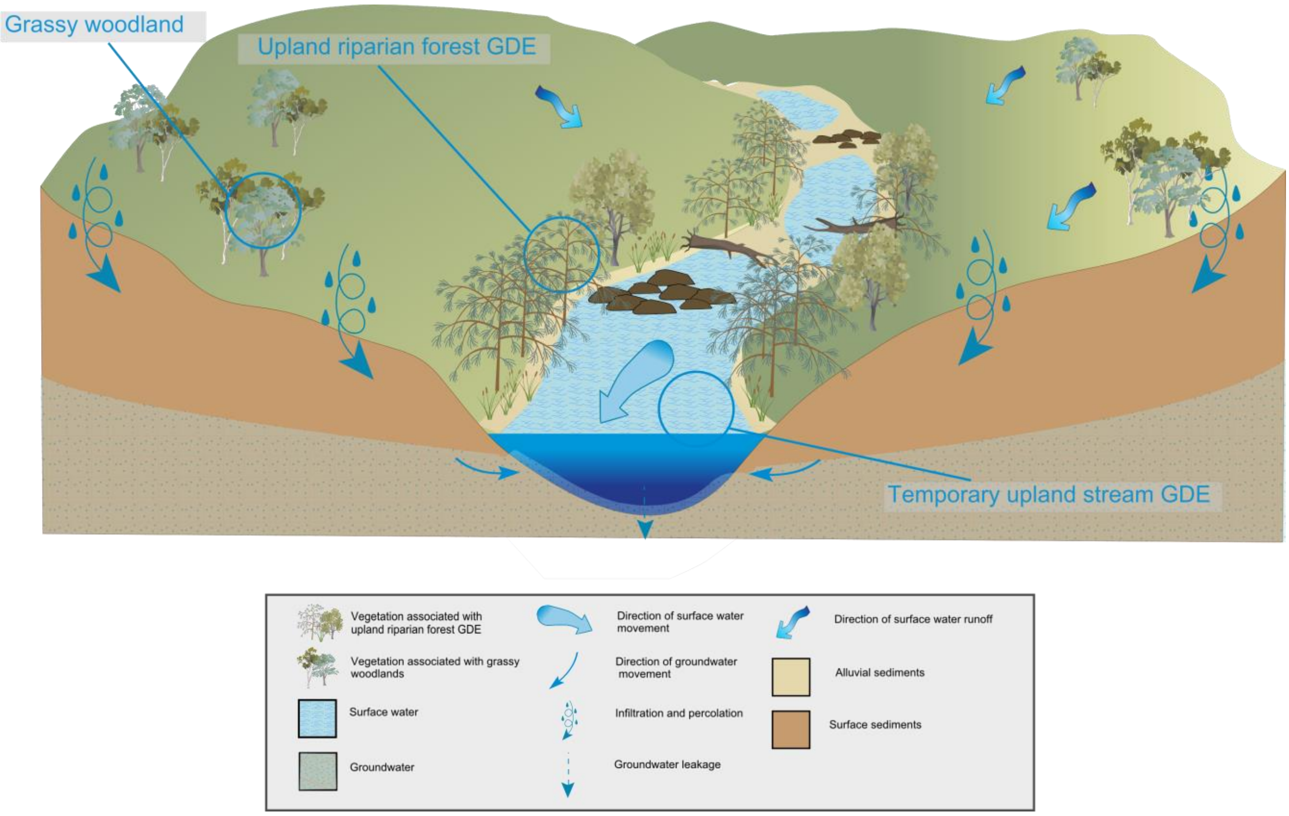

Figure 15 Conceptual model of the hydrological connectivity and flow paths of a typical upland riverine environment that has a gaining connection to the underlying watertable

Some key landscape classes are labelled including: 'Temporary upland stream GDE', 'Upland riparian forest GDE' and 'Grassy woodland' (non- water-dependent).
GDE = groundwater-dependent ecosystem
Source: Symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols/)

The majority (84%) of the riverine environment non-Pilliga portion of the zone of potential hydrological change in the Namoi subregion is classified as 'Temporary upland stream' (745.1 km or 13.5% of the zone), reflecting the intermittent or ephemeral nature of many of the stream segments (Table 6). The remainder of the stream network is classified as 'Permanent upland stream' (92.6 km or 1.7%), 'Temporary upland stream GDE' (34.7 km or 0.6%) and 'Permanent upland stream GDE' (14.2 km or 0.3%) (Table 6). Most of these riverine landscape classes are located in the Kaputar and Liverpool Plains Interim Biogeographic Regionalisation for Australia (IBRA) subregions (Department of Sustainability, Environment, Water, Population and Communities, Dataset 1) and form the upper reaches and tributaries of Coxs Creek, Mooki River, Maules Creek and the Namoi River (Figure 16). There are small segments of the upland riverine system classified as GDE, reflecting the gaining nature of some reaches across the zone of potential hydrological change. The hydrological connectivity within a typical upland riverine environment where the streambed is receiving water from the watertable is detailed in Figure 15.

The majority of the non-riverine landscape in the 'Non-floodplain or upland riverine' group in the zone of potential hydrological change is the 'Grassy woodland GDE' class (72.8 km^2 or 1% of the zone of change; Table 6). The 'Upland riparian forest GDE' makes up a very small area of the zone (2.9 km^2 or <0.1% of the zone) along with a small area of 'Non-floodplain wetland' (13.1 km^2 or 0.2% of the zone) and 'Non-floodplain wetland GDE' landscape classes (8.1 km^2 or 0.1% of the zone). These wetland classes are mostly found along the western portion of the 'mid-Namoi' reporting region of the zone of potential hydrological change and in the southern region of the 'upper-Namoi' reporting region and intersects with part of Goran Lake.

Table 18 Areas and/or lengths of the ‘Non-floodplain or upland riverine’ landscape classes within the entire assessment extent and the non-Pilliga region of the zone of potential hydrological change of the Namoi subregion

Landscape class	Area in assessment extent (km^2)	Area in the zone of potential hydrological change (km^2)	Percentage of total area in zone of potential hydrological change (%)	Length in assessment extent (km)	Length in the zone of potential hydrological change (km)	Percentage of total length in zone of potential hydrological change (%)
Grassy woodland GDE	3,247.6	72.8	1%	na	na	na
Non-floodplain wetland	130.3	13.1	0.2%	na	na	na
Non-floodplain wetland GDE	23.5	8.1	0.1%	na	na	na
Upland riparian forest GDE	87.4	2.9	<0.1%	na	na	na
Permanent upland stream	0.1	0	0%	1,646.1	92.6	1.7%
Permanent upland stream GDE	1.1	0.1	<0.1%	227.4	14.2	0.3%
Temporary upland stream	0	0	0%	16,512.8	745.1	13.5%
Temporary upland stream GDE	0.1	0	0%	464	34.7	0.6%
Total – ‘Non-floodplain or upland riverine’ classes	**3,490.1**	**97**	**1.4%**	**18,850.3**	**886.6**	**16.1%**
Total – all landscape classes	**35,659.6**	**7013.9**	**100%**	**29,558.3**	**5521.2**	**100%**

GDE = groundwater-dependent ecosystem, na = not applicable
Data: Bioregional Assessment Programme (Dataset 2)

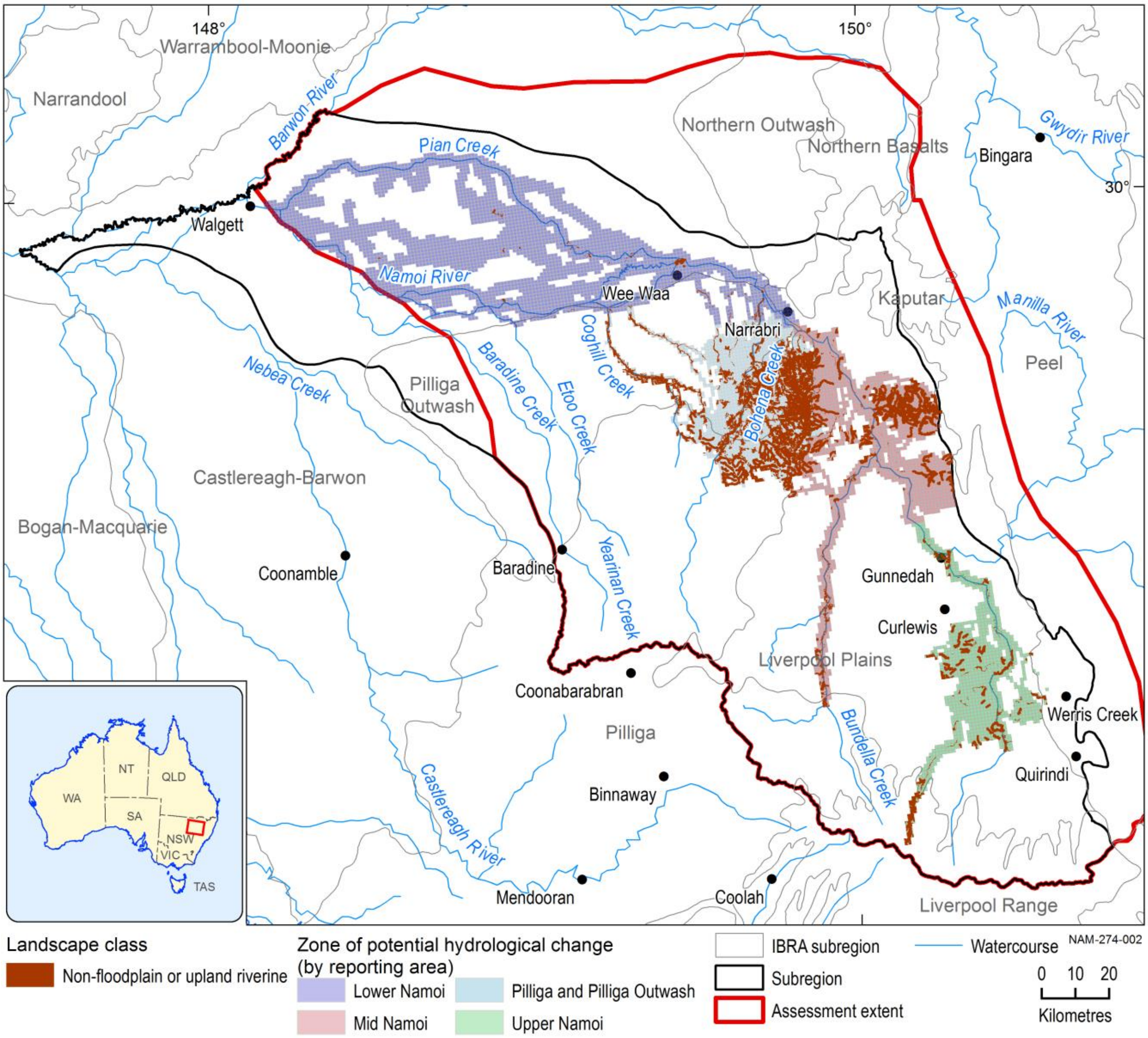

Figure 16 Location of the 'Non-floodplain or upland riverine' landscape group within the different reporting areas of the zone of potential hydrological change

IBRA = Interim Biogeographic Regionalisation for Australia
Data: Bioregional Assessment Programme (Dataset 2, Dataset 3); Bureau of Meteorology (Dataset 4)

Surface water flow regimes in upland riverine systems tend to be more intermittent than in lowland riverine systems for many of the streams in the Namoi region. The extent of flooding from overbank flows is reduced compared to lowland riverine systems and alluvial development tends to be confined (Figure 15).

The major stream segments of the Namoi catchment were classified into seven river 'zones' by Thoms (1998), each with its own set of physical characteristics. The location and extent of the zones reflect the geomorphological influences on the control of flow of water and sediment. The upland riverine landscape classes discussed here fall largely into zones associated with 'pool' and 'constrained' zones with stable channels and pool and/or run habitats (Thoms et al., 1999). The 'armour', 'mobile' and 'meander' zones typically have more active sediment movement from channel and bed stores and some floodplain development in the 'meander' zone (Thoms et al., 1999). Thoms et al. (1999) also investigated riverine health in these upland streams noting that these parts of the river systems were generally in better physical condition than those lowland parts of the Namoi river basin. Some exceptions of upland river systems with poor physical condition were the Mooki River and Coxs Creek with a lack of riparian vegetation and bank instability (Thoms et al., 1999).

Ecologically important components of the surface water regime for upland streams can be broadly summarised (Dollar, 2004) as: cease-to-flow periods, periods of low flow, freshes, and periods of high flow (including overbench and overbank flows) as illustrated in Figure 9. Further background information on the linkages between these flow components and riverine ecosystems is covered in the preceding section on lowland riverine systems (Section 2.7.3).

The riparian vegetation occurring along the upland riverine stream network is classified as 'Grassy woodland GDE' (72.8 km^2) or 'Upland riparian forest GDE' (2.9 km^2). The 'Grassy woodland GDE' landscape class is predominantly comprised of vegetation belonging to the 'Western Slopes Grasslands' and 'Western Slopes Dry Sclerophyll Forests' and 'Brigalow Clay Plain Woodlands' classes defined by Keith (2004). Thus, this landscape group represents a relatively diverse set of vegetation communities that occupy several different landforms with groundwater contributions from potentially different flow paths and hydrogeological units. In the eastern portion of the zone of potential hydrological change (i.e. mid-Namoi basin) the upland riverine and associated terrestrial classes (e.g. 'Grassy woodland GDE') are associated with basalt or permeable rock types. In these systems, groundwater is stored and transmitted through fractures, inter-granular spaces or weathered zones, and is typically discharged to the surface at contact zones between two rock types (DSITI, 2015). The 'Upland riparian forest GDE' class comprises the 'Eastern Riverine Forests' Keith class and is dominated by *Casuarina cunninghamiana* (river sheoak).

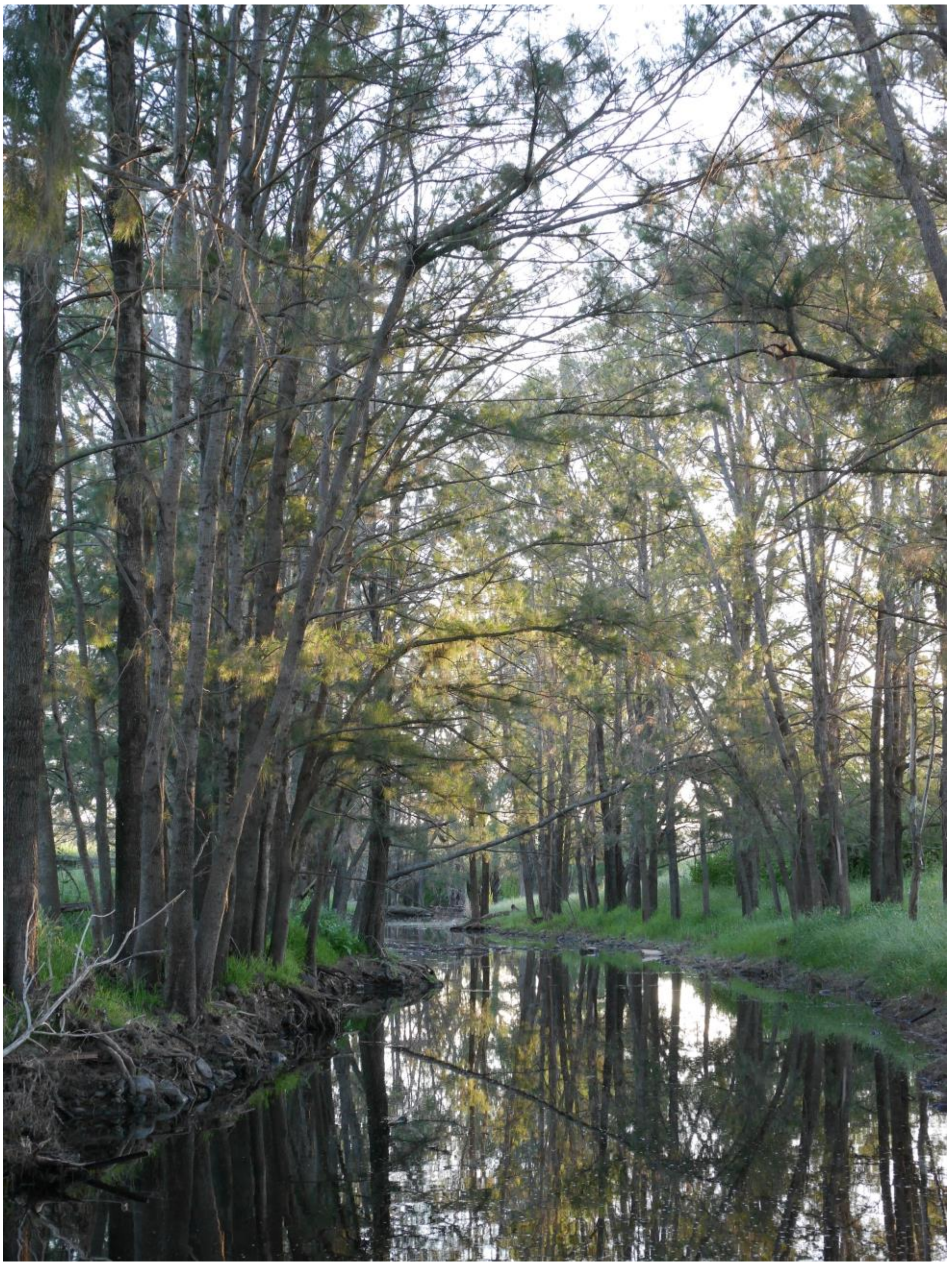

Figure 17 A typical stream reach classified as ‘Temporary upland stream’ lined with *Casuarina cunninghamiana* (10 km north or Quirindi)

Credit: Bioregional Assessment Programme, Patrick Mitchell (CSIRO), January 2016

Riparian vegetation performs important functions for upland riverine ecosystems including: stabilising stream banks, filtering sediment, acting as habitat and corridors for terrestrial biota, regulating nutrient and pollutants and modifying stream microclimate (Gregory et al., 1991; Naiman and Decamps, 1997). Upland streams typical of the Namoi subregion, where the riparian vegetation is relatively intact (Figure 17), have a larger proportion of the stream that is shaded thus regulating stream conditions and limiting algal growth (Bunn, 1986). The riparian vegetation provides a large proportion of the organic carbon and other energy inputs to the surrounding catchment (Briggs and Maher, 1983; Thomas et al., 1992). The allochthonous detritus enters the stream either directly or after spending some time breaking down along the stream bank or floodplain (Reid et al., 2008). Both leaf and woody material provide important habitat structures within the stream and potential sources of carbon for some animals such as stream invertebrates and tadpoles (McKie and Cranston, 2001). These inputs of organic matter help to sustain the underlying hyporheic biota via interstitial flow through the streambed (Boulton et al., 2010).

2.7.4.1.2 Qualitative model

Upland riverine

A discussion of landscape classes for streams at the qualitative modelling workshop determined that the streams could be divided into two general groups based on their landscape classification – upland riverine and lowland riverine. The riparian vegetation and floodplain (which is only relevant for the lowland riverine group) were also included as components of the model. As described above, the upland riverine systems have intermittent flow characteristics across much of the stream network in the Namoi assessment extent. The qualitative modelling had an initial focus on populations of stream invertebrates and tadpoles inhabiting the streams in periods of flow with ecological preferences for fast- or slow-water habitats (Figure 18). These habitats are defined and enhanced by structure provided by riparian trees and other riparian vegetation, such as sedges and rushes. Riparian trees (the most common being river sheoak) provide a critical role in reducing water velocity of floods and stabilising stream banks, thereby reducing erosion and the entry of fine and suspended sediments into the stream channel (Bunn, 1986). Riparian trees are dependent on soil moisture which is replenished by overbank flows, the frequency of which was described as a specific hydrological regime (HR1). Riparian trees, sedges and rushes contribute to the structure of riparian stream habitat which benefits stream and semi-aquatic invertebrate populations, as well as mammals, reptiles, frogs and birds (Figure 18). They also contribute to stores of coarse particulate organic matter, which, when submerged, has an associated biofilm community (Figure 18). The breakdown of coarse particulate organic matter contributes to stores of fine particulate organic matter and dissolved organic matter (Figure 18). These stores of organic matter are the primary carbon (energy) source for populations of stream invertebrates and tadpoles in both slow- and fast-water habitats (Figure 18). Hyporheic biota living in subsurface sediments are sustained by the supply of particulate organic matter, dissolved organic matter and high levels of dissolved oxygen through the streambed via interstitial flow (Hose et al., 2015).

Concentrations of dissolved oxygen within the stream and streambed are influenced by flow volume (e.g. may decline during low flows and high water temperatures), and are reduced by biological oxygen demand, which depends on levels of submerged and dissolved organic matter in the stream (Reid et al., 2008) (Figure 18). Phosphorus adsorbed onto particles of suspended sediment and in runoff from cleared lands increases the growth of cyanobacteria and the likelihood of algal blooms (Figure 18). Cyanobacteria and algal photosynthesis can increase levels of dissolved oxygen during the day, and algae are an important food resource for populations of some invertebrates and tadpoles; both contribute to stores of organic matter that lead to increased levels of biological oxygen demand (Reid et al., 2008). Water temperature is regulated by the volume of streamflow, the amount of shade from riparian trees, and the proportional contribution of groundwater and water turbidity (Naiman and Decamps, 1997). High water temperatures promote cyanobacteria and reduce dissolved oxygen in stream water (Bowling and Baker, 1996). Top aquatic predators in the system include native fishes with preferences for slow- or fast-water habitats. Many species of native fishes are sensitive to the concentration of dissolved oxygen and are suppressed by high salinity and the toxic effects of cyanobacteria (Bowling and Baker, 1996).

Riparian trees in the upland riverine landscape class were described as being dependent on groundwater, such that the changes to the maximum depth of the watertable would be an important hydrologic response variable (Figure 18). River sheoaks were described as requiring periodic overbank flows for successful regeneration (Roberts and Marston, 2011). The frequency and duration of zero- and low-flow days were considered as important in maintaining slow- and fast-water habitats, riparian vegetation, and water quality (Bond et al., 2008).

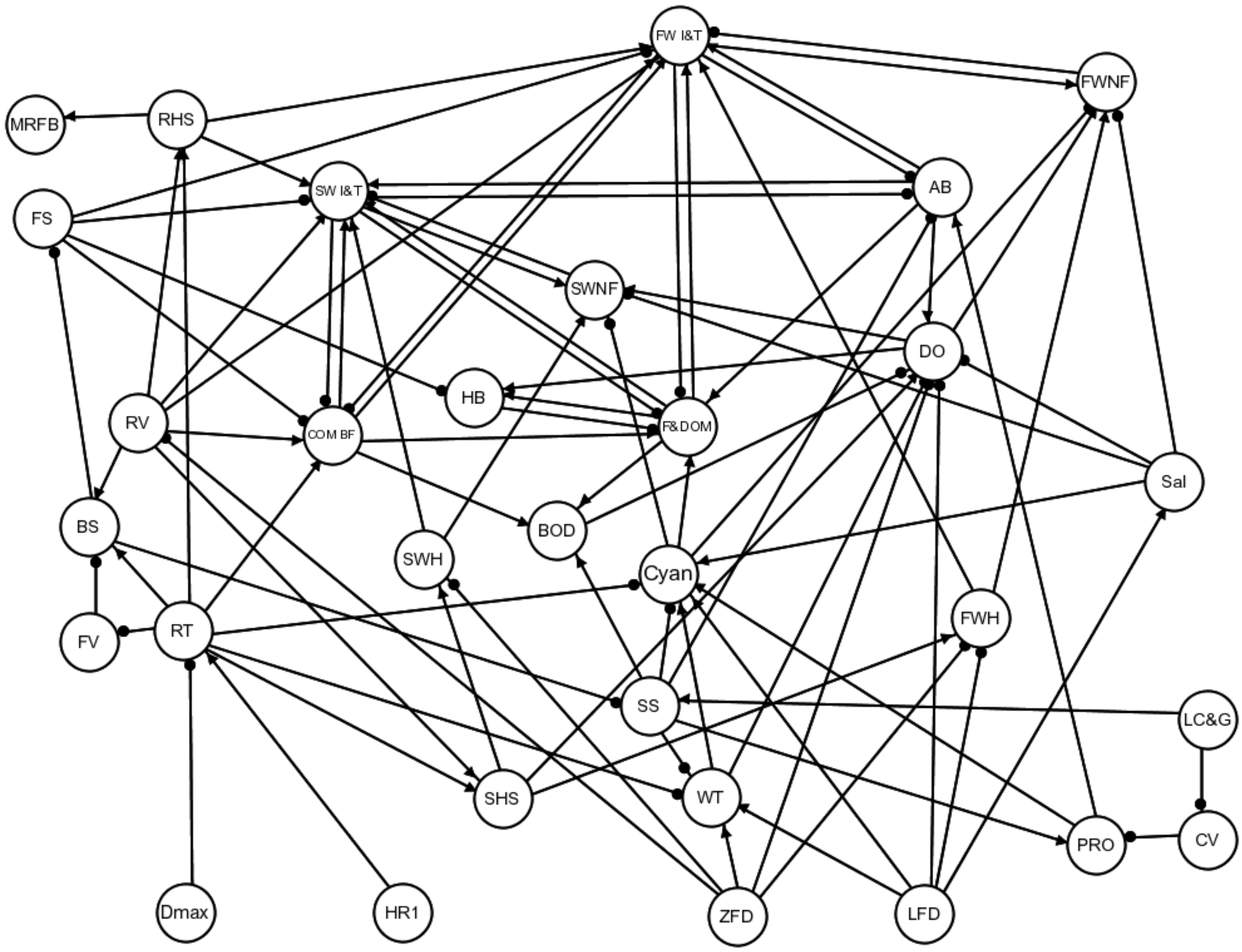

Figure 18 Signed digraph model of upland riverine landscape classes

Model variables are: algal bloom (AB), biological oxygen demand (BOD), bank stability (BS), cyanobacteria (Cyan), coarse particulate organic matter and biofilm (COM BF), catchment vegetation (CV), maximum decrease in watertable (Dmax), dissolved oxygen (DO), fine particulate and dissolved organic matter (F&DOM), fine sediments (FS), flood velocity (FV), fast-water invertebrates and tadpoles (FW I&T), fast-water habitat (FWH), fast-water native fishes (FWNF), hyporheic biota (HB), land clearing and grazing (LC&G), mammals, reptiles, frogs and birds (MRFB), phosphorous runoff (PRO), riparian habitat structure (RHS), riparian trees (RT), riparian vegetation (e.g. sedges & rushes) (RV), salinity (Sal), stream habitat structure (SHS), suspended sediment (SS), slow-water invertebrates and tadpoles (SW I&T), slow-water habitat (SWH), slow-water native fishes (SWNF), water temperature (WT), zero-flow days (ZFD), low-flow days (LFD), hydrological regime 1 (HR1).
Data: Bioregional Assessment Programme (Dataset 5)

Surface water and groundwater modelling predict significant potential impacts to hydrological regime 1 (overbank flows), low-flow days, zero-flow days, and maximum depth to groundwater level. Combinations of these impacts were considered in seven scenarios (Table 19).

Table 19 Summary of the (cumulative) impact scenarios (CISs) for upland riverine landscape classes

CIS	HR1	LFD	ZFD	Dmax
C1	–	0	0	+
C2	–	+	0	0
C3	–	+	+	0
C4	0	+	0	+
C5	0	+	+	+
C6	–	+	0	+
C7	–	+	+	+

Pressure scenarios are determined by combinations of no-change (0), increase (+) or a decrease (–) in the following signed digraph variables: hydrological regime 1 (HR1, i.e. overbank flow), low-flow days (LFD), zero-flow days (ZFD), and maximum decrease in watertable (Dmax).
Data: Bioregional Assessment Programme (Dataset 5)

Qualitative analyses of the signed digraph model (Figure 18) generally indicate a negative or ambiguous response prediction for all biological variables within the upland riverine ecosystem (Table 20). Riparian trees were predicted to decrease across all of the seven cumulative impact scenarios, as were both groups of native fishes. Similarly, hyporheic fauna were predicted to decrease in all cumulative impact scenarios, while riparian vegetation (sedges and rushes) were predicted to decrease only in response to an increase in zero-flow days (i.e. C3, C5, C7).

Table 20 Predicted response of the signed digraph variables in the upland riverine landscape classes to (cumulative) changes in hydrological response variables

Signed digraph variable (full name)	Signed digraph variable (shortened form)	C1	C2	C3	C4	C5	C6	C7
Slow-water invertebrates and tadpoles	SW I&T	(–)	?	?	?	?	?	?
Fine particulate and dissolved organic matter	F&DOM	(+)	(+)	(+)	(+)	(+)	(+)	+
Coarse particulate organic matter and biofilm	COM BF	(–)	–	–	–	–	–	–
Fine sediments	FS	+	(+)	(+)	(+)	(+)	+	+
Bank stability	BS	–	(–)	(–)	(–)	(–)	–	–
Stream habitat structure	SHS	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Flood velocity	FV	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Riparian trees	RT	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Riparian vegetation (e.g. sedges and rushes)	RV	0	0	(–)	0	(–)	0	(–)
Biological oxygen demand	BOD	?	?	?	?	?	?	(+)
Algal bloom	AB	(+)	?	?	?	?	?	(+)
Fast-water invertebrates and tadpoles	FW I&T	(–)	?	?	?	?	?	?
Hyporheic biota	HB	(–)	–	–	–	–	–	–
Riparian habitat structure	RHS	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Mammals, reptiles, frogs and birds	MRFB	(–)	(–)	(–)	(–)	(–)	(–)	(–)
Slow-water native fishes	SWNF	–	–	–	–	–	–	–
Fast-water native fishes	FWNF	–	–	–	–	–	–	–
Dissolved oxygen	DO	(–)	(–)	–	(–)	–	–	–
Water temperature	WT	(–)	?	?	?	?	?	?
Salinity	Sal	0	(+)	(+)	(+)	(+)	(+)	(+)
Phosphorous runoff	PRO	+	(+)	(+)	(+)	(+)	+	+
Cyanobacteria	Cyan	?	(+)	(+)	(+)	(+)	(+)	(+)
Fast-water habitat	FWH	(–)	(–)	–	(–)	–	(–)	–
Slow-water habitat	SWH	(–)	(–)	(–)	(–)	(–)	(–)	–

Qualitative model predictions that are completely determined are shown without parentheses. Predictions that are ambiguous but with a high probability (0.80 or greater) of sign determinancy are shown with parentheses. Predictions with a low probability (less than 0.80) of sign determinancy are denoted by a question mark. Zero denotes completely determined predictions of no change.
Data: Bioregional Assessment Programme (Dataset 5)

Non-floodplain wetland

The non-floodplain wetland qualitative model focused on internally draining lakes in the Namoi assessment extent, with the Lake Goran ecosystem being the primary focus, but also including Yarrie Lake (both defined as 'Non-floodplain wetland' landscape class). The majority of Lake Goran's bed is frequently dry, and when lake levels are at a minimum many areas of the exposed bed are used for agriculture (Environment Australia, 2001). When the lake fills from flood events the lake water is used for irrigation. In a filled state, the lake has a number of isolated islands that provide significant roosting and nesting habitat for migratory birds. By comparison, Yarrie Lake is more permanent, smaller than Lake Goran and has no islands (Environment Australia, 2001).

The modelling exercise initially focused on the wetted area of the lake, which is increased during flood events in its catchments via local sheet flow over nearby valley slopes or channel flow in tributary streams. When the wetted area of the lake increases, it provides a surge of growth in populations of algae, macrophytes, aquatic invertebrates and fish, which are capitalised on by bird populations, including the functional groups of herbivorous, insectivorous, piscivorous and wading birds (Driver et al., 2012) (Figure 19). An increase in the wetted area of the lake favours the growth of river red gum, poplar box and lignum shrubs, with river red gum and poplar box providing critical habitat and resources for koalas, and roosting and nesting sites for populations of piscivorous, insectivorous and wading birds (Figure 19). Additionally, an increase in the wetted area provides feeding opportunities for wading birds and also contributes to roosting and nesting opportunities in predator-free areas by the isolation of islands within the lake perimeter. Lignum shrubs, and other fringing vegetation, provide habitat and resources for reptiles, frogs and terrestrial invertebrates, and populations of insectivorous birds (Figure 19).

Lignum shrubs, river red gum and poplar box depend on groundwater (Roberts and Marston, 2011). Potential impacts to this ecosystem from coal resource development includes local interception of rainfall from open-cut mines that can reduce recharge of groundwater and diminish the magnitude of sheet flow during high rainfall events (Figure 19), where this effect is localised into lowland channels adjacent to the coal mine and not tributary channels in general. Coal seam gas and open-cut coal mine development was depicted as having the potential to reduce the level of the watertable.

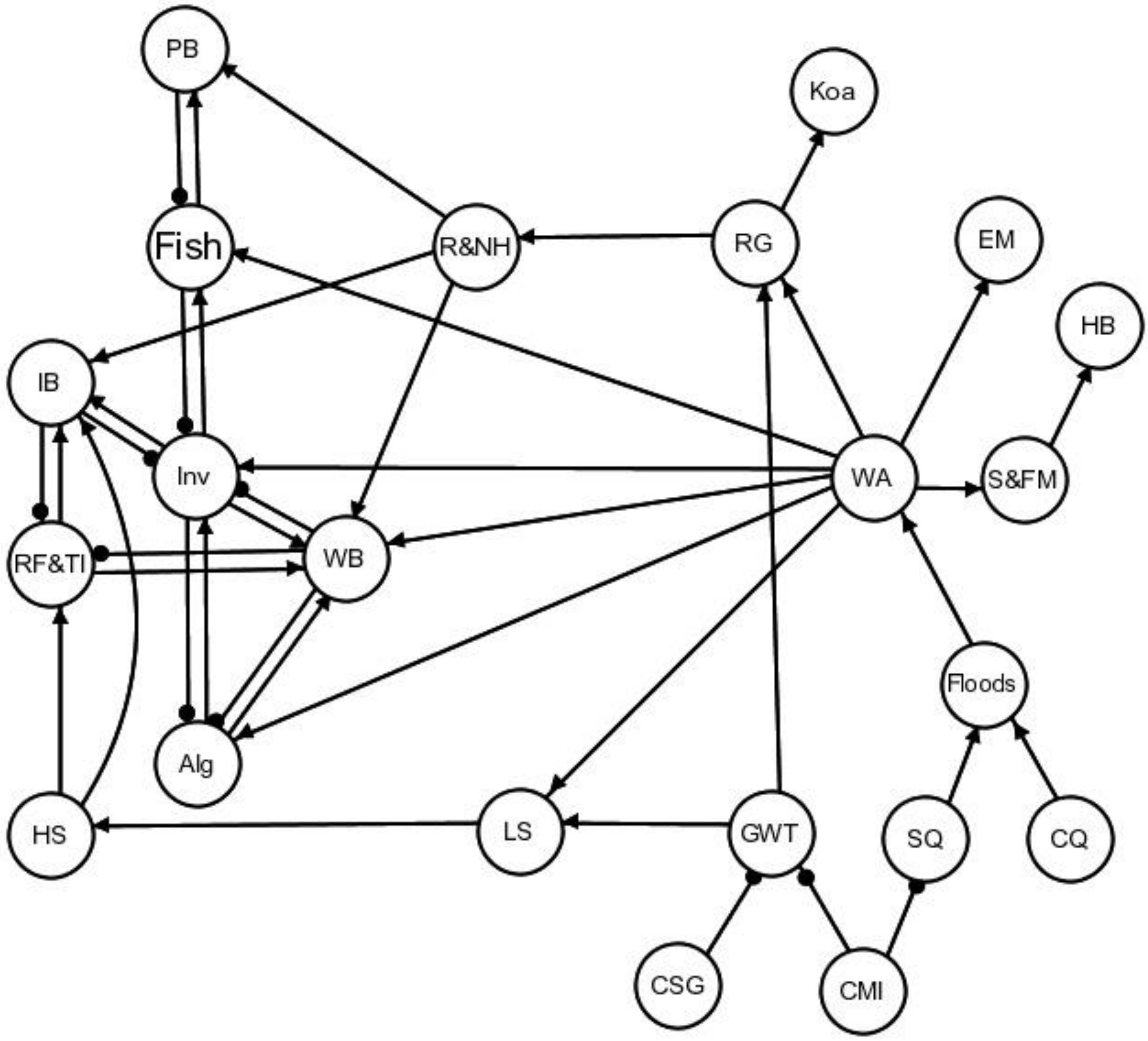

Figure 19 Signed digraph model of the 'Non-floodplain wetland' landscape class

Model variables are: algae (Alg), coal mine interception (CMI), channel flow (CQ), coal seam gas development (CSG), emergent macrophytes (EM), fish (Fish), floods (Floods), groundwater table (GWT), herbivorous birds (HB), habitat structure (HS), insectivorous birds (IB), invertebrates (Inv), koalas (Koa), lignum shrubs (LS), piscivorous birds (PB), roosting and nesting habitat (R&NH), reptiles, frogs and terrestrial invertebrates(RF&TI), river red gum (and poplar box) (RG), submerged and floating macrophytes (S&FM), sheet flow (SQ), wetted area (WA), wading birds (WB).
Data: Bioregional Assessment Programme (Dataset 5)

Surface water and groundwater modelling predict significant potential impacts to the watertable and to overland sheet flow. These potential impacts were considered in two cumulative impact scenarios that were developed for qualitative analysis of response predictions (Table 21).

Table 21 Summary of the (cumulative) impact scenarios (CISs) for the 'Non-floodplain wetland' landscape class

CIS	GWT	SQ
C1	–	0
C2	–	–

Pressure scenarios are determined by combinations of no-change (0) or a decrease (–) in the following signed digraph variables: groundwater table (GWT) and sheet flow (SQ).
Data: Bioregional Assessment Programme (Dataset 5)

Qualitative analyses of the signed digraph model (Figure 19) generally indicate a negative or ambiguous response prediction for most biological variables within the non-permanent wetland ecosystem (Table 22). Tree and shrub groups were predicted to decline in both impact scenarios, which lead to negative impacts to habitats for birds, frogs and terrestrial invertebrates. A predicted decrease in wading birds and piscivorous and insectivorous birds leads to a release, or increase, in their prey populations (i.e. fish, reptiles, frogs and terrestrial invertebrates). The potential impact of decreased sheet flow in the second cumulative impact scenario is predicted to lead to a decrease in all forms of aquatic macrophytes and herbivorous birds.

Table 22 Predicted response of the signed digraph variables in the 'Non-floodplain wetland' landscape class to (cumulative) changes in hydrological response variables

Signed digraph variable (full name)	Signed digraph variable (shortened form)	C1	C2
Roosting and nesting habitat	R&NH	(–)	(–)
Wetted area	WA	0	(–)
Wading birds	WB	?	(–)
Fish	Fish	(+)	(+)
Invertebrates	Inv	?	?
Insectivorous birds	IB	(–)	(–)
Reptiles, frogs and terrestrial invertebrates	RF&TI	?	(+)
Habitat structure	HS	(–)	(–)
Lignum shrubs	LS	(–)	(–)
Piscivorous birds	PB	?	(–)
Algae	Alg	?	?
Emergent macrophytes	EM	0	(–)
Submerged and floating macrophytes	S&FM	0	(–)
Herbivorous birds	HB	0	(–)
Floods	Floods	0	(–)
River red gum (and poplar box)	RG	(–)	(–)
Koalas	Koa	(–)	(–)

Qualitative model predictions that are completely determined are shown without parentheses. Predictions that are ambiguous but with a high probability (0.80 or greater) of sign determinancy are shown with parentheses. Predictions with a low probability (less than 0.80) of sign determinancy are denoted by a question mark. Zero denotes completely determined predictions of no change.
Data: Bioregional Assessment Programme (Dataset 5)

2.7.4.1.3 Choice of hydrological response variables and receptor impact variables

In bioregional assessments (BAs), the potential ecological impacts of coal resource development are assessed in two future years – 2042 and 2102. These are labelled as the short- and long-assessment years, respectively. Potential ecological changes are quantified in BAs by predicting the state of a select number of receptor impact variables in the short- and long-assessment years.

These predictions are made conditional on the values of certain groundwater and surface water statistics that summarise the outputs of numerical model predictions in that landscape class in an interval of time that precedes the assessment year. In all cases these predictions also allow for the possibility that changes in the future may depend on the state of the receptor impact variable in the reference year 2012, and consequently this is also quantified by conditioning on the predicted hydrological conditions in a reference interval that precedes 2012 (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)).

For surface water and groundwater variables in the Namoi subregion, the reference assessment interval is defined as the 30 years preceding and including 2012 (i.e. 1983 to 2012). For surface water variables in the Namoi subregion, the short-assessment interval is defined as the 30 years preceding the short-assessment year (i.e. 2013 to 2042), and the long-assessment interval is defined as the 30 years that precede the long-assessment year (i.e. 2073 to 2102). For groundwater, maximum drawdown (metres) and time to maximum drawdown are considered across the full 90-year modelling window: 2013 to 2102.

In BAs, choices about receptor impact variables must balance the project's time and resource constraints with the objectives of the assessment and the expectations of the community (companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018)). This choice is guided by selection criteria that acknowledge the potential for complex direct and indirect effects within perturbed ecosystems, and the need to keep the expert elicitation of receptor impact models tractable and achievable (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)).

For upland riverine landscape classes, the qualitative modelling workshop identified three hydrological response variables thought to: (i) be instrumental in maintaining and shaping the ecosystem and, (ii) have the potential to change due to coal resource development. All of the ecological components and processes represented in the qualitative model are potential receptor impact variables and all of these are predicted to vary as the hydrological response variables vary either individually or in combination (Table 22).

Following advice received from participants during (and after) the qualitative modelling workshop, and guided by the availability of experts for the receptor impact modelling workshop, the scope of the BA numerical modelling and the receptor impact variable selection criteria, the receptor impact models focused on the following relationships:

1. The response of the upland riparian trees (RT) to changes in hydrological regime 1 (EventsR3.0) and groundwater (dmaxRef)
2. The response of fast-water macroinvertebrates (FW I & T) to changes in number of zero-flow days (ZQD) and maximum length of spells with zero flow (ZME)
3. The response of tadpoles (FW I & T) to changes in ZQD and ZME.

The hydrological factors identified by the participants in the qualitative modelling workshops have been interpreted as a set of hydrological response variables. The hydrological response variables are summary statistics that: (i) reflect these hydrological factors, and (ii) can be extracted from the BA's numerical surface water and groundwater models during the reference, short- and long-assessment intervals defined previously. The hydrological factors and associated hydrological response variables for the upland riverine landscape class are summarised in Table 23. The precise definition of each receptor impact variable, typically a species or group of species represented by a qualitative model node, was determined during the receptor impact modelling workshop.

Using this interpretation of the hydrological response variables, and the receptor impact variable definitions derived during the receptor impact modelling workshop, the relationships identified in the qualitative modelling workshop were formalised into three receptor impact models (Table 24).

Table 23 Summary of the hydrological response variables used in the receptor impact models for landscape classes in the 'Non-floodplain or upland riverine' landscape group, together with the signed digraph variables that they correspond to

Signed digraph variable	Hydrological response variable	Definition
GW	dmaxRef	Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012)
GW	tmaxRef	The year that the maximum difference in drawdown relative to the reference period (1983 to 2012) (dmaxRef) occurs
HR1	EventsR3.0	The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.
ZFD	ZQD	The number of zero-flow days per year, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.
ZFD	ZME	The maximum length of spells (in days per year) with zero flow, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

Table 24 Summary of the three receptor impact models developed for landscape classes in the 'Non-floodplain or upland riverine' landscape group in the Namoi subregion

Relationship being modelled	Receptor impact variable (with associated sample units)	Hydrological response variable
Response of the upland riparian forest to changes in hydrological regime 1 and groundwater	Annual mean projected foliage cover of species group that includes: Casuarina, yellow box, Blakely's red gum, *Acacia salicina*, *Angophora floribunda*, grey box. Transect of 50 m length and 20 m width that extends from first bench ('toe') on both sides of stream	EventsR3.0 dmaxRef tmaxRef
Response of fast-water macroinvertebrates to changes in number of zero-flow days and maximum zero-flow event	Average number of families of aquatic macroinvertebrates in riffle habitat sampled using the NSW AUSRIVAS method for riffles	ZQD ZME
Response of tadpoles to changes in number of zero-flow days and maximum zero-flow event	Probability of presence of tadpoles from *Limnodynastes* genus (species *dumerilii*, *salmini*, *interioris* and *terraereginae*), sampled using standard 30 cm dip net	ZQD ZME

Hydrological response variables are as defined in Table 23.

2.7.4.1.4 Receptor impact model

Upland riparian forest

Table 25 summarises the elicitation design matrix for the projected foliage cover of riparian trees in the upland riverine landscape classes. The first design point – design point identifier 1 – addresses the predicted variability (across the streams in the landscape class during the reference interval) in the overbank (EventsR3.0) flows that define floods with a return interval of 0.33 events per year. Note that the design point identifiers are simply index variables that identify the row of the elicitation design matrix. They are included here to maintain an auditable path between analysis and reporting.

The first design point provides for an estimate of the uncertainty in mean foliage cover across the landscape class in the reference year 2012 (Yref). The remaining design points represent hydrological scenarios that span the uncertainty in the values of the hydrological response variables in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years.

Table 25 Elicitation design matrix for annual mean projected foliage cover of species group that includes: casuarina, yellow box, Blakely's red gum, *Acacia salicina, Angophora floribunda*, grey box in the ‘Non-floodplain or upland riverine’ landscape group in the Namoi subregion zone of potential hydrological change

Id	EventsR3.0	dmaxRef	Yref	Year	tmaxRef
1	0.33	0.0	na	2012	0
26	0.45	188.0	0.22	2042	2103
28	0.13	0.2	0.34	2042	1983
48	0.80	0.2	0.34	2042	2103
15	0.80	15.7	0.22	2042	2043
36	0.80	188.0	0.34	2042	1983
52	0.13	188.0	0.34	2042	2103
86	0.45	15.7	0.34	2102	1983
61	0.13	188.0	0.22	2102	1983
73	0.13	0.2	0.22	2102	2103
57	0.80	0.2	0.22	2102	1983
92	0.45	0.2	0.34	2102	2043
108	0.80	188.0	0.34	2102	2103

Receptor impact modelling elicitation design matrix for annual mean projected foliage cover, over a 50 m x 20 m transect that extends from first bench (‘toe’) on both sides of stream in upland riparian forests. Design points for Yref in the future (short- and long-assessment periods) are calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers Id) are either default values or values determined by groundwater and surface water modelling. Hydrological response variables are as described in Table 23. na = not applicable
Data: Bioregional Assessment Programme (Dataset 5)

Design point identifiers 15 through to 108 (as listed in Table 25) represent combinations of the three hydrological response variables (dmaxRef, tmaxRef, EventsR3.0), together with high and low values of Yref (see companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). The high and low values for Yref were calculated during the receptor impact modelling workshop following the experts’ response to the first design point, and then automatically included within the design for the elicitations at the subsequent design points.

The receptor impact modelling methodology allows for a very flexible class of statistical models to be fitted to the values of the receptor impact variables elicited from the experts at each of the design points (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). The model fitted to the elicited values of mean projected foliage cover for the upland riverine landscape classes is summarised in Figure 20 and Table 26. The fitted model takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \sum_{j=1}^{3} \beta_{h_j} x_{h_j} \quad (4)$$

where x_0 is an intercept term (a vector of ones), x_f is a binary indicator variable scored 1 for the case of an assessment in the short- or long-assessment year, x_l is a binary indicator variable scored 1 for the case of an assessment in the long-assessment year, x_r is a continuous variable that represents the value of the receptor impact variable in the reference year (Yref, set to zero for the case of an assessment in the reference year), and $x_{h_j}, j = 1 \ldots 4$ are the (continuous or integer) values of the three hydrological response variables (dmaxRef, tmaxRef, EventsR3.0). Note that the modelling framework provides for more complex models, including quadratic value of, and in interactions between, the hydrological response variables but in this instance the simple linear model (Equation 4) was identified as the most parsimonious representation of the experts’ responses.

The model estimation procedure adopts a Bayesian approach. The model coefficients $(\beta_0, \beta_f, \beta_l, \beta_r, \beta_{h_j})$ are assumed to follow a multivariate normal distribution. The Bayesian estimation procedure quantifies how compatible different values of the parameters of this distribution are with the data (the elicited expert opinion) under the model. The (marginal) mean and 80% central credible intervals[2] of the three hydrological response variable coefficients are summarised in partial regression plots in Figure 20, whilst Table 26 summarises the same information for all seven model coefficients.

The model indicates that the experts’ opinion provides strong evidence for Yref having a positive effect on average percent foliage cover. This suggests that given a set of hydrological response variable values in the future, a site with a higher foliage cover at the 2012 reference point is more likely to have a higher foliage cover in the future than a site with a lower foliage cover value at this time point. This reflects the lag in the response of foliage cover to changes in hydrological response variables that would be expected of mature trees with long life spans.

[2] A central credible interval is the region in the centre of a posterior or prior distribution that contains a specified amount of the probability of the distribution, such that there is equal probability above and below the interval. Hence, an 80% central credible interval is defined as the range of values with posterior (or prior) probability (1 – 0.8)/2 above and below the interval.

The model also indicates that the experts' opinion provides strong evidence for dmaxRef having a negative effect on average projected foliage cover. This suggests that projected foliage cover will decrease as groundwater drawdown increases due to coal resource development. The model predicts that (holding all other hydrological response variables constant at the mid-point of their elicitation range) the mean of the average projected foliage cover will drop from just under 25% without any change in groundwater level, to about 20% if the levels decrease by 150 m relative to the reference level in 2012. There is, however, considerable uncertainty in these predictions, with an 80% chance that the foliage cover will lie somewhere between approximately 15% and 30% in the short-assessment period, and somewhere between roughly 10% and 30% in the long-assessment period, with a 6-m drop in groundwater level. In relation to dmaxRef, Yrs2tmax is also significant. The interpretation is that on average (that means for a range of drawdown from negligible to very important) long-term drawdown will have a larger effect on projected foliage cover than short-term drawdown. This is likely driven by the fact that a long-term very deep drawdown will have a more severe effect on the vegetation. Another important factor is the correlation between drawdown and time to drawdown, which will prevent some scenarios and plays a role in the marginal interpretation of the time to drawdown effect. Also note that the potential change in groundwater level relative to reference was elicited over a wide range, as the elicitations were based on preliminary groundwater modelling. Subsequent groundwater modelling identified a much lower and narrower range of drawdown as plausible than is presented in Figure 20. Predictions of projected foliage cover in the impact and risk analysis (Herr et al., 2018) use the final groundwater model results and focus only on the relationship over that narrower range.

The model indicates that the experts' opinion provides strong evidence for EventsR3.0 having a positive effect on average projected foliage cover. The model predicts that (holding all other hydrological response variables constant at the mid-point of their elicitation range) the mean of the average projected foliage cover will increase from just under 24% without any change in overbank events frequency, to about 30% if the frequency increases to 0.8 (relative to the reference level of 0.33 in 2012).

Finally, the model also indicates some diverging influence between short-term and long-term influence. For the short-assessment period, experts believe in a relative increase of projected foliage cover, while they expect a decrease in the long-term assessment. An interpretation is that the effects of changes in hydrology are not immediate on foliage cover, and a worsening of the conditions starting today will only be observed by 2102.

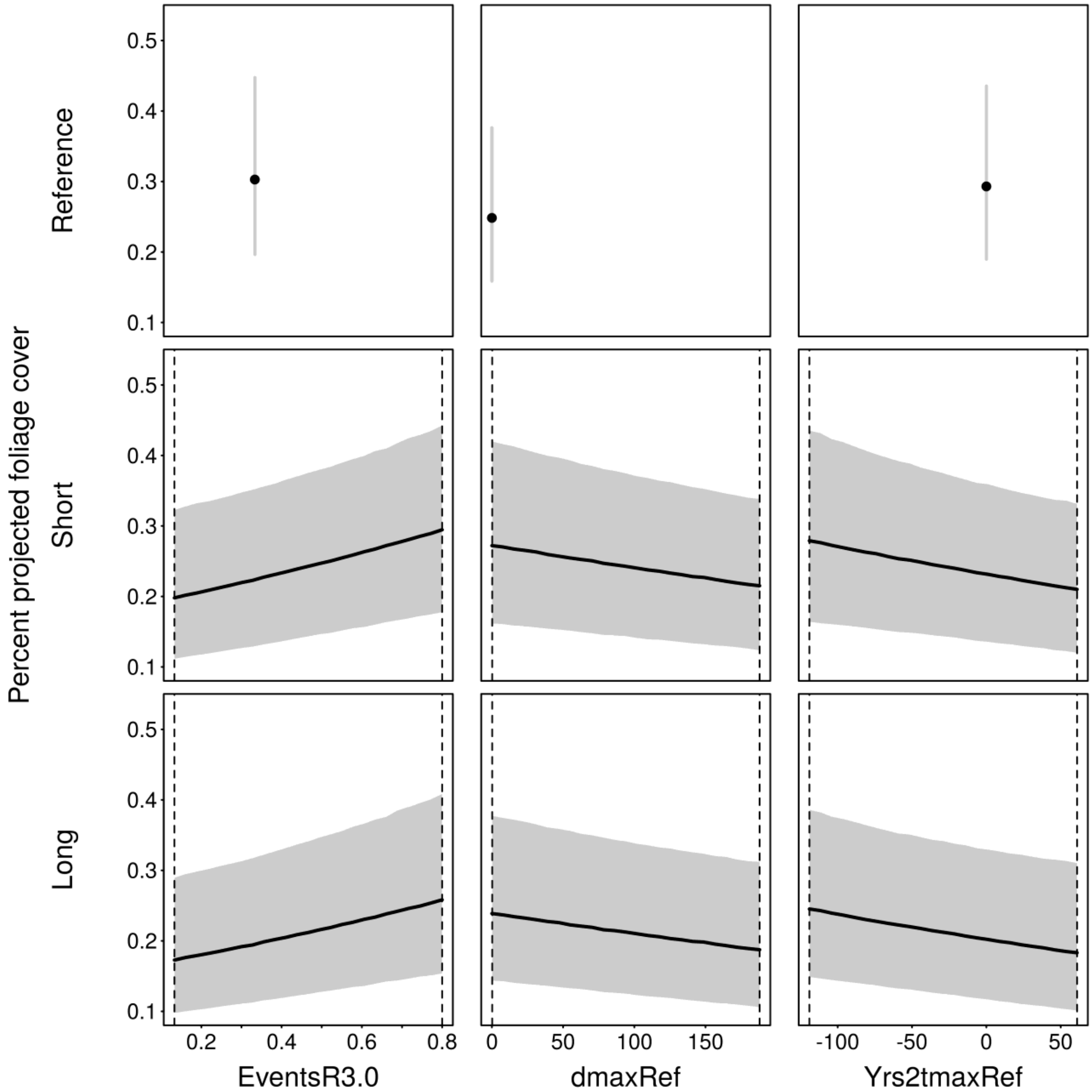

Figure 20 (Top row) Predicted mean (black dot) and 80% central credible interval (grey line) of annual mean projected foliage cover under reference hydrological conditions. (Middle and bottom rows) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of each hydrological response variable on annual mean projected foliage cover, holding all other hydrological response variables constant at the midpoint of their elicitation range (during risk estimation all hydrological response variables vary simultaneously)

Dashed vertical lines show hydrological response variable range used in the elicitation. EventsR3.0 and dmaxRef are as described in Table 23. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102). Note that dmaxRef was elicited and is plotted over a wider range as the elicitations were based on preliminary groundwater modelling. Subsequent modelling identified a much smaller range of drawdown as plausible, and thus relevant for predicting future projected foliage cover. The numbers on the y-axis range from 0 to 1 as the receptor impact model was constructed using the proportion for the statistical modelling. They should be interpreted as a percent foliage cover ranging from 0 to 100%.
Data: Bioregional Assessment Programme (Dataset 5)

Table 26 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for annual mean projected foliage cover in upland riparian forests

	Mean	q10	q90
(Intercept)	–1.34	–1.85	–0.853
future1	1.03	0.375	1.68
long1	–0.142	–0.39	0.106
Yref	1.09	0.679	1.49
EventsR3.0	0.68	0.281	1.08
dmaxRef	–0.00149	–0.00255	–0.000426
Yrs2tmaxRef	–0.00185	–0.00355	–0.000164

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). Yref quantifies the value of the receptor impact variable during the reference period. EventsR3.0 and dmaxRef are as defined in Table 23. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102).
Data: Bioregional Assessment Programme (Dataset 5)

Upland riverine

Table 27 summarises the elicitation matrix for the average number of families of aquatic macroinvertebrates from instream habitats. The first six design points – design points 1 to 7 as shown in Table 27 – address the predicted variability (across the landscape class in the reference interval) in ZQD (zero-flow days (averaged over 30 years) subsequently referred to in this section as 'zero-flow days') and ZME (maximum length of spells with zero flow, averaged over a 30-year period), capturing the lowest and highest predicted values together with two intermediate values. These design points provide for an estimate of the uncertainty in aquatic macroinvertebrates family abundance across the landscape class in the reference year 2012 (Yref).

Design points 10 to 22 inclusive (as listed in Table 27) represent scenarios that span the uncertainty in the predicted values of ZQD and ZME in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years, combined with high and low values of Yref. Again, the high and low values for Yref were calculated during the receptor impact modelling workshop.

The fitted model for number of families of macroinvertebrates from instream habitats takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \beta_{h_1} x_{h_1} + \beta_{h_2} x_{h_2} \quad (5)$$

where the terms x_0, x_f, x_l and x_r are as before and x_{h_1} is the integer value of ZQD and x_{h_2} is the integer value of ZME. The (marginal) mean and 80% central credible interval of the coefficient for this hydrological response variable are summarised in the partial regression plots in Figure 21, whilst Table 28 summarises the same information for all five model coefficients.

Table 27 Elicitation design matrix for average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools in the 'Non-floodplain or upland riverine' landscape group in the Namoi subregion zone of potential hydrological change

Id	ZQD	ZME	Yref	Year
5	320.08	7.13	na	2012
1	0.00	0.00	na	2012
4	160.69	81.93	na	2012
2	160.68	0.79	na	2012
7	321.37	81.93	na	2012
3	160.69	40.97	na	2012
12	0.00	0.00	4.5	2042
11	169.00	72.30	8.7	2042
14	339.00	157.00	8.7	2042
10	334.64	11.02	8.7	2042
20	169.00	157.00	4.5	2102
19	339.00	72.30	4.5	2102
16	168.99	0.86	4.5	2102
22	0.00	0.00	8.7	2102

Receptor impact modelling elicitation design matrix for the average number of families of aquatic macroinvertebrates in instream pool habitat in permanent and temporary upland streams. Design points for Yref in the future (short- and long-assessment periods) are calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers Id) are either default values or values determined by groundwater and surface water modelling. ZQD and ZME are as defined in Table 23. na = not applicable
Data: Bioregional Assessment Programme (Dataset 5)

Unlike the previous model, the hydrological response variable in the macroinvertebrates model varies during the reference interval and the future interval. The model indicates that the experts' elicited information strongly supports the hypothesis that an increase in ZQD and/or ZME will have a negative effect on the number of families of macroinvertebrates despite the experts being quite uncertain about its average value. The model suggests that it can vary substantially across the landscape class from less than 5 to almost 20 under conditions of constant flow (ZQD = zero), holding all other covariates at their mid-values. As the number of zero-flow days increases, however, experts were of the opinion that the number of families would drop quite dramatically with values <0.5 falling within the 80% credible interval under very intermittent flow conditions (ZQD >300 days) (Figure 21).

There was very little evidence in the elicited data to suggest that this effect would be substantially different in the future assessment years. Again, this is indicated by the almost identical partial regression plots in the reference, short- and long-assessment years (Figure 21), and the relatively large negative 10th and positive 90th percentiles for the long and future coefficients in Table 28. The model does, however, suggest that the experts' uncertainty increased for predictions in the future assessment years relative to the reference year.

Another notable difference between this model and the previous model is the estimated values for the Yref coefficient. In the projected foliage cover model, there was strong evidence within the experts’ elicited values that the average percent foliage cover in the reference year had a positive influence on the values in the future assessment years ($\beta_r > 0$). The best-fitting model in this case, however, is unable to eliminate the possibility that the average number of families of macroinvertebrates in the reference years has no influence on its number in the future years. This is indicated by the fact the model automatically dropped this variable from the model. This suggestion is consistent with the hypothesis that there is likely to be very little lag in the response of this short-lived group to changes in the hydrological response variables.

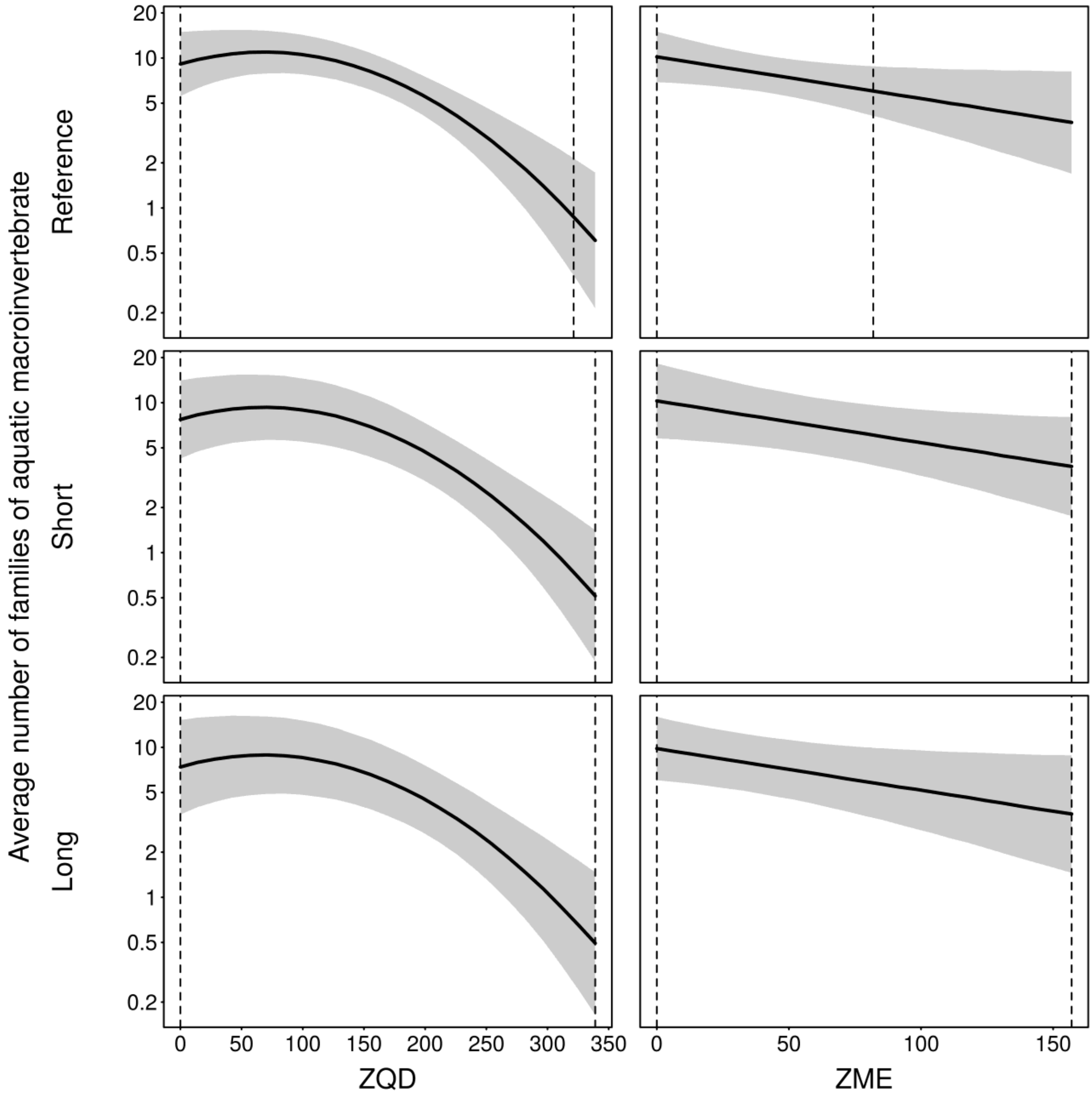

Figure 21 (Top row) Predicted mean (black line) and 80% central credible interval (grey polygon) of average number of families of aquatic macroinvertebrates in instream pool habitat in upland riverine landscape classes under reference hydrological conditions. (Middle and bottom rows) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of each hydrological response variable on average number of families of aquatic macroinvertebrates in instream pool habitat in upland riverine landscape classes holding all other hydrological response variables constant at the midpoint of their elicitation range (during risk estimation all hydrological response variables vary simultaneously)

Dashed vertical lines show hydrological response variable range used in the elicitation. ZQD and ZME are as defined in Table 23.
Data: Bioregional Assessment Programme (Dataset 5)

Table 28 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for the average number of families of aquatic macroinvertebrates in instream pool habitat in upland riverine landscape classes

	Mean	q10	q90
(Intercept)	2.47	2.06	2.88
future1	0.0762	–0.41	0.562
long1	–0.0466	–0.614	0.521
ZQD	0.0054	–0.000288	0.0111
ZME	–0.00641	–0.0128	–3.85e-05
I(ZQD^2)	–3.95e-05	–6.04e-05	–1.86e-05

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). ZQD and ZME are as defined in Table 23. I(ZQD^2) quantifies the quadratic effect of ZQD.
Data: Bioregional Assessment Programme (Dataset 5)

Table 29 summarises the elicitation matrix for the probability of presence of tadpoles from the *Limnodynastes* genus (*dumerilii, salmini, interioris and terraereginae*). The first six design points – design points 1 to 7 as shown in Table 29 – address the predicted variability (across the landscape class in the reference interval) in ZQD and ZME, capturing the lowest and highest predicted values together with two intermediate values. These design points provide for an estimate of the uncertainty in probability of presence of tadpoles across the landscape class in the reference year 2012 (Yref).

Table 29 Elicitation design matrix for probability of presence of tadpoles from *Limnodynastes* genus (*dumerilii, salmini, interioris and terraereginae*) in the 'Non-floodplain or upland riverine' landscape group in the Namoi subregion zone of potential hydrological change

Id	ZQD	ZME	Yref	Year
5	320.08	7.13	na	2012
1	0.00	0.00	na	2012
4	160.69	81.93	na	2012
2	160.68	0.79	na	2012
7	321.37	81.93	na	2012
3	160.69	40.97	na	2012
12	0.00	0.00	0.34	2042
11	169.00	72.30	0.53	2042
14	339.00	157.00	0.53	2042
10	334.64	11.02	0.53	2042
20	169.00	157.00	0.34	2102
19	339.00	72.30	0.34	2102
16	168.99	0.86	0.34	2102
22	0.00	0.00	0.53	2102

Receptor impact modelling elicitation design matrix for the probability of presence of tadpoles in pools and riffles in permanent and temporary upland streams. Design points for Yref in the future (short- and long-assessment periods) are calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers Id) are either default values or values determined by groundwater and surface water modelling. ZQD and ZME are as defined in Table 23. na = not applicable
Data: Bioregional Assessment Programme (Dataset 5)

Design points 10 to 22 inclusive (as listed in Table 29) represent scenarios that span the uncertainty in the predicted values of ZQD and ZME in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years, combined with high and low values of Yref. Again, the high and low values for Yref were calculated during the receptor impact modelling workshop.

The fitted model for probability of the presence of tadpoles takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \beta_{h_1} x_{h_1} + \beta_{h_2} x_{h_2} \quad (6)$$

where the terms x_0, x_f, x_l and x_r are as before and x_{h_1} is the integer value of ZQD and x_{h_2} is the integer value of ZME. The (marginal) mean and 80% central credible interval of the coefficient for this hydrological response variable are summarised in the partial regression plots in Figure 22, whilst Table 30 summarises the same information for all six model coefficients.

Like the previous model, the hydrological response variable in the tadpole model varies during the reference interval and the future interval. The model indicates that the experts' elicited information strongly supports the hypothesis that an increase in ZQD and/or ZME will have a negative effect on probability of the presence of tadpoles. The model suggests that the probability of tadpoles is fairly high with low uncertainty across the landscape classes with a value of almost 1 under conditions of constant flow (ZQD = zero), holding all other covariates at their mid-values. As the number of zero-flow days increases, however, experts were of the opinion that the probability of presence would drop quite dramatically with values <0.1 falling within the 80% credible interval under very intermittent flow conditions (ZQD >300 days) (Figure 22).

There was very little evidence in the elicited data to suggest that this effect would be substantially different in the future assessment years. Again, this is indicated by the almost identical partial regression plots in the reference, short- and long-assessment years (Figure 22), and the relatively large negative 10th and positive 90th percentiles for the long and future coefficients in Table 30. The model does, however, suggest that the experts' uncertainty increased for predictions in the future assessment years relative to the reference year.

Like the previous model, the best-fitting model in this case is unable to eliminate the possibility that the probability of the presence in the reference years has no influence on the probability of the presence in the future years. This is indicated by the fact the model automatically dropped this variable from the model. This suggestion is consistent with the hypothesis that there is likely to be very little lag in the response of this short-lived group to changes in the hydrological response variables.

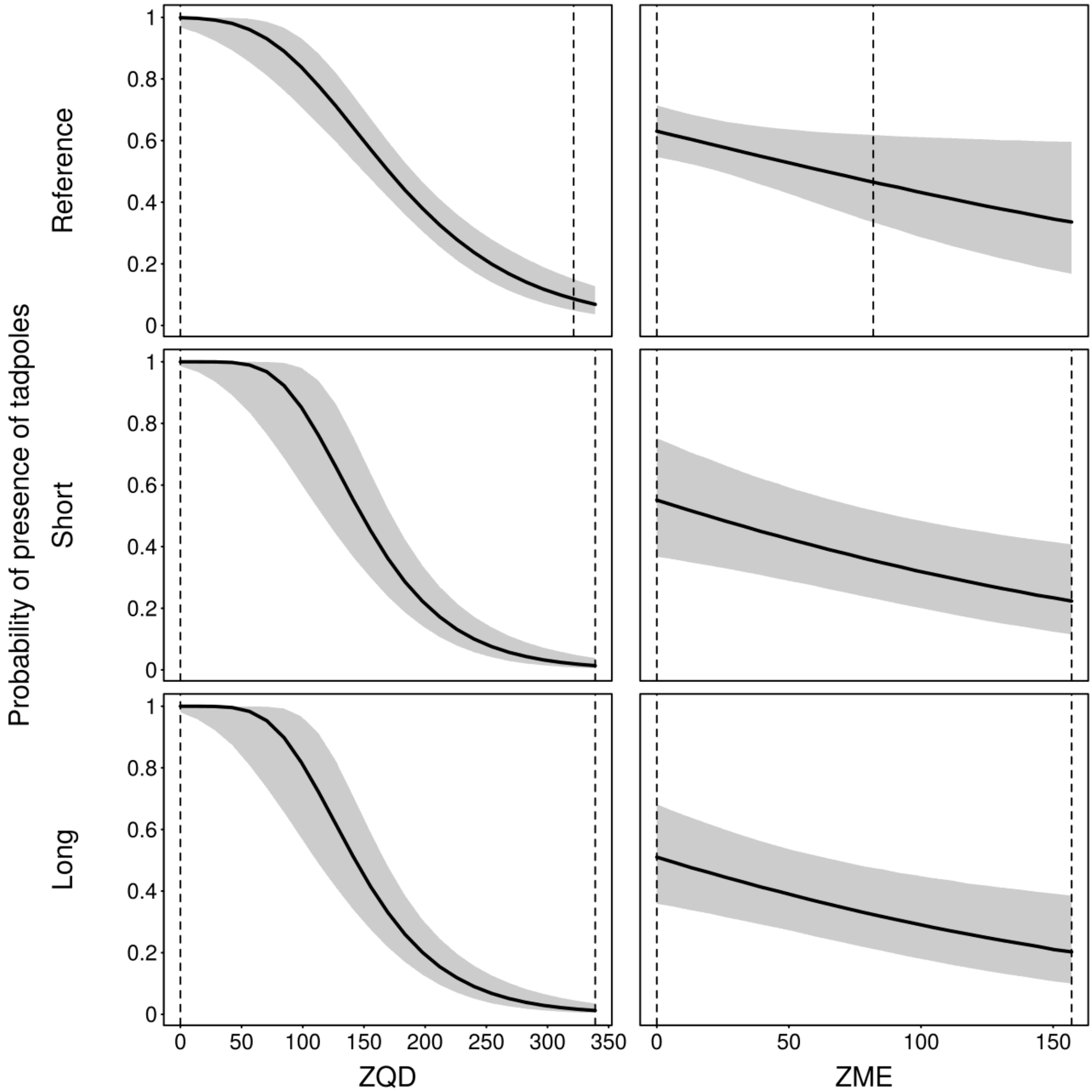

Figure 22 (Top row) Predicted mean (black line) and 80% central credible interval (grey polygon) of Probability of presence of tadpoles in pools and riffles in permanent and temporary upland streams under reference hydrological conditions. (Middle and bottom rows) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of each hydrological response variable on probability of presence of tadpoles in pools and riffles in upland riverine landscape classes holding all other hydrological response variables constant at the midpoint of their elicitation range (during risk estimation all hydrological response variables vary simultaneously)

Dashed vertical lines show hydrological response variable range used in the elicitation. ZQD and ZME are as defined in Table 23.
Data: Bioregional Assessment Programme (Dataset 5)

Table 30 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for the probability of the presence of tadpoles in pools and riffles in upland riverine landscape classes

	Mean	q10	q90
(Intercept)	0.942	0.36	1.52
future1	–0.169	–0.734	0.396
long1	–0.113	–0.762	0.535
ZQD	–0.00589	–0.0093	–0.00248
ZME	0.0243	0.00842	0.0401
ZQD:ZME	–0.000186	–0.000271	–0.000102

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). ZQD and ZME are as defined in Table 23. ZQD:ZME quantifies the effect of the interaction between ZQD and ZME.
Data: Bioregional Assessment Programme (Dataset 5)

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2.7.5 Pilliga riverine landscape classes

Summary

The Pilliga and Pilliga Outwash Interim Biogeographic Regionalisation for Australia (IBRA) regions represent a unique set of ecological systems within the Namoi subregion. In consultation with experts in this region, it was considered appropriate to develop a set of separate ecological models for the relevant riverine and terrestrial landscape classes in this region to improve the assessment of potential ecological impacts.

The zone of potential hydrological change identified for the Pilliga region extends across a large portion of the Pilliga and Pilliga Outwash IBRA regions within the assessment extent. Both lowland and upland riverine landscape classes are represented in the zone of potential hydrological change. The lowland riverine classes ('Temporary lowland stream', 'Temporary lowland stream groundwater-dependent ecosystem (GDE)' and a small portion of 'Permanent lowland stream' landscape classes) cover approximately 13.1% of streams in the zone of potential hydrological change and are mainly confined to the Pilliga Outwash portion where the streams flow north onto the broad floodplains of the Castlereagh-Barwon IBRA region. Bohena Creek is one of the major streams in the Pilliga region and has highly intermittent flow, flowing less than 20% of days on average.

Among the upland riverine landscape classes, the 'Temporary upland stream' landscape class (530.4 km or 9.6% of the zone of potential hydrological change) is the most widespread, whereas the 'Temporary upland stream GDE' landscape class occupies only a small fraction of the stream network (11.5 km or 0.2% of the zone). The 'Grassy woodland GDE' landscape class occupies a very large area of the terrestrial environment in the Pilliga region (561.7 km^2 or 8.0% of the zone). Non-floodplain wetlands are also found within the zone of potential hydrological change and tend to be located in the northern part of the Pilliga region where the Pilliga Outwash adjoins the Castlereagh-Barwon IBRA region. These wetlands include the 'Non-floodplain wetland' (2.5 km^2 or <0.1% of the zone) and 'Non-floodplain wetland GDE' (1.8 km^2 or <0.1% of the zone) landscape classes.

A qualitative model for all Pilliga riverine landscape classes was developed that included the aquatic habitat as well as the fringing riparian vegetation. From this model, key hydrological response variables were identified: groundwater drawdown, change in annual zero-flow days (averaged over 30 years) and maximum zero-flow spells. The receptor impact modelling workshop used two different receptor impact variables to evaluate potential ecological impacts in this system: projected foliage cover of riparian trees and number of families of aquatic macroinvertebrates in instream pool habitats. A qualitative model for the 'Grassy woodland GDE' landscape class was also formulated, but no quantitative modelling was developed due to limitations in resources and local expertise.

Receptor impact modelling indicates that foliage cover during the reference period is an important predictor of foliage cover in the future. It also indicates that the experts' opinion provides some evidence for the maximum additional drawdown having a negative effect, and strong evidence for the number of zero-flow days having a negative effect on average percent

projected foliage cover. Receptor impact modelling also supports the hypothesis that an increase in the mean number of zero-flow days and/or the mean maximum length of zero-flow spells will have a slightly negative effect on the number of families of macroinvertebrates despite the experts being somewhat uncertain about its average value. There is also strong evidence for additional drawdown having negative effect on macroinvertebrates, and that the number of families of macroinvertebrates will decrease as groundwater drawdown increases due to coal resource development. There is, however, considerable uncertainty in these predictions.

2.7.5.1 Description

The Pilliga and Pilliga Outwash IBRA regions represent a unique set of ecological systems within the Namoi subregion. By comparison to the other landscapes across the Namoi subregion, the Pilliga and Pilliga Outwash is unique in many attributes of its ecology, geomorphology, hydrogeology, soils and ecohydrology. In consultation with ecological experts in this region it was deemed necessary to develop a specific set of receptor impact models to define potential ecological impacts for the Pilliga and Pilliga Outwash IBRA regions. Here, the Pilliga and Pilliga Outwash IBRA regions under consideration are referred to as simply the ‘Pilliga region’. Figure 23 provides a conceptual model of a typical landscape in the Pilliga Nature Reserve and examples of the hydrologic connectivity and water movement found in it.

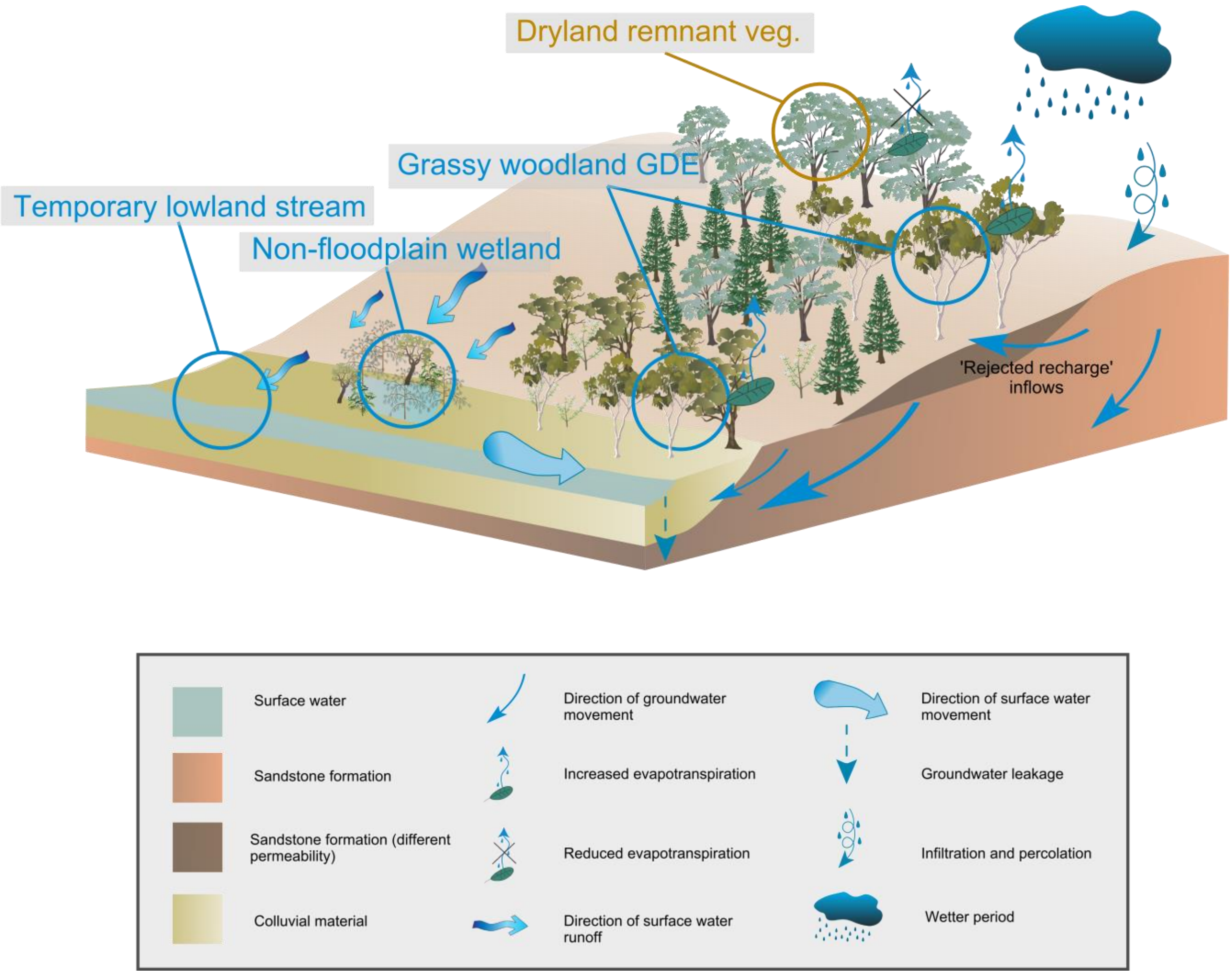

Figure 23 Pictorial conceptual model of the hydrologic connectivity and water movement across a typical landscape in the Pilliga Nature Reserve

GDE = groundwater-dependent ecosystem, 'veg.' = vegetation
Source: Symbols courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/)

The zone of potential hydrological change identified for the Pilliga region extends across a large portion of the Pilliga and Pilliga Outwash IBRA regions within the assessment extent. Lowland streams ('Temporary lowland stream', 'Temporary lowland stream GDE' and a small portion of 'Permanent lowland stream' landscape classes, Table 31) are mainly confined to the Pilliga Outwash portion of the Pilliga where the streams flow north onto the broad floodplains of the Castlereagh-Barwon IBRA region (SEWPaC, 2012). Bohena Creek is one of the major streams flowing through the Pilliga, and flows north-east towards Narrabri. It is classified predominately as 'Temporary lowland stream GDE' and 'Temporary lowland stream'. This is a highly intermittent stream – flowing less than 20% of days on average (Table 32). The flow regime is highly seasonal with lowest monthly volumes occurring in May and higher monthly flow volumes occurring between July and November.

Among the upland riverine landscape classes, the 'Temporary upland stream' landscape class (530.4 km or 9.6% of the zone of potential hydrological change) is the most widespread, whereas the 'Temporary upland stream GDE' landscape class occupies only a small fraction of the stream network (11.5 km or 0.2% of the zone) (Table 31). The 'Grassy woodland GDE' landscape class occupies a very large area of the terrestrial environment in the Pilliga region (561.7 km^2 or 8.0% of the zone) (Table 31). Non-floodplain wetlands are also found within the zone of potential hydrological change and tend to be located in the northern part of the Pilliga region where the Pilliga Outwash adjoins the Castlereagh-Barwon IBRA region (Figure 24). These wetlands include the ‘Non-floodplain wetland’ (2.5 km^2 or <0.1% of the zone) and ‘Non-floodplain wetland GDE’ (1.8 km^2 or <0.1% of the zone) landscape classes (Table 31).

Table 31 Areas and/or lengths of the 'Floodplain or lowland riverine' and 'Non-floodplain or upland riverine' landscape groups within the entire assessment extent and the Pilliga region of the zone of potential hydrological change

Landscape class	Area in assessment extent (km^2)	Area in the zone of potential hydrological change (km^2)	Percentage of total area in zone of potential hydrological change (%)	Length in assessment extent (km)	Length in the zone of potential hydrological change (km)	Percentage of total length in zone of potential hydrological change (%)
Floodplain grassy woodland	400.2	2.9	<0.1%	na	na	na
Floodplain grassy woodland GDE	1,445.4	0.2	<0.1%	na	na	na
Floodplain riparian forest GDE	148.7	0.2	<0.1%	na	na	na
Floodplain wetland	30.1	0.5	<0.1%	na	na	na
Floodplain wetland GDE	151.8	1.6	<0.1%	na	na	na
Permanent lowland stream	na	na	na	1,688.6	14.3	0.3%
Temporary lowland stream	na	na	na	8,053.3	624.6	11.3%
Temporary lowland stream GDE	8.3	2.4	<0.1%	509.3	86.9	1.6%
Total – 'Floodplain or lowland riverine' landscape classes	**2,184.5**	**7.8**	**0.1%**	**10,251.2**	**725.8**	**13.1%**
Grassy woodland GDE	3,247.6	561.7	8%	na	na	na
Non-floodplain wetland	130.3	2.5	<0%	na	na	na
Non-floodplain wetland GDE	23.5	1.8	<0%	na	na	na
Temporary upland stream	na	na	na	16,512.8	530.4	9.6%
Temporary upland stream GDE	na	na	na	464	11.5	0.2%
Total – 'Non-floodplain or upland riverine' classes	**3,401.4**	**566**	**8.1%**	**16,976.8**	**541.9**	**9.8%**
Total – all landscape classes	**35,659.6**	**7013.9**	**100%**	**29,558.3**	**5521.2**	**100%**

na = not applicable
Data: Bioregional Assessment Programme (Dataset 2)

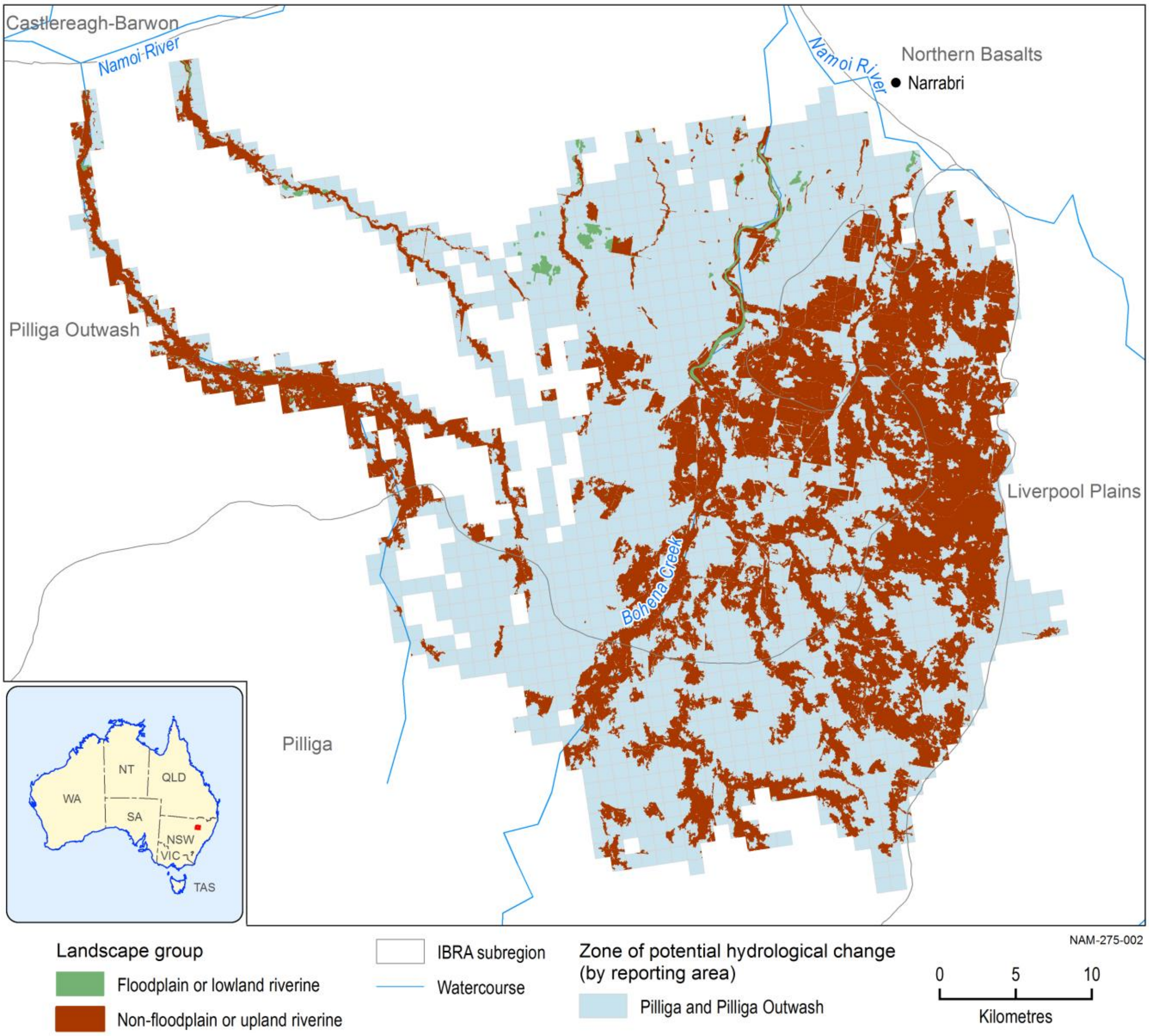

Figure 24 Location of the 'Floodplain or lowland riverine' landscape group within the Pilliga region

IBRA = Interim Biogeographic Regionalisation for Australia
Data: SEWPaC (Dataset 1); Bioregional Assessment Programme (Dataset 2); Bureau of Meteorology (Dataset 3)

Table 32 Maximum, median, 10th, 25th, 75th and 90th percentile flows (ML/day) for the Pilliga region

Gauge #	Gauge name	Landscape class	Maximum	10th	25th	Median	75th	90th
419905	Bohena Creek	Temporary lowland stream GDE	22,826	0	0	0	0	334

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 2)

The stream network across most of the Pilliga region is predominantly infilled Quaternary sediments derived from sandstone and deposited by dendritic streams draining north and west (Norris, 1996). The sediments become finer towards the Namoi River valley where extensive clearing for agriculture has occurred. The eastern margins of the Pilliga region include the recharge beds of the Great Artesian Basin and paleochannels of overlying alluvium can be incised into aquifer units such as the Pilliga Sandstone (see companion product 2.3 for the Namoi subregion

(Herr et al., 2018)). Under these conditions upward leakage of groundwater can occur where the paleochannel has eroded the underlying low-permeability saprolite. Such connectivity is poorly understood, but is considered to be highly variable across the region (Ransley et al., 2012). It is likely that water in the Pilliga Sandstone aquifer is providing baseflow to the Namoi River near the confluence of the Narrabri River and Bohena Creek (companion product 2.3 for the Namoi subregion (Herr et al., 2018)).

The ephemeral nature of streamflow across most of the lowland riverine stream network means that riffle habitat is uncommon and there are few permanent, disconnected pools within the stream channel. In some reaches, there may be longitudinal subsurface flow of water from the underlying watertable. Most fauna in these riverine systems are adapted to desiccation and wet–dry phases. This means they are transitory and take advantage of available pools or damp patches along the streambed.

Riparian vegetation along lowland streams in the Pilliga region is often dominated by *Eucalyptus* spp. including *E. chloroclada, E. blakelyi, E. fibrosa, E. melliodora, E. conica* and *E. crebra. Angophora floribunda* and *Callitris columellaris* are also found in association with these eucalypts. Sedges are also found interspersed along the riparian areas and streambed (Figure 25).

Figure 25 Disconnected pool habitat and adjacent riparian vegetation along Bohena Creek ('Temporary lowland stream GDE' landscape class)

Credit: Bioregional Assessment Programme, Patrick Mitchell (CSIRO), January 2016

It was decided during the qualitative modelling workshop by experts of this region that the ecological processes and associated biota were similar across much of the upland and lowland riverine streams in the Pilliga region (excluding some areas in the north where the Pilliga Outwash adjoins the broader floodplains of the Castlereagh-Barwon IBRA subregion). Thus, there is an assumption here that modelled hydrological changes across all riverine landscape classes in the Pilliga region have similar impacts on associated ecological receptor impact variables. This means that the ecological modelling presented for riverine landscape classes in the Pilliga region include both upland and lowland stream landscape classes.

The 'Grassy woodland GDE' landscape class covers a range of vegetation communities across the Pilliga region and tends to be concentrated around the drainage lines and stream network. This is probably attributable to both groundwater discharge from surrounding sandstone aquifers particularly in the lowland riverine systems within the Pilliga Outwash area (northward portion) and localised subsurface runoff (Figure 23). Some plant communities such as the broombush plain (dominated by *Melaleuca uncinata*) in the Pilliga are known to receive subsurface run-on from upslope sites where soils are shallow and can become waterlogged (Norris, 1996). The level of groundwater dependency of these plant communities was inferred from multiple criteria (including remote sensing of canopy greenness and density) that were not necessarily verified by field assessment (Kuginis et al., 2016). Thus, some caution needs to be exercised when discussing the nature of water dependency in this landscape class (as noted in Section 2.3.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018)).

Some of the non-floodplain wetlands located within the zone of potential hydrological change (particularly in the outwash part of the Pilliga region) are 'tank gilgai' type wetlands described in Bell et al. (2012). They are commonly fringed by buloke (*Allocasuarina luehmannii*) and various sedge, rush and other herbaceous plant communities (Bell et al., 2012) and tend to occur within a mosaic of woodlands and shrublands largely dominated by buloke, *E. chloroclada, E. pilligaensis, E. sideroxylon* and *Melaleuca densispicata* (Benson et al., 2010). The nature of wet and dry phases within these wetlands is determined by localised runoff from rainfall, which means that their dependency on flow systems at larger scales is likely to be negligible.

2.7.5.2 Qualitative mathematical model

2.7.5.2.1 Pilliga riverine (upland and lowland)

The Pilliga riverine qualitative model includes all upland and lowland riverine landscape classes in the Pilliga due to streams in this region having a unique set of conditions (Figure 26). These streams were characterised as having sandy beds, temporary flow with some permanent pools above highly stratified sandstone, and channels that often form shallow and poorly defined ephemeral wetlands.

A model was developed for these streams based on the model for streams in the upland and lowland riverine landscape classes (Figure 26). The sand-dominated substrate and low gradient of these stream channels meant that fast-water habitats are of minimal importance, and thus the fast-water associated variables were omitted from the model. Other variables that were deemed to not be important to these streams, and thus omitted, included flood velocity, bank stability, fine sediment, suspended sediment, biological oxygen demand, algal blooms, phosphorus runoff, land clearing and grazing, catchment vegetation, cyanobacteria and salinity (Figure 26).

There were several components and processes considered important to these stream systems that were added to the model. Tannins that leach into stream water from particulate organic matter were considered to be an important regulator of water temperature (Morrongiello et al., 2011) (Figure 26). Additionally, iron flocculants from groundwater inputs have the effect of suppressing levels of dissolved oxygen and impact on native fishes. Groundwater inputs were also described as being important in maintaining slow-water habitats, riparian trees and riparian vegetation. Non-native fishes were portrayed as having a negative impact on native fishes and slow-water invertebrates and tadpoles, though in return, the abundance of these two prey groups was determined to not be a significant factor in controlling the population of non-native fish (thus no positive link from these prey back to non-native fish predator). The abundance of non-native fishes, however, was described as being regulated by periodic disconnection of the stream channel into pool habitats during periods of low and zero flows (Figure 26).

Riparian trees were described as being dependent on groundwater and also water obtained from the stream channel, hence, the maximum depth of the watertable and the number of low-flow days were considered as potentially important hydrology variables (Pfautsch et al., 2015) (Figure 26). The maximum depth of the watertable was also considered important in controlling the amount of groundwater input to the stream channel (Brunner et al., 2009). The number of low-flow days was deemed to be important in determining the degree to which pool habitats were maintained and connected, and in regulating levels of dissolved oxygen and water temperature (Rolls et al., 2012) (Figure 26).

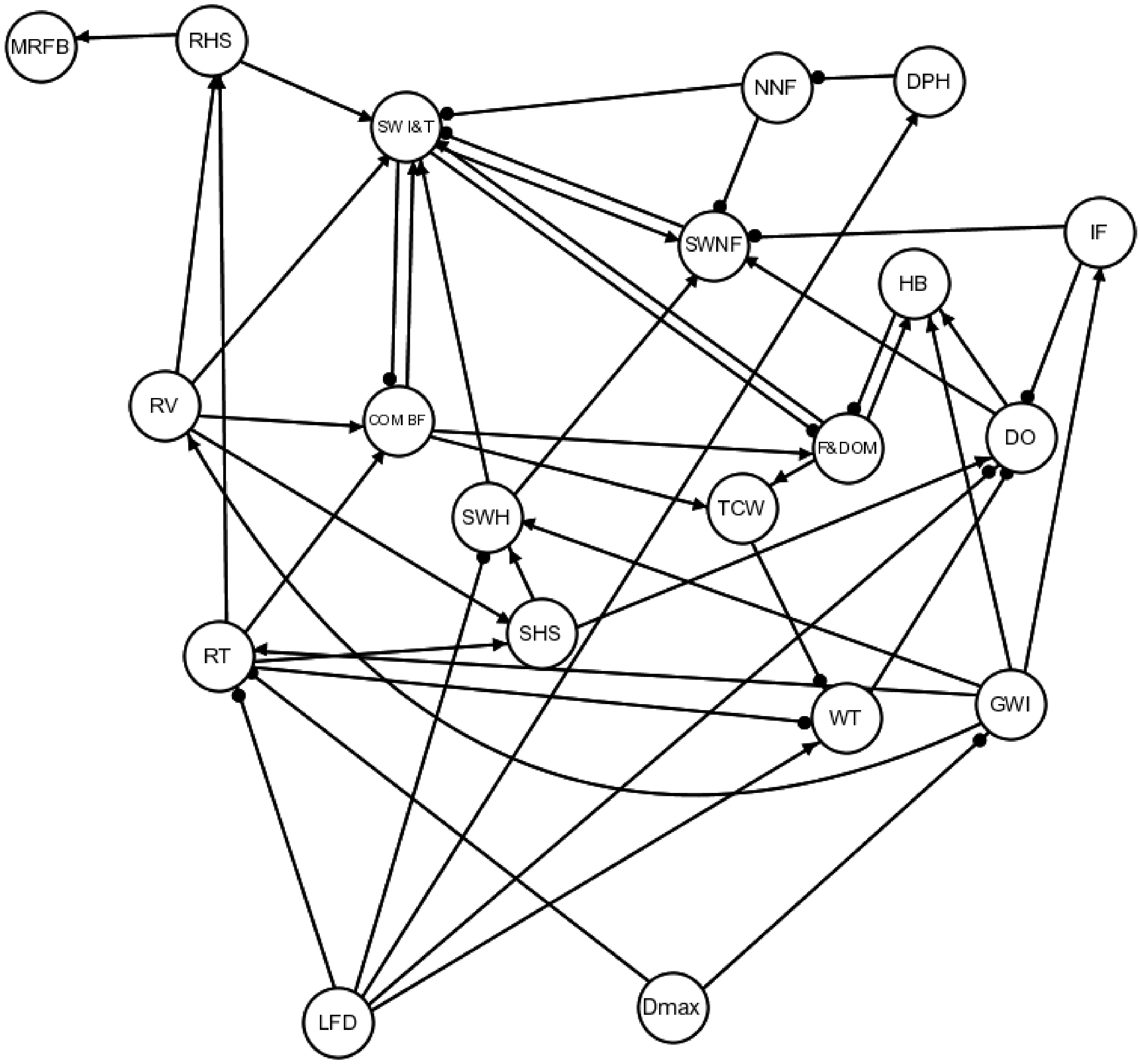

Figure 26 Signed digraph model of the Pilliga riverine ecosystem

Model variables are: coarse particulate organic matter and biofilm (COM BF), maximum decrease in watertable (Dmax), dissolved oxygen (DO), disconnected pool habitats (DPH), fine particulate and dissolved organic matter (F&DOM), groundwater input to river (GWI), hyporheic biota (HB), iron flocculate (IF), low-flow days (LFD), mammals, reptiles, frogs and birds (MRFB), non-native fishes (NNF), riparian habitat structure (RHS), riparian trees (RT), riparian vegetation (excluding trees) (RV), stream habitat structure (SHS), slow-water invertebrates and tadpoles (SW I&T), slow-water habitat (SWH), slow-water native fishes (SWNF), tannin-coloured water (TCW), water temperature (WT).
Data: Bioregional Assessment Programme (Dataset 4)

Surface water and groundwater modelling predict significant potential impacts to low-flow days and maximum depth to groundwater level. Based on all combinations of these impacts, three cumulative impact scenarios were developed for qualitative analysis of response predictions (Table 33).

Table 33 Summary of the (cumulative) impact scenarios (CIS) for the Pilliga riverine ecosystem

CIS	LFD	Dmax
C1	+	0
C2	0	+
C3	+	+

Pressure scenarios are determined by combinations of no-change (0) or an increase (+) in the following signed digraph variables: low-flow days (LFD) and maximum decrease in watertable (Dmax).
Data: Bioregional Assessment Programme (Dataset 4)

Qualitative analyses of the signed digraph model (Figure 26) generally indicate a negative or ambiguous response prediction for all biological variables within the Pilliga riverine ecosystem (Table 34). Riparian trees and riparian vegetation were generally predicted to decline, as were native fishes, mammals, reptiles, frogs and birds. Hyporheic biota were predicted to decrease in scenarios involving an increase in the number of low-flow days. The predicted response of slow-water invertebrates and tadpoles, however, was ambiguous across all cumulative impact scenarios.

Table 34 Predicted response of the signed digraph variables in the Pilliga riverine ecosystem to (cumulative) changes in hydrological response variables

Signed digraph variable (full name)	Signed digraph variable (shortened form)	C1	C2	C3
Slow-water invertebrates and tadpoles	SW I&T	?	?	?
Fine particulate and dissolved organic matter	F&DOM	?	?	?
Coarse particulate organic matter and biofilm	COM BF	(–)	?	(–)
Stream habitat structure	SHS	(–)	(–)	(–)
Riparian trees	RT	(–)	(–)	(–)
Riparian vegetation (excluding trees)	RV	0	(–)	(–)
Hyporheic biota	HB	(–)	?	(–)
Riparian habitat structure	RHS	(–)	(–)	(–)
Mammals, reptiles, frogs and birds	MRFB	(–)	(–)	(–)
Slow-water native fishes	SWNF	(–)	(–)	(–)
Dissolved oxygen	DO	(–)	(–)	(–)
Water temperature	WT	(+)	?	(+)
Slow-water habitat	SWH	(–)	(–)	(–)
Tannin-coloured water	TCW	?	?	?
Iron flocculate	IF	0	(–)	(–)
Groundwater input to river	GWI	0	(–)	(–)
Non-native fishes	NNF	(–)	0	(–)
Disconnected pool habitats	DPH	(+)	0	(+)

Qualitative model predictions that are completely determined are shown without parentheses. Predictions that are ambiguous but with a high probability (0.80 or greater) of sign determinancy are shown with parentheses. Predictions with a low probability (less than 0.80) of sign determinancy are denoted by a question mark. Zero denotes completely determined predictions of no change.
Data: Bioregional Assessment Programme (Dataset 4)

2.7.5.2.2 Grassy woodland GDE – Pilliga region

The vast majority of the 'Grassy woodland GDE' landscape class in the Namoi assessment extent is located in the Pilliga region. The qualitative model centred on the ecological processes associated with trees, shrubs and grasses, with three functional groups of shrubs defined by their relationship with fire (Figure 27). Fire-sensitive shrubs are suppressed by fire; fire-obligate shrubs, which require fire events for regeneration; and fire-tolerant shrubs, which can survive fire (Purdie and Slatyer, 1976). Fire events in this landscape class are fuelled by large woody debris, leaf litter and grasses (Figure 27). All groups of shrubs suppress the growth of grasses. Finer soil textures favour grasses over shrubs (Norris, 1996). The stores of woody debris and litter that are not consumed by fire contribute, through decomposition, to the soil microbial community and populations of ground-dwelling insects (York, 1999). These insects are a primary food resource for ground-dwelling invertebrates and burrowing frogs, both of which benefit from the habitat structure provided by grass communities (Figure 27). Trees (specifically large old-growth trees) were described as providing the key habitat of tree hollows for arboreal vertebrates (i.e. birds and mammals) (Figure 27).

The soil microbial community was identified as a major contributor to stores of dissolved organic matter and nutrients in soil; trees were also identified as making contributions to these stores via root excretions (Lambers et al., 2006) (Figure 27). The dissolved organic matter and nutrients in soil constitute a resource consumed by groundwater biota, which were also described as possibly increasing the availability of both water and nutrients to tree roots via increasing local hydraulic conductivity. These latter two processes, however, were considered as being uncertain, which led to development of two alternative models, one with a positive effect from groundwater biota to trees (Figure 27) and one without this link (Figure 28).

The level of the watertable is a critical factor for the survival of burrowing frogs, both clay-cocooning and sandy-soil aestivators, and also the growth and survival of trees and fire-tolerant shrubs (Figure 27). The maximum depth below ground to the watertable was identified as a potentially important hydrologic response variable that could affect the growth and survival of trees.

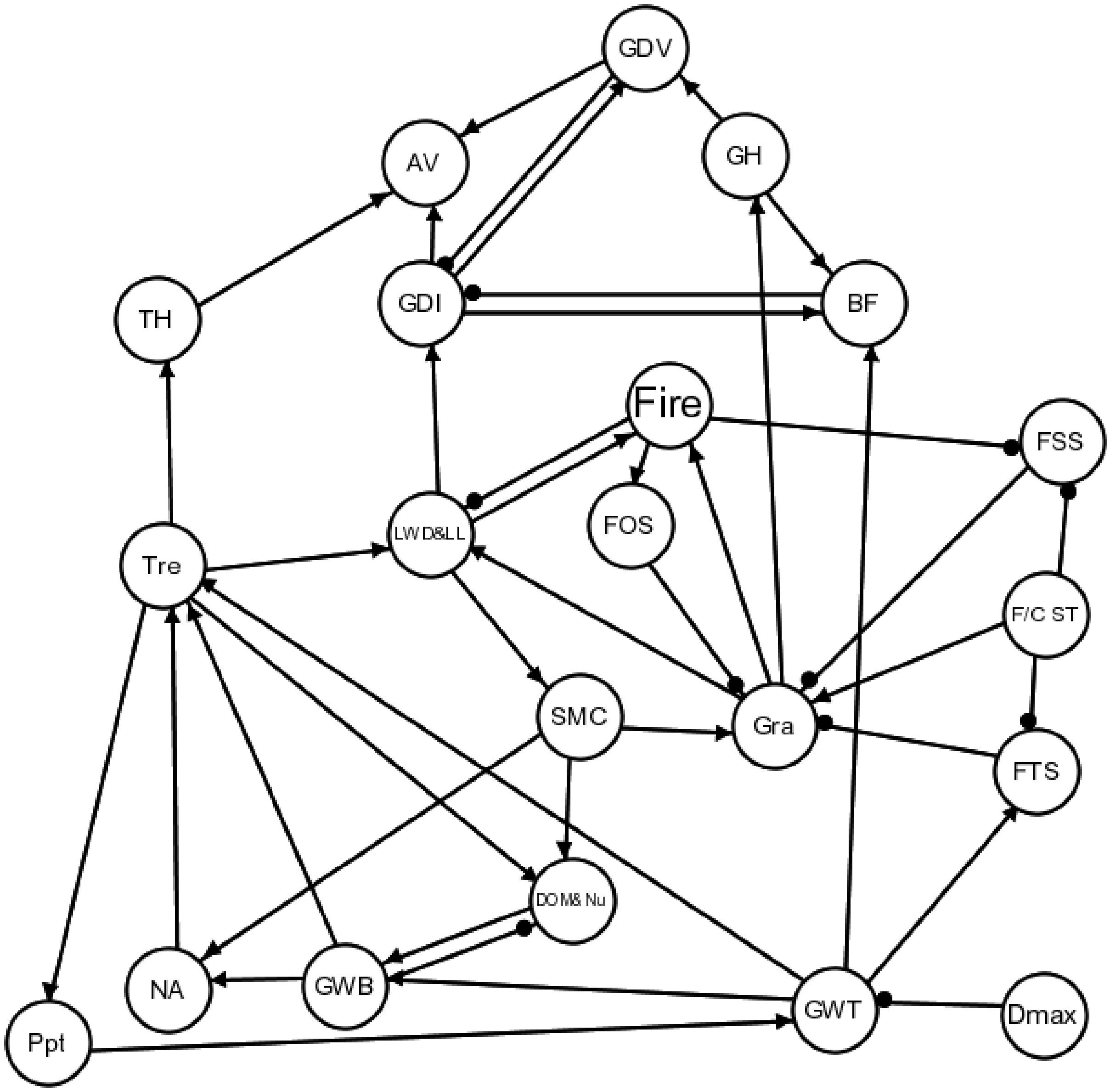

Figure 27 Signed digraph model of the 'Grassy woodland GDE' landscape class (Model 1)

Model variables are: arboreal vertebrates (AV), burrowing frogs (BF), maximum decrease in watertable (Dmax), dissolved organic matter and nutrients (DOM&Nu), fine-coarse soil texture ratio (F/C ST), wildfire (Fire), fire-obligate shrubs (FOS), fire-sensitive shrubs (FSS), fire-tolerant shrubs (FTS), ground-dwelling invertebrates (GDI), ground-dwelling vertebrates (GDV), ground habitat (GH), grass (Gra), groundwater biota (GWB), groundwater table (GWT), large woody debris and leaf litter (LWD&LL), nutrient availability (NA), precipitation (Ppt), soil microbial community (SMC), tree habitat (TH), trees (Tre).
Data: Bioregional Assessment Programme (Dataset 4)

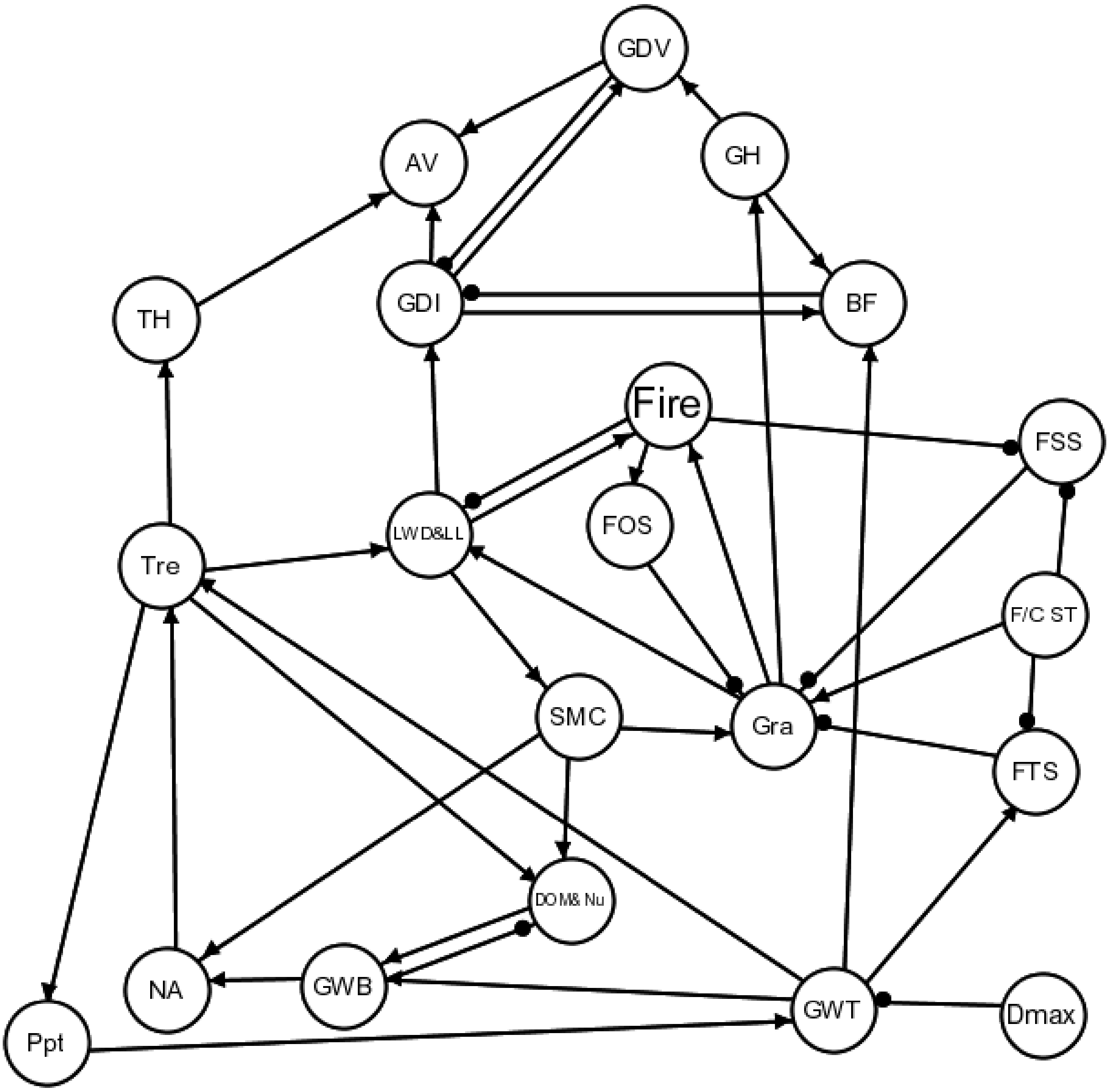

Figure 28 Signed digraph model of the 'Grassy woodland GDE' landscape class (Model 2)

Model variables are: arboreal vertebrates (AV), burrowing frogs (BF), maximum decrease in watertable (Dmax), dissolved organic matter and nutrients (DOM&Nu), fine-coarse soil texture ratio (F/C ST), wildfire (Fire), fire-obligate shrubs (FOS), fire-sensitive shrubs (FSS), fire-tolerant shrubs (FTS), ground-dwelling invertebrates (GDI), ground-dwelling vertebrates (GDV), ground habitat (GH), grass (Gra), groundwater biota (GWB), groundwater table (GWT), large woody debris and leaf litter (LWD&LL), nutrient availability (NA), precipitation (Ppt), soil microbial community (SMC), tree habitat (TH), trees (Tre).
Data: Bioregional Assessment Programme (Dataset 4)

Surface water and groundwater modelling predict significant potential impacts to the maximum depth of groundwater, from which a single cumulative impact scenario (C1) was developed (Table 35).

Table 35 Summary of the (cumulative) impact scenario (CIS) for the 'Grassy woodland GDE' landscape class

CIS	Dmax
C1	+

Pressure scenario is determined by combinations of no-change (0) or a decrease (–) in the following signed digraph variable: maximum decrease in watertable (Dmax).
Data: Bioregional Assessment Programme (Dataset 4)

Qualitative analysis of the signed digraph models indicates ambiguous response prediction for many of the biological variables within the grassy woodland ecosystem for both Model 1 and Model 2 (Table 36). This widespread ambiguity in the predictions is a result of positive feedback in a number of subsystems of this model. Such subsystems include the grass- large woody debris and leaf litter-soil microbial community system, and the grass-fire-fire sensitive shrub system. Trees, tree habitat, grass and ground habitat were all predicted to decrease in Model 1, but had ambiguous predictions in Model 2. Wildfire was predicted to decrease in both models, leading to a predicted increase in fire-sensitive shrubs and a decrease in fire-obligate shrubs.

Table 36 Predicted response of the signed digraph variables for Model 1 (Figure 28) and Model 2 (Figure 29) in the 'Grassy woodland GDE' landscape class to (cumulative) changes in hydrological response variables

Signed digraph variable (full name)	Signed digraph variable (shortened form)	Model 1 C1	Model 2 C1
Precipitation	Ppt	(–)	?
Trees	Tre	(–)	?
Soil microbial community	SMC	?	?
Dissolved organic matter and nutrients	DOM&Nu	?	?
Ground-dwelling invertebrates	GDI	?	?
Groundwater biota	GWB	?	?
Fire-sensitive shrubs	FSS	(+)	(+)
Large woody debris and leaf litter	LWD&LL	?	?
Tree habitat	TH	(–)	?
Arboreal vertebrates	AV	?	?
Ground-dwelling vertebrates	GDV	?	?
Wildfire	Fire	(–)	(–)
Burrowing frogs	BF	?	?
Fire-tolerant shrubs	FTS	?	?
Groundwater table	GWT	?	?
Fire-obligate shrubs	FOS	(–)	(–)
Fine-coarse soil texture ratio	F/C ST	0	0
Grass	Gra	(–)	?
Ground habitat	GH	(–)	?
Nutrient availability	NA	(–)	(–)

Qualitative model predictions that are completely determined are shown without parentheses. Predictions that are ambiguous but with a high probability (0.80 or greater) of sign determinancy are shown with parentheses. Predictions with a low probability (less than 0.80) of sign determinancy are denoted by a question mark. Zero denotes completely determined predictions of no change.
Data: Bioregional Assessment Programme (Dataset 4)

2.7.5.3 *Choice of hydrological response variables and receptor impact variables*

In bioregional assessments (BAs), the potential ecological impacts of coal resource development are assessed in two future years – 2042 and 2102. These are labelled as the short- and long-assessment years, respectively. Potential ecological changes are quantified in BAs by predicting the state of a select number of receptor impact variables in the short- and long-assessment years. These predictions are made conditional on the values of certain groundwater and surface water statistics that summarise the outputs of numerical model predictions in that landscape class in an interval of time that precedes the assessment year. In all cases these predictions also allow for the possibility that changes in the future may depend on the state of the receptor impact variable in the reference year 2012, and consequently this is also quantified by conditioning on the predicted hydrological conditions in a reference interval that precedes 2012 (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)).

For surface water and groundwater variables in the Namoi subregion, the reference assessment interval is defined as the 30 years preceding and including 2012 (i.e. 1983 to 2012). For surface water variables in the Namoi subregion, the short-assessment interval is defined as the 30 years preceding the short-assessment year (i.e. 2013 to 2042), and the long-assessment interval is defined as the 30 years that precede the long-assessment year (i.e. 2073 to 2102). For groundwater, maximum drawdown (metres) and time to maximum drawdown are considered across the full 90-year window: 2013 to 2102.

In BAs, choices about receptor impact variables must balance the project's time and resource constraints with the objectives of the assessment and the expectations of the community (companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018)). This choice is guided by selection criteria that acknowledge the potential for complex direct and indirect effects within perturbed ecosystems, and the need to keep the expert elicitation of receptor impact models tractable and achievable (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)).

For all riverine landscape classes in the Pilliga, the qualitative modelling workshop identified three variables – two flow regimes and groundwater – as the hydrological factors that were thought to (i) be instrumental in maintaining and shaping the ecosystem and, (ii) have the potential to change due to coal resource development. All of the ecological components and processes represented in the qualitative model are potential receptor impact variables and all of these are predicted to vary as the hydrological factors vary either individually or in combination (Table 36).

Following advice received from participants during (and after) the qualitative modelling workshop, and guided by the availability of experts for the receptor impact modelling workshop, the scope of the BA numerical modelling and the receptor impact variable selection criteria, the receptor impact models focused on the following relationships:

1. the response of the riparian trees to changes in zero-flow days (ZQD) and groundwater (dmaxRef)
2. the response of families of aquatic macroinvertebrates in instream pool habitats to changes in zero-flow regime (ZQD, ZME) and groundwater drawdown (dmaxRef).

The hydrological factors identified by the participants in the qualitative modelling workshops have been interpreted as a set of hydrological response variables. The hydrological response variables are summary statistics that (i) reflect these hydrological factors, and (ii) can be extracted from the BA numerical surface water and groundwater models during the reference, short- and long-assessment intervals defined previously. The hydrological factors and associated hydrological response variables for the Pilliga riverine landscape classes are summarised in Table 37. The precise definition of each receptor impact variable, typically a species or group of species represented by a qualitative model node, was determined during the receptor impact modelling workshop.

Using this interpretation of the hydrological response variables, and the receptor impact variable definitions derived during the receptor impact modelling workshop, the relationships identified in the qualitative modelling workshop were formalised into two receptor impact models (Table 38).

Table 37 Summary of the hydrological response variables used in the receptor impact models for the Pilliga riverine (upland and lowland) landscape classes, together with the signed digraph variables

Signed digraph variable	Hydrological response variable	Definition
GW	dmaxRef	Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012)
GW	tmaxRef	The year that the maximum difference in drawdown relative to the reference period (1983 to 2012) (dmaxRef) occurs.
ZFD	ZQD	The number of zero-flow days per year, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.
ZFD	ZME	The maximum length of spells (in days per year) with zero flow, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

Table 38 Summary of the receptor impact models developed for the Pilliga riverine (upland and lowland) landscape classes

Relationship being modelled	Receptor impact variable (with associated sample units)	Hydrological response variable
Response of the riparian trees to changes in zero-flow regime and groundwater	Annual mean projected foliage cover of species group that includes: yellow box, white cypress pine, *Eucalyptus crebra*, dirty gum, Blakely's red gum, *Angophora floribunda*, *Eucalyptus fibrosa*, fuzzy box. Transect of 50 m length and 20 m width that extends from first bench (‘toe’) on both sides of stream	ZQD dmaxRef tmaxRef
Response of slow-water macroinvertebrates to changes in zero-flow days and groundwater	Average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools	ZQD, ZME dmaxRef tmaxRef

Hydrological response variables are as defined in Table 37.

2.7.5.4 Receptor impact models

2.7.5.4.1 Pilliga riverine (upland and lowland)

Table 39 summarises the elicitation design matrix for the projected foliage cover of riparian trees in the riverine landscape classes in the Pilliga region. The first three design points – design point identifiers 1 to 3 – address the predicted variability (across the streams in the landscape class during the reference interval) in the zero-flow regime. Note that the design point identifiers are simply index variables that identify the row of the elicitation design matrix. They are included here to maintain an auditable path between analysis and reporting.

The first design points provide for an estimate of the uncertainty in mean projected foliage cover across the landscape class in the reference year 2012 (Yref). The remaining design points represent hydrological scenarios that span the uncertainty in the values of the hydrological response variables in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years.

Table 39 Elicitation design matrix for the annual mean projected foliage cover of riparian trees along Pilliga riverine landscape classes that includes: yellow box, white cypress pine, *Eucalyptus crebra*, dirty gum, Blakely's red gum, *Angophora floribunda*, *Eucalyptus fibrosa*, fuzzy box in the Namoi subregion zone of potential hydrological change

Id	ZQD	dmaxRef	Yref	Year	tmaxRef
3	176.67	na	na	2012	0
1	0.00	na	na	2012	0
2	88.34	na	na	2012	0
26	83.40	56.80	0.12	2042	2103
28	0.00	0.20	0.20	2042	2027
48	178.00	0.20	0.20	2042	2103
15	178.00	8.16	0.12	2042	2065
36	178.00	56.80	0.20	2042	2027
52	0.00	56.80	0.20	2042	2103
86	83.40	8.16	0.20	2102	2027
61	0.00	56.80	0.12	2102	2027
73	0.00	0.20	0.12	2102	2103
57	178.00	0.20	0.12	2102	2027
92	83.40	0.20	0.20	2102	2065
108	178.00	56.80	0.20	2102	2103

Receptor impact modelling elicitation design matrix for annual mean projected foliage cover in a transect of 50 m length and 20 m width that extends from first bench ('toe') on both sides of the stream in permanent and temporary upland streams. Design points for Yref in the future (short- and long-assessment periods) are calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers Id) are either default values or values determined by groundwater and surface water modelling. Hydrological response variables are as described in Table 37. na = not applicable
Data: Bioregional Assessment Programme (Dataset 4)

Design point identifiers 15 through to 108 (as listed in Table 39) represent combinations of the three hydrological response variables (dmaxRef, tmaxRef and ZQD), together with high and low values of Yref (see companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). The high and low values for Yref were calculated during the receptor impact modelling workshop following the experts' response to the first design point, and then automatically included within the design for the elicitations at the subsequent design points.

The receptor impact modelling methodology allows for a very flexible class of statistical models to be fitted to the values of the receptor impact variables elicited from the experts at each of the design points (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). The model fitted to the elicited values of mean foliage cover for the Pilliga riverine landscape classes is summarised in Figure 29 and Table 40. The fitted model takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \sum_{j=1}^{3} \beta_{h_j} x_{h_j} \qquad (7)$$

where x_0 is an intercept term (a vector of ones), x_f is a binary indicator variable scored 1 for the case of an assessment in the short- or long-assessment year, x_l is a binary indicator variable scored 1 for the case of an assessment in the long-assessment year, x_r is a continuous variable that represent the value of the receptor impact variable in the reference year (Yref, set to zero for the case of an assessment in the reference year), and $x_{h_j}, j = 1 \dots 4$ are the (continuous or integer) values of the three hydrological response variables (dmaxRef, tmaxRef and ZQD). Note that the modelling framework provides for more complex models, including quadratic value of, and in interactions between, the hydrological response variables but in this instance the simple linear model (Equation 7) was identified as the most parsimonious representation of the experts' responses.

The model estimation procedure adopts a Bayesian approach. The model coefficients $(\beta_0, \beta_f, \beta_l, \beta_r, \beta_{h_j})$ are assumed to follow a multivariate normal distribution. The Bayesian estimation procedure quantifies how compatible different values of the parameters of this distribution are with the data (the elicited expert opinion) under the model. The (marginal) mean and 80% central credible intervals[3] of the three hydrological response variable coefficients are summarised in partial regression plots in Figure 29, while Table 40 summarises the same information for all seven model coefficients.

The model indicates that the experts' opinion provides strong evidence for Yref having a positive effect on average percent projected foliage cover. This suggests that given a set of hydrological response variable values in the future, a site with a higher foliage cover at the 2012 reference point is more likely to have a higher foliage cover in the future than a site with a lower foliage

[3] A central credible interval is the region in the centre of a posterior or prior distribution that contains a specified amount of the probability of the distribution, such that there is equal probability above and below the interval. Hence, an 80% central credible interval is defined as the range of values with posterior (or prior) probability (1 – 0.8)/2 above and below the interval.

cover value at this time point. This reflects the lag in the response of foliage cover to changes in hydrological response variables that would be expected of mature trees with long life spans.

The model also indicates that the experts' opinion provides some evidence for dmaxRef having a negative effect on average percent projected foliage cover (Figure 29). This suggests that percent projected foliage cover will decrease as groundwater drawdown increases due to coal resource development. The model predicts that (holding all other hydrological response variables constant at the mid-point of their elicitation range) the mean of the average percent projected foliage cover will drop from just under 12% without any change in groundwater level, to about 10% if the levels decrease by 50 m relative to the reference level in 2012. There is, however, considerable uncertainty in these predictions, with an 80% chance that the foliage cover will lie somewhere between approximately 8% and 16% on the short-assessment period, and somewhere between roughly 7% and 17% in the long-assessment period, with a 6 m drop in groundwater level. In relation to dmaxRef, Yrs2tmax is also found slightly significant, but with a positive effect. This suggests that a maximum drawdown happening very early would have a larger effect on foliage cover than a maximum drawdown reached after a long time.

The model indicates that the experts' opinion provides strong evidence for ZQD (zero-flow days (averaged over 30 years) subsequently referred to in this Section as 'zero-flow days') having a negative effect on average percent projected foliage cover. The model predicts that (holding all other hydrological response variables constant at the mid-point of their elicitation range) the mean of the average percent projected foliage cover will decrease from just under 25% without any zero-flow days to about 10% if the number of zero-flow days increases to 180.

Finally, the model also indicates some diverging influence between short-term and long-term influence (holding hydrological response variables constant). For the short-assessment period, experts believe in a relative increase of foliage cover, while they are left uncertain about the long-term assessment effect. An interpretation is that the effects of changes in hydrology are not immediate on foliage cover, and 2102 is a very long time into the future to make assessments without uncertainty.

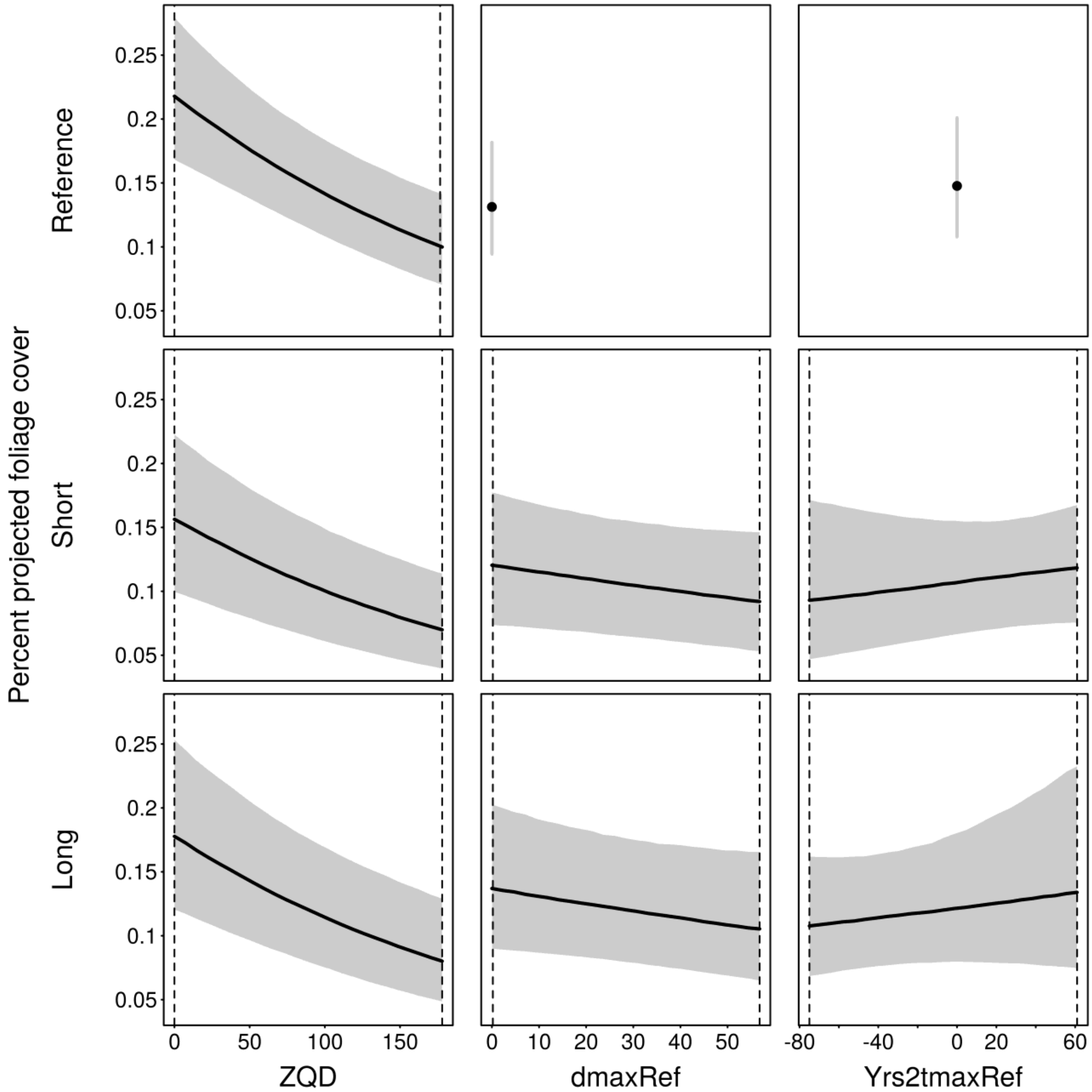

Figure 29 (Top row) Predicted mean (black dot) and 80% central credible interval (grey polygon or line) of annual mean projected foliage cover along Pilliga riverine landscape classes under reference hydrological conditions. (Middle and bottom rows) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of each hydrological response variable on annual mean projected foliage cover along Pilliga riverine landscape classes, holding all other hydrological response variables constant at the midpoint of their elicitation range (during risk estimation all hydrological response variables vary simultaneously)

Dashed vertical lines show hydrological response variable range used in the elicitation. Hydrological response variables ZQD and dmaxRef are as defined in Table 37. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102). The numbers on the y-axis range from 0 to 1 as the receptor impact model was constructed using the proportion for the statistical modelling. They should be interpreted as a percent foliage cover ranging from 0 to 100%.
Data: Bioregional Assessment Programme (Dataset 4)

Table 40 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for annual mean projected foliage cover along Pilliga riverine landscape classes

	Mean	q10	q90
(Intercept)	–1.4	–1.69	–1.11
future1	1.47	0.335	2.6
long1	0.161	–0.332	0.653
Yref	0.938	0.238	1.64
dmaxRef	–0.00493	–0.0116	0.00171
Yrs2tmaxRef	0.0018	–0.00306	0.00666
ZQD	–0.00477	–0.00678	–0.00276

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). Yref quantifies the value of the receptor impact variable during the reference period. Hydrological response variables dmaxRef and ZQD are as defined in Table 37. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102).
Data: Bioregional Assessment Programme (Dataset 4)

Table 41 summarises the elicitation matrix for the average number of families of aquatic macroinvertebrates in instream pool habitats. The first six design points – design points 1 to 7 as shown – address the predicted variability (across the landscape class in the reference interval) in ZQD and ZME, capturing the lowest and highest predicted values together with two intermediate values. These design points provide for an estimate of the uncertainty in aquatic macroinvertebrate family abundance across the landscape class in the reference year 2012 (Yref).

Design points 21 to 213 inclusive (as listed in Table 41) represent scenarios that span the uncertainty in the predicted values of ZQD and ZME in the relevant time period of hydrological history associated with the short- (2042) and long- (2102) assessment years, combined with high and low values of Yref, as well as groundwater drawdown and time to drawdown combinations. Again, the high and low values for Yref were calculated during the receptor impact modelling workshop.

The fitted model for number of families of macroinvertebrates in instream pool habitats takes the form:

$$\eta = h(y) = \beta_0 x_0 + \beta_f x_f + \beta_l x_l + \beta_r x_r + \sum_{j=1}^{4} \beta_{h_j} x_{h_j} \quad (8)$$

where x_0 is an intercept term (a vector of ones), x_f is a binary indicator variable scored 1 for the case of an assessment in the short- or long-assessment year, x_l is a binary indicator variable scored 1 for the case of an assessment in the long-assessment year, x_r is a continuous variable that represent the value of the receptor impact variable in the reference year (Yref, set to zero for the case of an assessment in the reference year), and $x_{h_j}, j = 1 \ldots 4$ are the (continuous or integer) values of the four hydrological response variables (dmax, tmax, ZQD and ZME). Note that the modelling framework provides for more complex models, including quadratic value of, and in interactions between, the hydrological response variables but in this instance the simple linear model (Equation 8) was identified as the most parsimonious representation of the experts' responses.

Table 41 Elicitation design matrix of the average number of families of aquatic macroinvertebrates in instream pool habitat along Pilliga riverine landscape classes in Namoi subregion zone of potential hydrological change

Id	ZQD	ZME	dmaxRef	Yref	Year	tmaxRef
2	88.33	0.32	na	na	2012	0
4	88.34	39.87	na	na	2012	0
5	176.66	0.94	na	na	2012	0
1	0.00	0.00	na	na	2012	0
3	88.34	19.93	na	na	2012	0
7	176.67	39.87	na	na	2012	0
59	177.99	0.95	56.80	13	2042	2103
29	0.00	0.00	8.16	13	2042	2065
70	178.00	39.60	0.20	19	2042	2027
87	177.99	0.95	0.20	19	2042	2065
42	178.00	39.60	56.80	13	2042	2065
41	83.40	19.30	0.20	13	2042	2027
111	83.40	39.60	0.20	19	2042	2103
67	83.40	19.30	0.20	19	2042	2027
21	83.40	0.30	0.20	13	2042	2027
213	177.99	0.95	0.20	19	2102	2065
132	83.40	39.60	0.20	13	2102	2027
210	178.00	39.60	56.80	19	2102	2027
139	83.40	39.60	8.16	13	2102	2027
212	83.40	0.30	0.20	19	2102	2065
190	0.00	0.00	0.20	19	2102	2027
170	83.40	0.30	0.20	13	2102	2103
131	178.00	19.30	0.20	13	2102	2027

Receptor impact modelling elicitation design matrix for average number of families of aquatic macroinvertebrates in instream pool habitat in permanent and temporary upland and lowland streams (Pilliga riverine landscape classes). Design points for Yref in the future (short- and long-assessment periods) are calculated during the receptor impact modelling elicitation workshop using elicited values for the receptor impact variable in the reference period. All other design points (with identifiers Id) are either default values or values determined by groundwater and surface water modelling. Hydrological response variables are as described in Table 37.
na = not applicable
Data: Bioregional Assessment Programme (Dataset 4)

The hydrological response variable in the macroinvertebrate model varies during the reference interval and the future interval. The model indicates that the experts' elicited information supports the hypothesis that an increase in ZQD and/or ZME will have a slightly negative effect on the number of families of macroinvertebrates despite the experts being somewhat uncertain about its average value. The model suggests that it can vary across the landscape class from less than 15 to almost 20 under conditions of constant flow (ZQD = zero), holding all other covariates at their mid-values. As the number of zero-flow days increases, however, experts were of the opinion that the number of families would drop quite dramatically with values between 13 and 6 (under very intermittent flow conditions ZQD >150 days) (Figure 30).

There was very little evidence in the elicited data to suggest that this effect would be substantially different in the future assessment years. Again, this is indicated by the almost identical partial regression plots in the reference, short- and long-assessment years (Figure 30), and the relatively large negative 10th and positive 90th percentiles for the long and future coefficients in Table 42. The model does, however, suggest that the experts' uncertainty increased a lot for predictions in the future assessment years relative to the reference year.

The best-fitting model is unable to eliminate the possibility that the average number of families of macroinvertebrates in the reference years has no influence on its number in the future years. This is indicated by the fact the model automatically dropped this variable from the model. This suggestion is consistent with the hypothesis that there is likely to be very little lag in the response of this short-lived species to changes in the hydrological response variables.

The model also indicates that the experts' opinion provides strong evidence for dmaxRef having a negative effect on macroinvertebrates in instream pool habitats. This suggests that the number of families of macroinvertebrates will decrease as groundwater drawdown increases due to coal resource development. The model predicts that (holding all other hydrological response variables constant at the mid-point of their elicitation range) the number of families will drop from just under 12 without any change in groundwater level, to about 6 if the levels decrease by 55 m relative to the reference level in 2012. There is, however, considerable uncertainty in these predictions, with an 80% chance that the number of families will lie somewhere between approximately 1 and 12 on the short-assessment period and in the long-assessment period. In relation to the time of drawdown, Yrs2tmax is not found significant, meaning that the time at which the maximum drawdown will occur does not carry much influence over the number of families of aquatic macroinvertebrates.

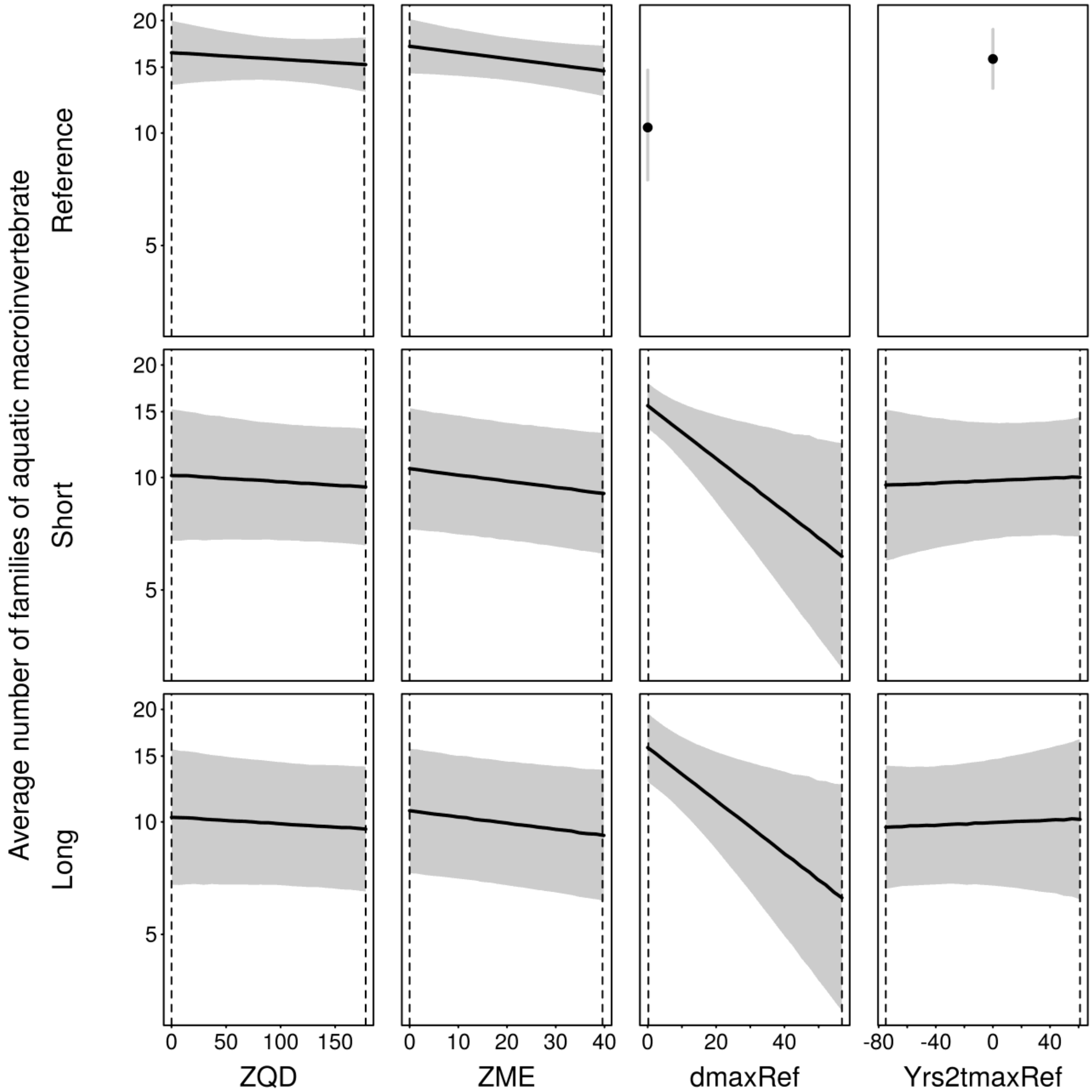

Figure 30 (Top row) Predicted mean (black dot) and 80% central credible interval (grey polygon) of average number of families of aquatic macroinvertebrates in instream pool habitat in Pilliga riverine landscape classes under reference hydrological conditions. (Middle and bottom rows) Predicted future effect (mean = black line, 80% central credible interval = grey polygon) of each hydrological response variable on average number of families of aquatic macroinvertebrates in instream pool habitat in Pilliga riverine landscape classes, holding all other hydrological response variables constant at the midpoint of their elicitation range (during risk estimation all hydrological response variables vary simultaneously)

Dashed vertical lines show hydrological response variable range used in the elicitation. Hydrological response variables are as defined in Table 37. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102).
Data: Bioregional Assessment Programme (Dataset 4)

Table 42 Mean, 10th and 90th percentile of the coefficients of the receptor impact model for average number of families of aquatic macroinvertebrates in instream pool habitat in Pilliga riverine landscape classes

	Mean	q10	q90
(Intercept)	2.87	2.66	3.08
future1	–0.0138	–0.198	0.17
long1	0.0151	–0.268	0.298
dmaxRef	–0.0163	–0.0285	–0.0041
Yrs2tmaxRef	0.000373	–0.00274	0.00349
ZQD	–0.00379	–0.0084	0.000817
ZME	–0.000412	–0.00186	0.00101

Future1 is the indicator variable for the short-assessment year (2042). Long1 is the indicator variable for the long-assessment year (2102). Hydrological response variables are as defined in Table 37. Yrs2tmaxRef is the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102).
Data: Bioregional Assessment Programme (Dataset 4)

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2.7.6 'Rainforest' landscape group

Summary

The 'Rainforest' landscape group is distinguished primarily by its vegetation structure and composition. The 'Rainforest' landscape group is predominately 'Dry Rainforest' or 'Western Vine Thickets' (both threatened vegetation classes in NSW). 'Rainforest' and 'Rainforest groundwater-dependent ecosystem (GDE)' landscape classes in the eastern portion of the Namoi assessment extent tend to occupy higher elevations on scree slopes and gullies in Mt Kaputar National Park and other similar mountainous terrain. Further west on the Liverpool Plains, the remnants of the 'Rainforest' landscape group are predominantly semi-evergreen thicket or low microphyll vine forest occupying habitats on basalt outcrops and sandstone hills.

A very small proportion of the 'Rainforest' landscape group within the assessment extent is located within the zone of potential hydrological change. There is 4 km^2 of the 'Rainforest' landscape class and 0.3 km^2 of the 'Rainforest GDE' landscape class within the zone of potential hydrological change in the Namoi subregion.

A qualitative model was developed for this landscape group given the conservation values surrounding the vegetation types common to this group. This model identified groundwater drawdown as being critical to supporting many biophysical components of the model. Given the limited resources and the limited extent of this landscape group, a receptor impact model was not formulated.

2.7.6.1 Description

The 'Rainforest' landscape group is distinguished primarily by its vegetation structure and composition. Rainforests were identified based on Keith's vegetation classification system, where 'vegetation formation' is the top level of the hierarchy, and included the 'Rainforest' and 'Wet sclerophyll' vegetation formations (Keith, 2004) (see Section 2.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018) for details on the landscape classification methodology). The 'Wet sclerophyll' vegetation formation makes up less than 0.3 km^2 of the Namoi assessment extent, whereas most of the 'Rainforest' landscape group comprises the 'Rainforest' vegetation formation, making up approximately 200 km^2 of the Namoi assessment extent (Table 6). A very small proportion of the 'Rainforest' landscape group within the assessment extent is located within the zone of potential hydrological change. There is 4 km^2 of the 'Rainforest' landscape class and 0.3 km^2 of the 'Rainforest GDE' landscape class within the zone of potential hydrological change (Table 6).

Table 43 Rainforest landscape classes and their corresponding areas and percentage contribution within the Namoi assessment extent and zone of potential hydrological change

Landscape class	Area in assessment extent (km^2)	Area in the zone of potential hydrological change (km^2)	Percentage of total area in zone of potential hydrological change (%)
Rainforest	153.1	4	0.1%
Rainforest GDE	43.5	0.3	0%
Total	**196.6**	**4.3**	**0.1%**

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

The 'Rainforest' vegetation formations of Keith are defined as forests with a closed canopy generally dominated by non-eucalypt species with soft, horizontal leaves, however, various eucalypt species may be present as emergents (Keith, 2004). The 'Rainforest' landscape group in bioregional assessments (BAs) is predominately 'Dry Rainforest' or 'Western Vine Thickets' (both threatened vegetation classes in NSW). A detailed typology of these dry rainforest communities in north-western NSW indicates two distinct floristic groups within the Namoi assessment extent (Curran et al., 2008). The detailed study of Curran et al. (2008) showed that rainforest situated in the Peel, Kaputar and Northern Basalts Interim Biogeographic Regionalisation for Australia (IBRA) regions is predominantly notophyll vine thicket dominated by *Ficus rubiginosa* and *Notelaea microcarpa*. Here, the 'Rainforest' and 'Rainforest GDE' landscape classes tend to occupy higher elevations on scree slopes and gullies in Mt Kaputar National Park and other similar mountainous terrain (Figure 31; Curran et al., 2008; Benson et al., 2010).

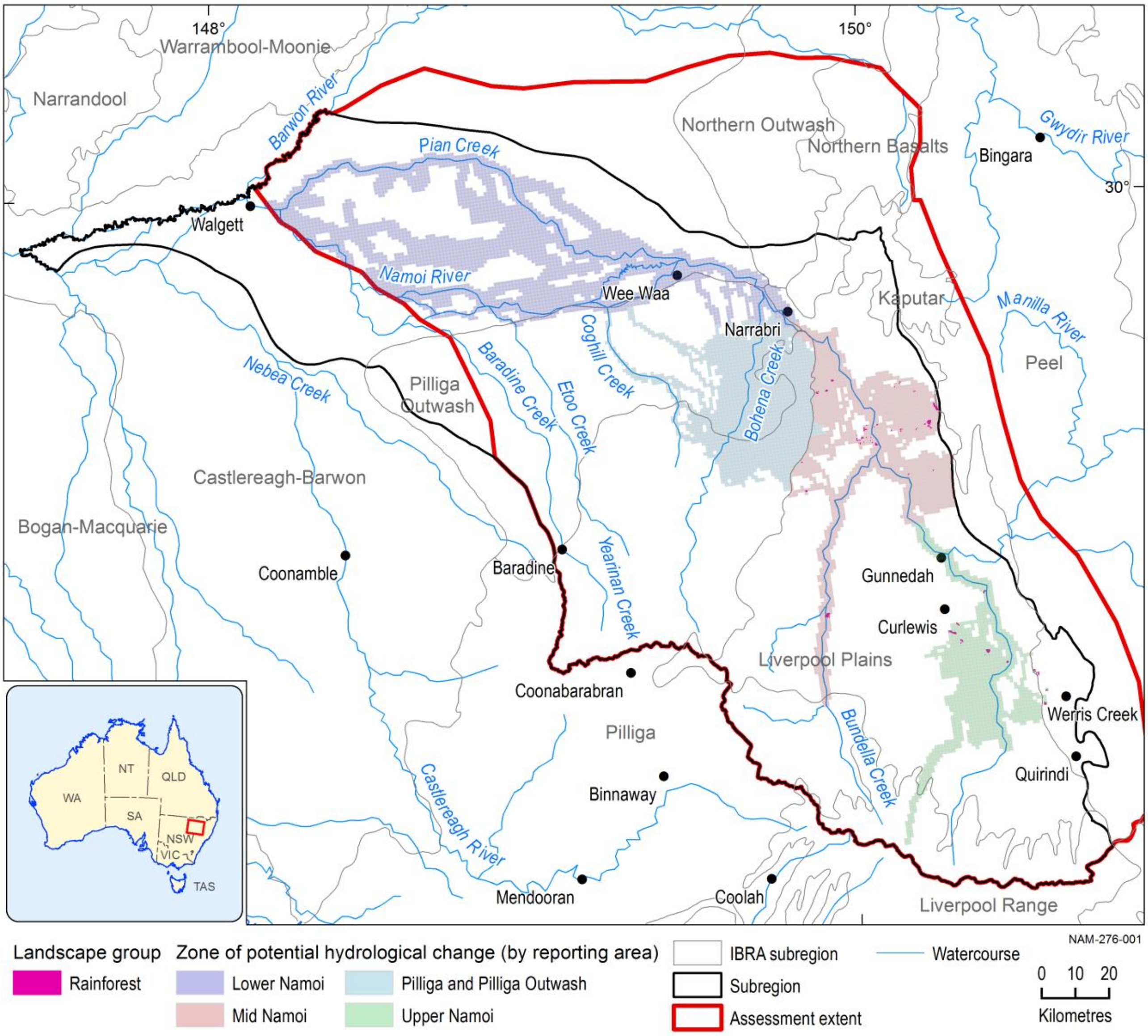

Figure 31 Location of the 'Rainforest' landscape group within the Namoi zone of potential hydrological change

IBRA = Interim Biogeographic Regionalisation for Australia
Data: Bioregional Assessment Programme (Dataset 1)

Further west on the Liverpool Plains, the 'Rainforest' landscape group is predominantly semi-evergreen thicket (dominated by *Notelaea microcarpa, Geijera parviflora* and *Ehretia membranifolia*) and low microphyll vine forest (dominated by *Cadellia pentastylis*) according to the typology proposed by Curran et al. (2008). These pockets of rainforest are found on basalt outcrops and sandstone hills across the Liverpool Plains and Northern Outwash.

The water dependency of the 'Rainforest' landscape group is likely to be mostly from localised surface runoff, and in the case of the 'Rainforest GDE' landscape class, from groundwater sourced from localised discharge from fractured or porous substrates. The localised flow paths of water through basalt outcrops is captured in the pictorial conceptual model in Figure 32. Further evidence of these rainforest communities' reliance on predominantly soil water derived from incident rain or fluctuating supply of subsurface water comes from studies by Curran et al. (2010). They showed large declines in tree water status across many different dry rainforest communities during drought (Curran et al., 2010). This would suggest limited or no access to the watertable and a heavy reliance on rainfall supply.

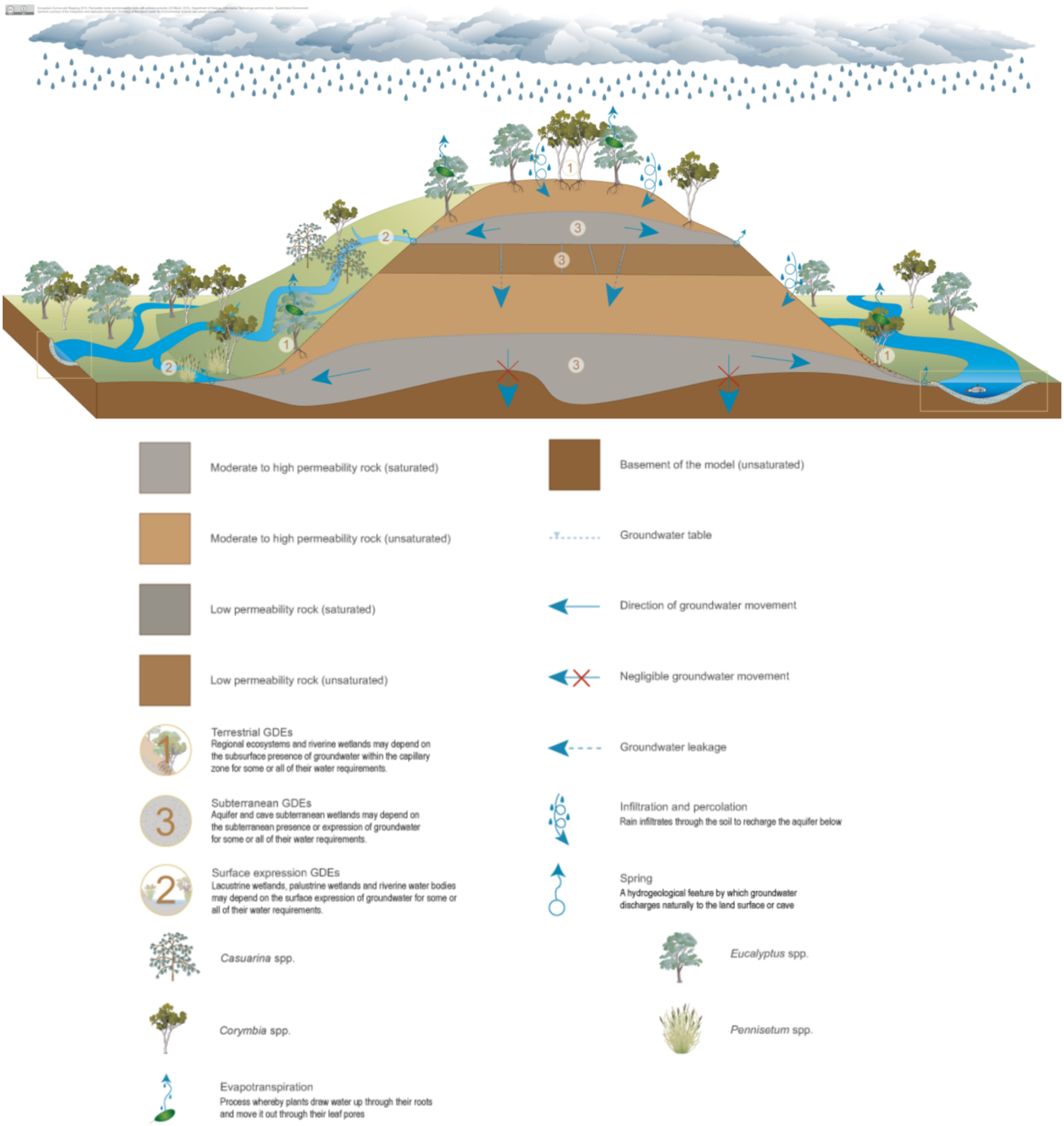

Figure 32 Pictorial conceptual model of groundwater-dependent ecosystems (GDEs) associated with permeable rock (basalt) types

These systems are typical of those landscapes that form on basaltic (volcanic) rocks in the east of the Namoi subregion.
Source: DEHP (2015)

2.7.6.2 Qualitative mathematical model

A qualitative model was developed to describe the ecological community associated with the 'Rainforest' landscape group (Figure 33). The model focused on the functional aspects of tree, shrub (tall and short) and vine vegetation, their ecological roles, and their dependency on soil moisture and groundwater (Figure 33). Tall shrubs are an important source of shade, which under optimal conditions, benefits shorter shrubs and contributes to a humid microclimate close to the ground (Figure 33). Shrubs also produce fruits that sustain populations of fruit-eating birds, mammals and arboreal invertebrates. Shrubs and vines provide habitat structure important for arboreal invertebrates and their leaf litter maintains surface soil moisture and is a food resource for soil-dwelling invertebrates (Figure 33). Both groups of invertebrates are a key food resource for frogs, birds, mammals and reptiles. These insectivores are in turn preyed upon by snakes, other reptiles, birds and mammals, which in turn are also being consumed by predatory birds and goannas (Figure 33).

A significant threat described in this system are populations of feral pigs, which consume the fruits of shrubs and plough through the upper soil layers in search of roots as well as frogs, reptiles and insects (OEH, 2010). They are a major source of disturbance to the system that destroys the humid microclimate of the forest floor. Fragmentation from land clearing similarly compromises the humid microclimate, and decreases the amount of shade and habitat structure (OEH, 2010) (Figure 33).

Trees and tall shrubs access and use deep soil moisture while shrubs and vines use shallow soil moisture (Figure 33). Where available, perched groundwater tables are accessed by all types of forest vegetation in the model. There was speculation regarding the role of trees in lifting water from depth and releasing it into surface soil (Burgess et al., 1998); but specific attributes of this process were considered to be relatively uncertain (Figure 33). The principal impact of coal mining was described as a possible lowering of the groundwater table from open-cut mining, which could then limit replenishment of deep soil moisture or even make it too deep to be accessed by tree roots. This effect, however, was deemed as being uncommon or slight for this landscape class over most of the area of interest in the Namoi subregion. Rainforests in this part of the Namoi subregion may access perched groundwater but were considered unlikely to be dependent on deeper groundwater (Curran et al., 2010). However, fauna from adjacent lowlands may use rainforests as a seasonal refuge and this may increase if the lowland watertable is drawn down (Figure 33).

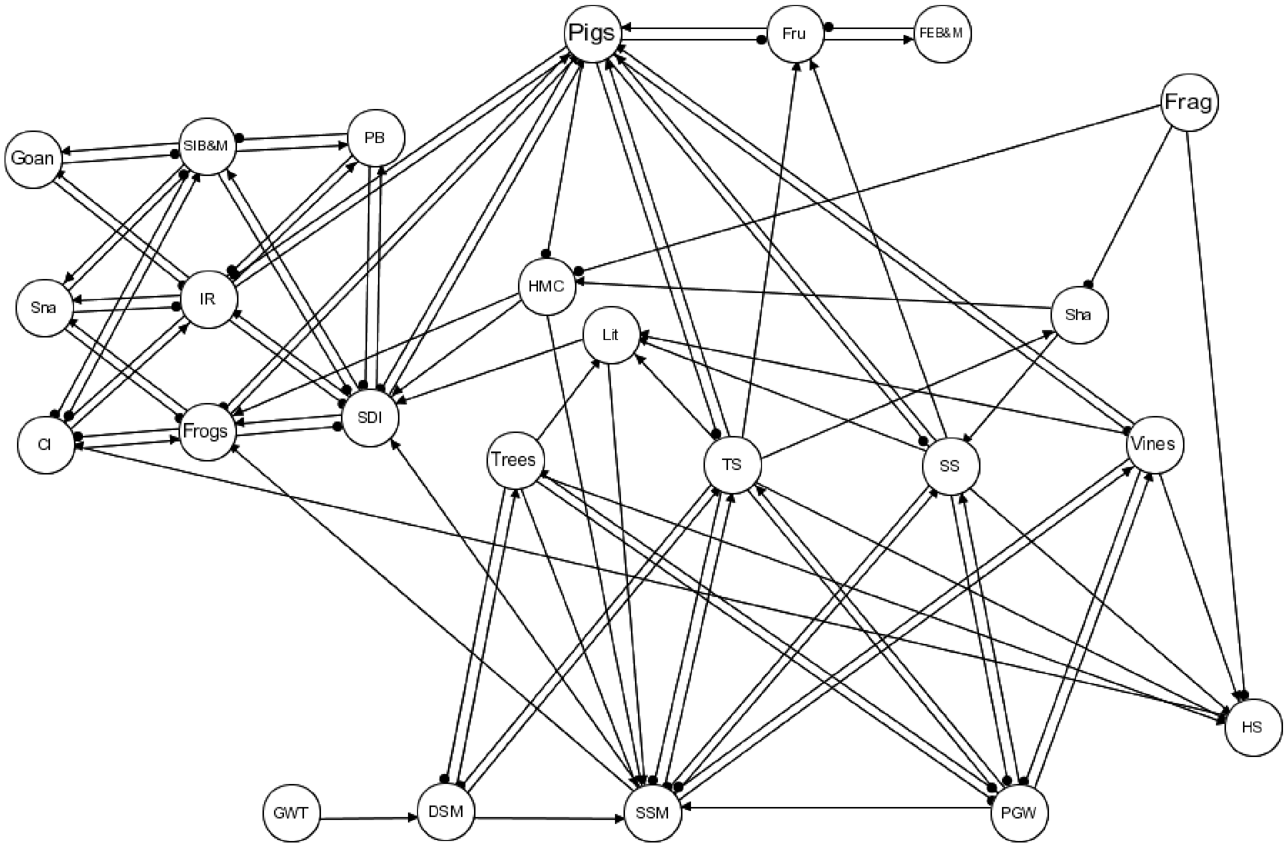

Figure 33 Signed digraph model of rainforest ecosystem

Model variables are: canopy insects (CI), deep soil moisture (DSM), fruit-eating birds and mammals (FEB&M), fragmentation (Frag), frogs (Frogs), fruits (Fru), goannas (Goan), groundwater table (GWT), humid microclimate (HMC), habitat structure (HS), insectivorous reptiles (IR), litter (Lit), pigs (Pigs), predatory birds (PB), perched groundwater (PGW), soil-dwelling insects (SDI), shade (Sha), small insectivorous birds and mammals (SIB&M), snakes (Sna), shorter shrubs (SS), surface soil moisture (SSM), tall shrubs (TS), trees (Trees), vines (Vines).
Data: Bioregional Assessment Programme (Dataset 2)

Surface water and groundwater modelling predict significant potential impacts to the watertable, from which a single cumulative impact scenario (C1) was developed (Table 44).

Table 44 Summary of the (cumulative) impact scenario (CIS) for the rainforest ecosystem

CIS	GWT
C1	–

Pressure scenario is determined by a decrease (–) in the following signed digraph variables: groundwater table (GWT).
Data: Bioregional Assessment Programme (Dataset 2)

Qualitative analysis of the signed digraph model (Figure 33) generally indicates a negative response prediction for most biological variables within the rainforest ecosystem as a result of decreasing the groundwater level (Table 45). A predicted decrease in pigs leads to reduced predation of insectivorous reptiles, a predicted increase of which also favours goannas.

Table 45 Predicted response of the signed digraph variables in the rainforest ecosystem to (cumulative) changes in hydrological response variables

Signed digraph variable (full name)	Signed digraph variable (shortened form)	C1
Trees	Trees	–
Deep soil moisture	DSM	–
Tall shrubs	TS	–
Shorter shrubs	SS	–
Vines	Vines	+
Surface soil moisture	SSM	–
Humid microclimate	HMC	+
Fragmentation	Frag	0
Litter	Lit	–
Perched groundwater	PGW	+
Soil-dwelling insects	SDI	–
Pigs	Pigs	–
Frogs	Frogs	–
Predatory birds	PB	–
Snakes	Sna	–
Small insectivorous birds and mammals	SIB&M	–
Goannas	Goan	+
Canopy insects	CI	–
Insectivorous reptiles	IR	+
Shade	Sha	–
Fruits	Fru	–
Habitat structure	HS	–
Fruit-eating birds and mammals	FEB&M	–

Zero denotes completely determined prediction of no change.
Data: Bioregional Assessment Programme (Dataset 2)

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2.7.7 'Springs' landscape group

Summary

The 'Springs' landscape group is comprised of two landscape classes: 'Great Artesian Basin (GAB) springs' and 'Non-GAB springs'. The distinction between these two landscape classes is based on the hydrological connectivity of the spring to the underlying aquifer. The 'GAB springs' landscape class is associated with sedimentary sequences of the GAB. Based on their hydrogeological setting and related flow paths, the 'GAB springs' springs can be characterised as 'discharge' or 'recharge' springs.

Two of the seven 'GAB springs' in the Namoi assessment extent are located within the zone of potential hydrological change. Given their location on the eastern edge of the Pilliga region, these springs were interpreted to be recharge springs.

A qualitative model was formulated for a typical recharge GAB spring that included the associated terrestrial and aquatic ecosystems. This model identified groundwater drawdown as the critical variable driving ecological function in this system. Given the nature of these springs and their limited extent in the zone of potential hydrological change, a receptor impact model was not formulated for this group.

2.7.7.1 Description

Springs are surface expressions of groundwater that create water flow at the surface and can discharge into wetlands and streams. The 'Springs' landscape group comprises two landscape classes: 'GAB springs' and 'Non-GAB springs'. The distinction between these two landscape classes is based on the rock type of the underlying source aquifer for a given spring. GAB springs in the Namoi subregion are surface expressions of groundwater sourced from aquifers contained in the Triassic, Jurassic and Cretaceous sedimentary sequences associated with the GAB (Habermehl, 1982). GAB springs may form surface water bodies that support aquatic ecosystems and typically contain endemic species and plant communities that have significant ecological, economic and cultural values (Fensham and Fairfax, 2003). GAB springs can be associated with faults or aquitards, thinning of the confining layer or topographic conditions, such as a change of slope or a depression into an aquifer, that allow groundwater to discharge at the surface (Queensland Water Commission, 2012). Based on their hydrogeological setting these springs can be classed as 'recharge' springs or 'discharge' springs. Recharge springs form where the sedimentary rocks that make up the aquifers of the GAB have surface expressions and tend to be situated within the recharge zones of the eastern margin of the GAB (Figure 34) (Fensham and Fairfax, 2003). Groundwater recharge into the GAB aquifers in these areas occurs along sandstone outcrop areas that can include hilly upland areas, where rainwater percolates into the GAB aquifers between confining layers (Figure 34). The discharge of localised recharge is also termed 'rejected recharge'. All other springs associated with GAB aquifers are known as discharge springs and tend to occur down-gradient from recharge areas, due to the presence of faults or where an aquifer comes to the surface (Figure 34) (Fensham and Fairfax, 2003).

'Non-GAB springs' are associated with local flow systems in the basalt aquifers in the eastern portions of the assessment extent and are disconnected from the underlying GAB aquifers. In the Namoi assessment extent, there are no artesian spring communities listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and are not known to occur (only predicted) in this region under the NSW *Biodiversity Conservation Act 2016* (OEH, 2016).

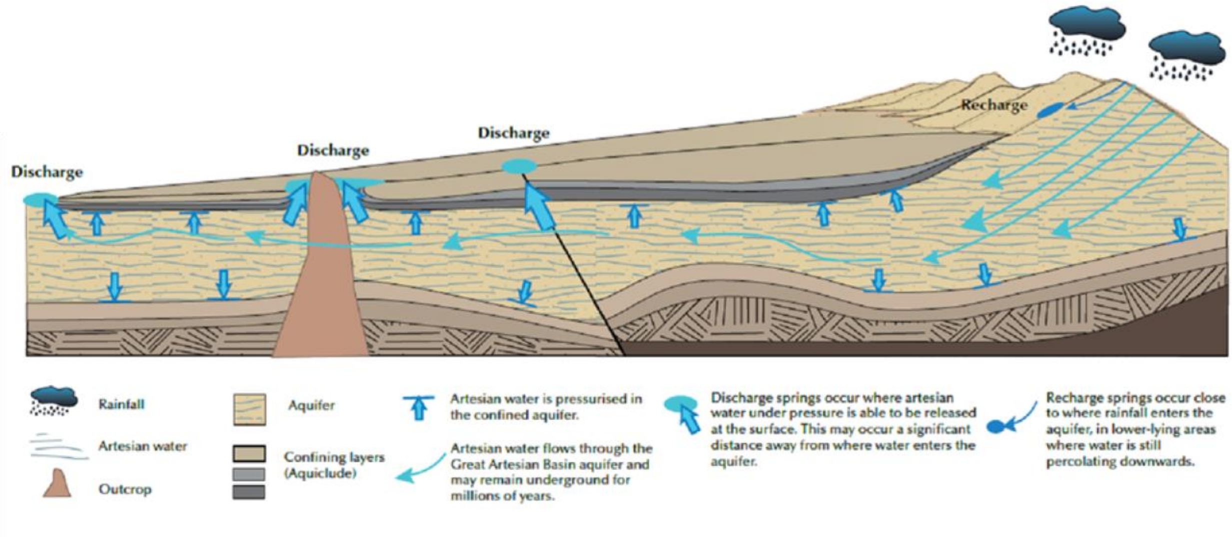

Figure 34 Pictorial representation of the hydrogeological characteristics of recharge and discharge springs associated with the Great Artesian Basin aquifers

Source: DEHP (2013)

There are two springs located within the Namoi subregion zone of potential hydrological change classified as 'GAB springs' given their association with underlying sandstone formations (Table 46). These two springs are located on the eastern edge of the Pilliga region (Figure 35) and are thought to be primarily recharge springs as shown in Figure 34. This conclusion is based on their location along the eastern fringe of the Great Artesian Basin and are located on sites proximal to the interface between Pilliga Sandstone and Purlawaugh Formation. These two springs are identified as Eather Spring (asset ID: 3061; Bioregional Assessment Programme, Dataset 1) and Hardys Spring (asset ID: 3064; Bioregional Assessment Programme, Dataset 1) and are considered high-priority groundwater-dependent ecosystems (GDEs) by the Namoi region state of the catchment report (OEH, 2010).

Table 46 Springs landscape classes within the zone of potential hydrological change and their corresponding numbers in the Namoi assessment extent

Landscape class	Number in assessment extent	Number in zone
GAB springs	7	2
Non-GAB springs	15	0

GAB = Great Artesian Basin
Data: Bioregional Assessment Programme (Dataset 1)

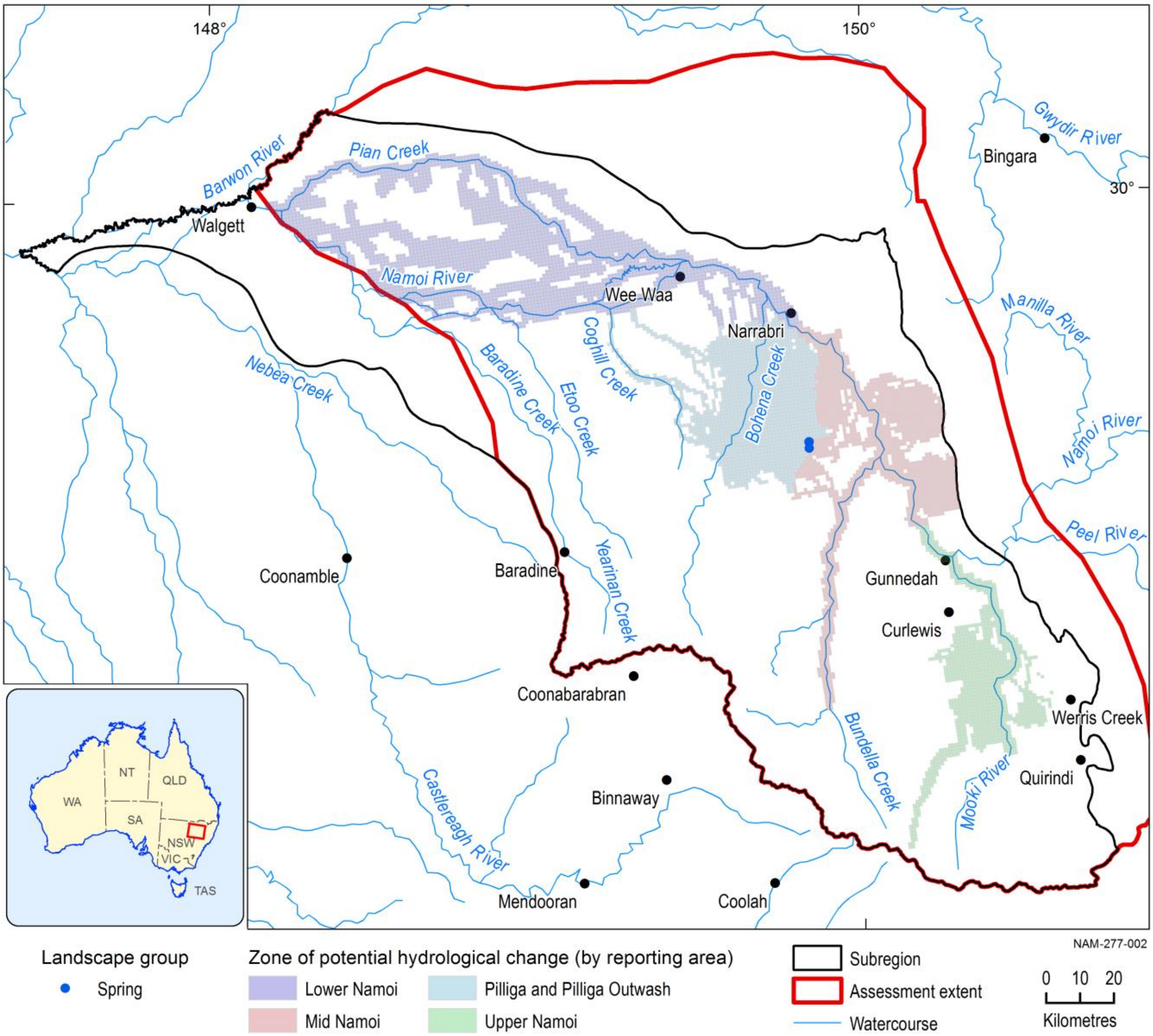

Figure 35 Location of the 'Springs' landscape group within the zone of potential hydrological change

Data: Bioregional Assessment Programme (Dataset 1)

2.7.7.2 Qualitative mathematical model

Workshop discussions on the 'Springs' landscape group in the Namoi subregion identified a general lack of knowledge about the actual locations of springs in the basin, however, it was concluded that, with respect to the potential impacts of coal resource development, the focus of modelling should address those springs thought to be in the zone of potential hydrological change. These springs were identified as most likely to be recharge springs (Fensham and Fairfax, 2003) (Figure 34). The experts in the workshop defined the flow path of these springs as originating from water that is absorbed into sandstone that outcrops on the margins of the GAB and later discharges locally after relatively short residence times.

The saturated zone or water depth of the spring was taken as a critical threshold; water depths above this threshold increased the amount of vegetation surrounding the spring (i.e. fringe vegetation), the amount of open water in the spring, and the amount of outflow (Figure 36). Below this threshold many of the ecological values of the spring cease to exist (Figure 36). Fringe vegetation provides habitat and other resources for populations of semi-aquatic and terrestrial invertebrates, which in turn are a food resource for frogs and terrestrial invertebrates, also living in the fringing vegetation (Fensham et al., 2004). While terrestrial invertebrates are considered an important food resource for their predators, the predator population in return was not considered to have a significant effect on their prey, thus there is no negative link back to terrestrial invertebrates from their predators in the models. Populations of submerged macrophytes depend on the amount of open-water habitat and contribute to stores of organic matter (Figure 36). This organic matter is a primary resource for tadpoles and aquatic invertebrates, which also depend on the volume of open-water habitat.

The amount of open-water habitat in a spring, and its depth, can be controlled by the structural influence of dams, excavations, and mud mounds (Fensham et al., 2012). The intensity of cattle grazing and populations of pigs, however, can dramatically diminish the depth of the open-water habitat by trampling and eroding its edges (Figure 36).

For recharge springs, the relative depth of a spring is determined by the level of the watertable (Figure 36). When the depth of the watertable falls below the bottom of the spring, subsurface habitats are vulnerable to drying, which can diminish the groundwater biota and invertebrate egg bank (Lamontagne, 2002). This invertebrate egg bank, which exists in the bottom and near-surface sediments of the spring, is an important source of propagules that allow the spring's invertebrate community to recover after drying spells (Ponder, 1986) (Figure 36).

The amount of precipitation and infiltration was inferred to contribute to groundwater. Coal resource development, through coal seam gas extraction and open-cut mines, could potentially lower the watertable, and thus impact the depth of recharge–rejection springs (Figure 36).

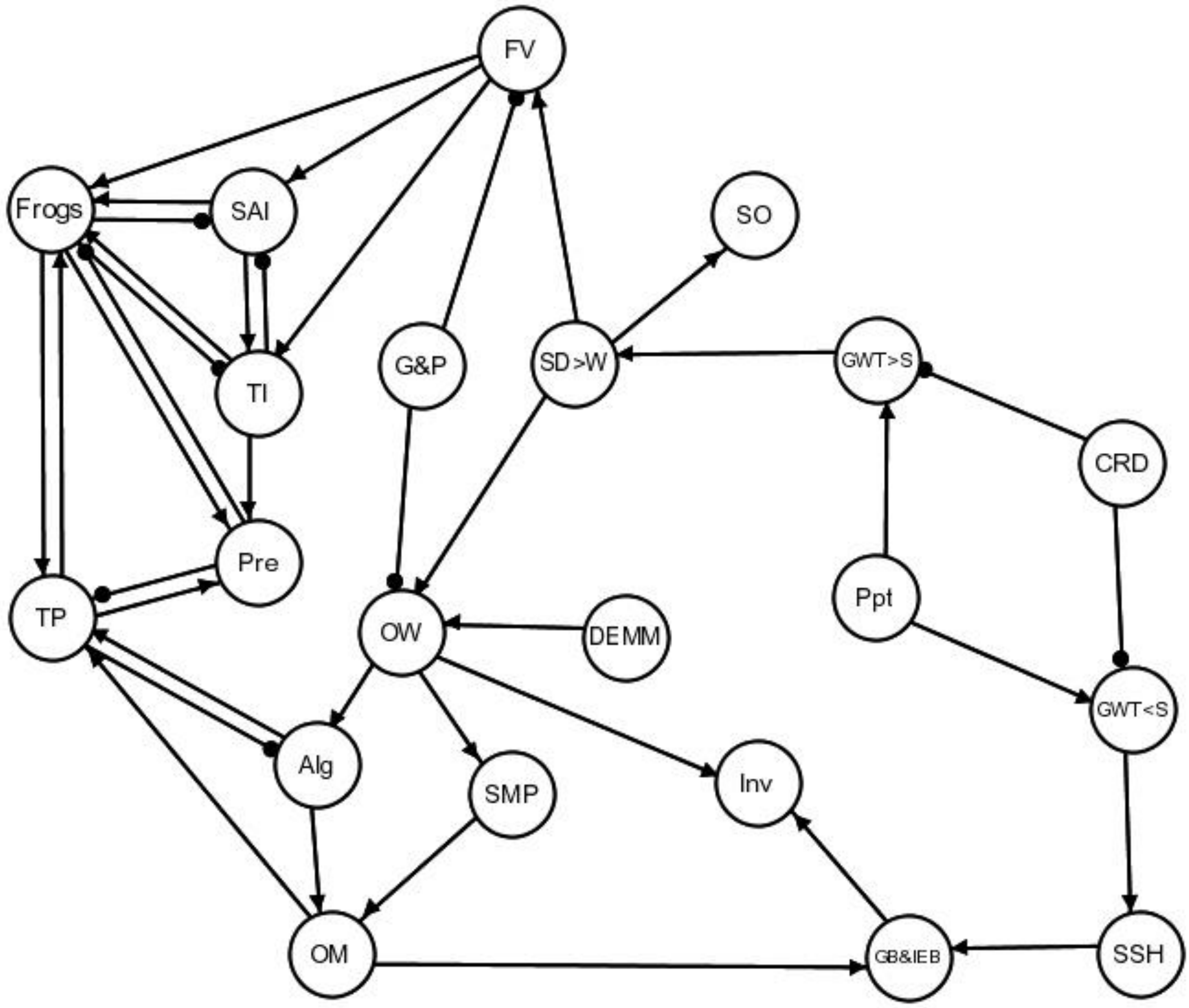

Figure 36 Signed digraph model of recharge–rejection spring ecosystem

Model variables are: algae (Alg), coal resource development (CRD), dams, excavations and mud mounds (DEMM), fringing vegetation (FV), frogs (Frogs), grazing and pigs (G&P), groundwater biota and invertebrate egg bank (GB&IEB), groundwater table levels below spring (GWT<S), groundwater table levels above spring (GWT>S), invertebrates (aquatic) (Inv), organic matter (OM), open water (OW), precipitation and infiltration (Ppt), predators (Pre), semi-aquatic invertebrates (SAI), spring depth above wetted level (SD>W), submerged macrophytes (SMP), spring outflow (SO), subsurface habitat (SSH), terrestrial invertebrates (TI), tadpoles (TP).
Data: Bioregional Assessment Programme (Dataset 2)

Surface water and groundwater modelling predict significant potential impacts to the level of the watertable. This impact was split into changes in depth of groundwater that was above (GWT>S) and below (GWT<S) the base of the springs, which was developed into two cumulative impact scenarios (Table 47).

Table 47 Summary of the (cumulative) impact scenarios (CIS) for the recharge–rejection spring ecosystem

CIS	GWT>S	GWT<S
C1	–	0
C2	–	–

Pressure scenarios are determined by combinations of no-change (0) or a decrease (–) in the following signed digraph variables: decrease in groundwater table level when spring is wet (GWT>S) and decrease in groundwater table below spring level (GWT<S).
Data: Bioregional Assessment Programme (Dataset 2)

Qualitative analyses of the signed digraph model (Figure 36) generally indicate an ambiguous or negative response prediction for all biological variables within the recharge–rejection spring as a result of a drop in the level of the watertable (Table 48).

Table 48 Predicted response of the signed digraph variables in the recharge–rejection spring ecosystem to (cumulative) changes in hydrological response variables

Signed digraph variable (full name)	Signed digraph variable (shortened form)	C1	C2
Spring depth above wetted level	SD>W	(–)	(–)
Fringing vegetation	FV	(–)	(–)
Frogs	Frogs	?	?
Grazing and pigs	G&P	0	0
Subsurface habitat	SSH	0	(–)
Spring outflow	SO	(–)	(–)
Groundwater table levels below spring	GWT<S	0	(–)
Precipitation and infiltration	Ppt	0	0
Coal resource development	CRD	0	0
Groundwater biota and invertebrate egg bank	GB&IEB	(–)	(–)
Semi-aquatic invertebrates	SAI	?	?
Terrestrial invertebrates	TI	?	?
Open water	OW	(–)	(–)
Submerged macrophytes	SMP	(–)	(–)
Dams, excavations and mud mounds	DEMM	0	0
Predators	Pre	(–)	(–)
Invertebrates (aquatic)	Inv	(–)	(–)
Tadpoles	TP	?	?
Organic matter	OM	(–)	(–)
Algae	Alg	?	?

Qualitative model predictions that are completely determined are shown without parentheses. Predictions that are ambiguous but with a high probability (0.80 or greater) of sign determinancy are shown with parentheses. Predictions with a low probability (less than 0.80) of sign determinancy are denoted by a question mark. Zero denotes completely determined predictions of no change.
Data: Bioregional Assessment Programme (Dataset 2)

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2.7.8 Limitations and gaps

Summary

Limitations of the bioregional assessment (BA) for the Namoi subregion receptor impact models and the knowledge gaps that prevented qualitative models for some potentially impacted landscape classes being developed into quantitative models are summarised. Some of the main hurdles encountered in the formulation of qualitative and quantitative models include the availability of resources and expertise to model all potentially impacted landscape classes and the spatial limitations on where hydrological impacts can be evaluated.

2.7.8.1 Prediction of receptor impact variables

Figure 3 in Section 2.7.1.2 summarises the receptor impact modelling workflow, starting from the identification of those landscape classes that occur within the zone of potential hydrological change and that may be impacted through to the prediction of receptor impact variables at assessment units. This product concludes with the construction and interpretation of the receptor impact models, and the relationship between the receptor impact variable and one or more hydrological response variables used in the model. While this allows some assessment of the sensitivity of the response to the hydrological response variables, it needs to be stressed that these should not be interpreted as risk predictions. Receptor impact variable prediction at assessment units occurs in the impact and risk product, where the hydrological response variables are propagated through the receptor impact models to produce a range or distribution of the predicted receptor impact variable response at different time points and for the two futures considered in BA. These distributions reflect the uncertainty in the hydrological response variables, the uncertainty the experts have in the potential ecosystem response to those hydrological response variables, and the spatial heterogeneity across the landscape class.

2.7.8.2 Limitations of the receptor impact modelling

Section 2.7.1 and companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018) detail the strengths and limitations of the expert elicitation process used in the BAs for building qualitative ecosystem models and quantitative receptor impact models. There is no need to revisit these here, except to acknowledge that the qualitative models and receptor impact models that were developed to represent the landscape classes in the Namoi zone of potential hydrological change reflect the subjectivity and bias inherent in the knowledge base of the assembled experts (e.g. in defining the scope of the model, its components and connections, ecologically important hydrological variables, representative receptor impact variables, and magnitude and uncertainty of responses to change). Thus, each model represents 'a view' of a landscape class or ecosystem; a view that might brook argument about some of the specifics but would generally be accepted as an adequate high-level conceptualisation of the important components of the ecosystem(s) it represents. It is acknowledged in Table 4 that this approach may create the potential to underestimate complex ecosystem function and is something that needs to be considered and evaluated against observations (monitoring) in the future.

Some important knowledge gaps and limitations were identified at the expert elicitation workshops, which limit the assessment of potential impacts from hydrological changes due to additional coal resource development for some landscape classes or components of landscape classes within the zone of potential hydrological change. In other words, they limit this BA and must be flagged as areas requiring further investigation.

While some models include salinity and/or nutrient components, the expert elicitations to define the results space for the receptor impact models are premised on changes in hydrology. Changes in water quality parameters that could occur with a shift in the relative contributions of surface water runoff and groundwater to streamflow or due to enhanced connectivity between aquifers of differing water quality, for example, are not represented. Thus, the potential ecological impacts due to additional coal resource development reported in the impact risk analysis for the Namoi subregion (companion product 3-4, Herr et al., 2018) reflect the risk from hydrological changes only; they could differ if changes in key water quality parameters had been included in the model formulation.

The selection of receptor impact variables was based on their ability to be used to detect changes in the ecohydrology of their respective landscape class. The criteria for selecting the receptor impact variables are discussed in detail in companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018). The receptor impact variables identified reflect those criteria and the ecological experts available at the workshops but may benefit from testing and further consideration of their optimality over time. The receptor impact variables selected may not capture all potential ecological changes brought about by alterations in the surface water and groundwater regimes from the coal resource development pathway. Limitations arising from selecting a receptor based on a particular taxa or functional group or ecosystem component include: the lack of differentiation between species that have differing vulnerability to hydrological change; variation in the different taxa within a receptor across the assessment extent; and assessment of one trophic level as opposed to an assessment of trophic interactions within and across landscape classes and ecosystems. This approach is also confounded by variation in the baseline conditions across a given landscape class that may make detection of changes in a certain variable difficult (i.e. poor condition of existing instream habitat for macroinvertebrates along a ‘Permanent lowland stream’ reach). Moreover, the extent to which the receptor impact variables are suitable indicators of ecosystem response for all terrestrial groundwater-dependent ecosystems (GDEs) and stream ecosystems across the Namoi subregion has not been established.

Based on feedback from the regional experts at the ecological modelling workshops, a decision was made to model the Pilliga region separately. However, the formulation of the landscape classification did not easily facilitate separating landscape classes in the Pilliga from the remaining assessment extent. While this did not create any inherent shortcomings in the ecological models, a separate Pilliga set of classes would have made their formulation and discussion less ambiguous. Efforts have been made to emphasise this within the text and results and future assessments of this kind might consider the Pilliga region separately from the outset.

The group of experts present at the ecological modelling workshops had some knowledge of Pilliga vegetation and geomorphology, however, it can be stated that there was a limited understanding of the nature of groundwater interactions both between riverine and terrestrial ecosystems. This was especially true for the 'Grassy woodland GDE' that occupies the largest extent of a terrestrial landscape class in the assessment extent considered to be water dependent. There has been limited assessment of groundwater dependency in the diverse vegetation communities of the Pilliga, despite GDE mapping (NSW Office of Water, Dataset 1) showing considerable patches of potentially dependent vegetation. Thus, a more complete picture of the hydrological connections among the Pilliga riverine, vegetation and wetland elements is considered a key priority for future work.

An inherent shortcoming of the ecological modelling process is that it is assumed that there is sufficient hydrological modelling across the full distribution of a class or group of classes when the quantitative models are elicited. In reality, surface water modelling particularly is limited by the extent to which model simulation and calibration nodes exist and can be used to interpolate model output across the stream network. In the Namoi subregion this limitation focuses much of the available surface water model output into the major lowland riverine reaches such as: Namoi River, Maules Creek, Peel River, Coxs Creek and Pian Creek. There is a paucity of surface water hydrological response information for the majority of the upland riverine reaches, and very limited coverage of the entire stream network in the Pilliga region. In many cases this may not hamper the assessment of potential risks across those parts of the landscape most affected from additional coal resource development, given their location toward the floodplain and lowland parts of the catchment. The extent of different landscape classes that are unquantified by surface water modelling is discussed in companion product 3-4 for the Namoi subregion (Herr et al., 2018).

Climate change is not included directly in the receptor impact modelling, but a mid-range climate projection is used and potential changes to precipitation factored into the process through the surface water modelling of hydrological response variables.

Receptor impact modelling was not conducted in full for several landscape classes that intersect the zone of potential hydrological change. These include the 'Floodplain grass woodland' and 'Floodplain grassy woodland GDE' landscape classes, the non-floodplain wetland landscape classes, 'Rainforest' landscape group and the 'GAB Springs' landscape class. While this choice reflects a prioritisation given known causal pathways, workshop logistics and expert availability, it is a gap and something that could be addressed through follow up analysis.

The experts considered the 'Rainforest' landscape group in the qualitative modelling workshop and defined its potential linkages. However, considerable uncertainty remains around the degree to which this group would normally access groundwater given its habitat within the Namoi subregion is generally in elevated portions of the landscape. The identification of potentially groundwater-dependent elements of the 'Rainforest' landscape group ('Rainforest GDE') is based to a large degree on remote-sensing information (Kuginis et al., 2016). It is possible that some of these rainforest elements exhibit spectral properties similar to GDEs (i.e. higher greenness values) while in reality not accessing groundwater during their life cycle. Further research would be needed to ascertain the potential for any reliance on groundwater, as well as a characterisation of the potential flow paths of this water supply within the rainforest landscape.

Specific local knowledge of the springs found within the Namoi subregion zone of potential hydrological change probably reflects the relatively low ecological importance of these elements. The ecological experts had some knowledge of other springs within the assessment extent but considered the aforementioned 'GAB springs' as relatively insensitive to hydrological change based on their location and hydrogeological setting (see Section 2.7.7). Thus, this gap in expertise was not considered to be particularly crucial for defining potential ecosystem risks in this case.

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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

additional drawdown: the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development

annual flow (AF): the volume of water that discharges past a specific point in a stream in a year, commonly measured in GL/year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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.

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. The assessment extent is created by revising the preliminary assessment extent on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis.

assessment unit: for the purposes of impact analysis, a geographic area that is used to partition the entire assessment extent into square polygons that do not overlap. The spatial resolution of the assessment units is closely related to that of the bioregional assessment groundwater modelling and is, typically, 1 x 1 km. Each assessment unit has a unique identifier. The partitioned data can be combined and recombined into any aggregation supported by the conceptual modelling, causal pathways and model data.

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.

baseflow: the portion of streamflow that comes from shallow and deep subsurface flow, and is an important part of the groundwater system

baseflow index: the ratio of baseflow to total streamflow over a long period of time (years)

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

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

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

conceptual model: abstraction or simplification of reality

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

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

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

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

dmax: maximum difference in drawdown, obtained by choosing the maximum of the time series of differences between two futures. For example, to calculate the difference in drawdown between the coal resource development pathway (CRDP) and baseline, use the equations dmax = max (dCRDP(t) – dbaseline(t)) where d is drawdown, or dmax = max (hbaseline(t) – hCRDP(t)) where h is groundwater level and t is time.

dmaxRef: maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development.

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 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).

ephemeral stream: a stream that flows only briefly during and following a period of rainfall, and has no baseflow component

EventsR3.0: the mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.

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

fractile: the value of a distribution below which some fraction of the sample lies. For example, the 0.95-fractile is the value below which there is a probability of 0.95 occurrence (or equivalently, 95% of the values lie below the 0.95-fractile).

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

groundwater: water occurring naturally below ground level (whether stored in or flowing through aquifers or within low-permeability aquitards), 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

groundwater zone of potential hydrological change: outside this extent, groundwater drawdown (and hence potential impacts) is very unlikely (less than 5% chance). It is the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the relevant aquifers.

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

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

high-flow days (FD): the number of high-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). The threshold for high-flow days is the 90th percentile from the simulated 90-year period. In some early products, this was referred to as ‘flood days’.

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 flow 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 and/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 mode: 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.

interquartile range (IQR): the interquartile range in daily flow (ML/day); that is, the difference between the daily flow rate at the 75th percentile and at the 25th percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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.

landscape group: for the purposes of bioregional assessments (BAs), a set of landscape classes grouped together based on common ecohydrological characteristics that are relevant for analysis purposes

length of low-flow spell (LLFS): the length (days) of the longest low-flow spell each year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

likelihood: probability that something might happen

low-flow days (LFD): the number of low-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). The threshold for low-flow days is the 10th percentile from the simulated 90-year period.

low-flow spells (LFS): the number of low-flow spells per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). A spell is defined as a period of contiguous days of flow below the 10th percentile threshold.

material: pertinent or relevant

maximum zero-flow spell (ZME): the maximum length of spells (in days per year) with zero flow, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

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

Namoi subregion: The Namoi subregion is located within the Murray–Darling Basin in central New South Wales. The subregion lies within the Namoi river basin, which includes the Namoi, Peel and Manilla rivers. However, the subregion being assessed is smaller than the Namoi river basin because the eastern part of the river basin does not overlie a coal-bearing geological basin. The largest towns in the subregion are Gunnedah, Narrabri and Walgett. The main surface water resource of the Namoi subregion is the Namoi River. There are three large dams that supply water to the subregion, of which Keepit Dam is the main water storage. More than half of the water released from Keepit Dam and river inflow may be extracted for use for agriculture, towns and households. Of this, the great majority is used for agricultural irrigation. The landscape has been considerably altered since European settlement for agriculture. Significant volumes of groundwater are also used for agriculture (cropping). Across the subregion there are a number of water-dependent ecological communities, and plant and animal species that are listed as threatened under either Commonwealth or New South Wales legislation. The subregion also contains Lake Goran, a wetland of national importance, and sites of international importance for bird conservation.

overbank flow: flood condition where water flows beyond and sub-parallel to the main channel of a river, but within the bounding floodplain

P01: the daily flow rate at the 1st percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

P99: the daily flow rate at the 99th percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

percentile: a specific type of quantile where the range of a distribution or set of runs is divided into 100 contiguous intervals, each with probability 0.01. An individual percentile may be used to indicate the value below which a given percentage or proportion of observations in a group of observations fall. For example, the 95th percentile is the value below which 95% of the observations may be found.

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. The PAE is estimated at the beginning of a bioregional assessment, and is updated to the ‘assessment extent’ on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis.

probability distribution: the probability distribution of a random variable specifies the chance that the variable takes a value in any subset of the real numbers. It allows statements such as 'There is a probability of x that the variable is between a and b'.

receptor impact model: a function that translates hydrological changes into the distribution or range of potential ecosystem outcomes that may arise from those changes. Within bioregional assessments, hydrological changes are described by hydrological response variables, ecosystem outcomes are described by receptor impact variables, and a receptor impact model determines the relationship between a particular receptor impact variable and one or more hydrological response variables. Receptor impact models are relevant to specific landscape classes, and play a crucial role in quantifying potential impacts for ecological water-dependent assets that are within the landscape class. In the broader scientific literature receptor impact models are often known as 'ecological response functions'.

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

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

recharge: see groundwater recharge

riparian: An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation.

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.

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.

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

surface water: water that flows over land and in watercourses or artificial channels and can be captured, stored and supplemented from dams and reservoirs surface water zone of potential hydrological change: outside this extent, changes in surface water hydrological response variables due to additional coal resource development (and hence potential impacts) are very unlikely (less than 5% chance). The area contains those river reaches where a change in any one of nine surface water hydrological response variables exceeds the specified thresholds. For the four flux-based hydrological response variables (annual flow (AF), daily flow rate at the 99th percentile (P99), interquartile range (IQR) and daily flow rate at the 1st percentile (P01)), the threshold is a 5% chance of a 1% change in the variable. That is, if 5% or more of model runs show a maximum change in results under coal resource development pathway (CRDP) of 1% relative to baseline. For four of the frequency-based hydrological response variables (high-flow days (FD), low-flow days (LFD), length of longest low-flow spell (LLFS) and zero-flow days (ZFD)), the threshold is a 5% chance of a change of 3 days per year. For the final frequency-based hydrological response variable (low-flow spells (LFS)), the threshold is a 5% chance of a change of 2 spells per year.

tmax: year of maximum change

tmaxRef: the year that the maximum difference in drawdown relative to the reference period (1983 to 2012) (dmaxRef) occurs

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.

very unlikely: less than 5% chance

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)

water use: the volume of water diverted from a stream, extracted from groundwater, or transferred to another area for use. It is not representative of 'on-farm' or 'town' use; rather it represents the volume taken from the environment.

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

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’.

Yrs2tmaxRef: the difference between tmaxRef and the assessment year that is relevant for the prediction (2012, 2042 or 2102) zero-flow days (ZFD): the number of zero-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

zero-flow days (averaged over 30 years) (ZQD): the number of zero-flow days per year, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

zone of potential hydrological change: outside this extent, hydrological changes (and hence potential impacts) are very unlikely (less than 5% chance). Each bioregional assessment defines the zone of potential hydrological change using probabilities of exceeding thresholds for relevant hydrological response variables. The zone of potential hydrological change is the union of the groundwater zone of potential hydrological change (the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the relevant aquifers) and the surface water zone of potential hydrological change (the area with a greater than 5% chance of exceeding changes in relevant surface water hydrological response variables due to additional coal resource development).

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