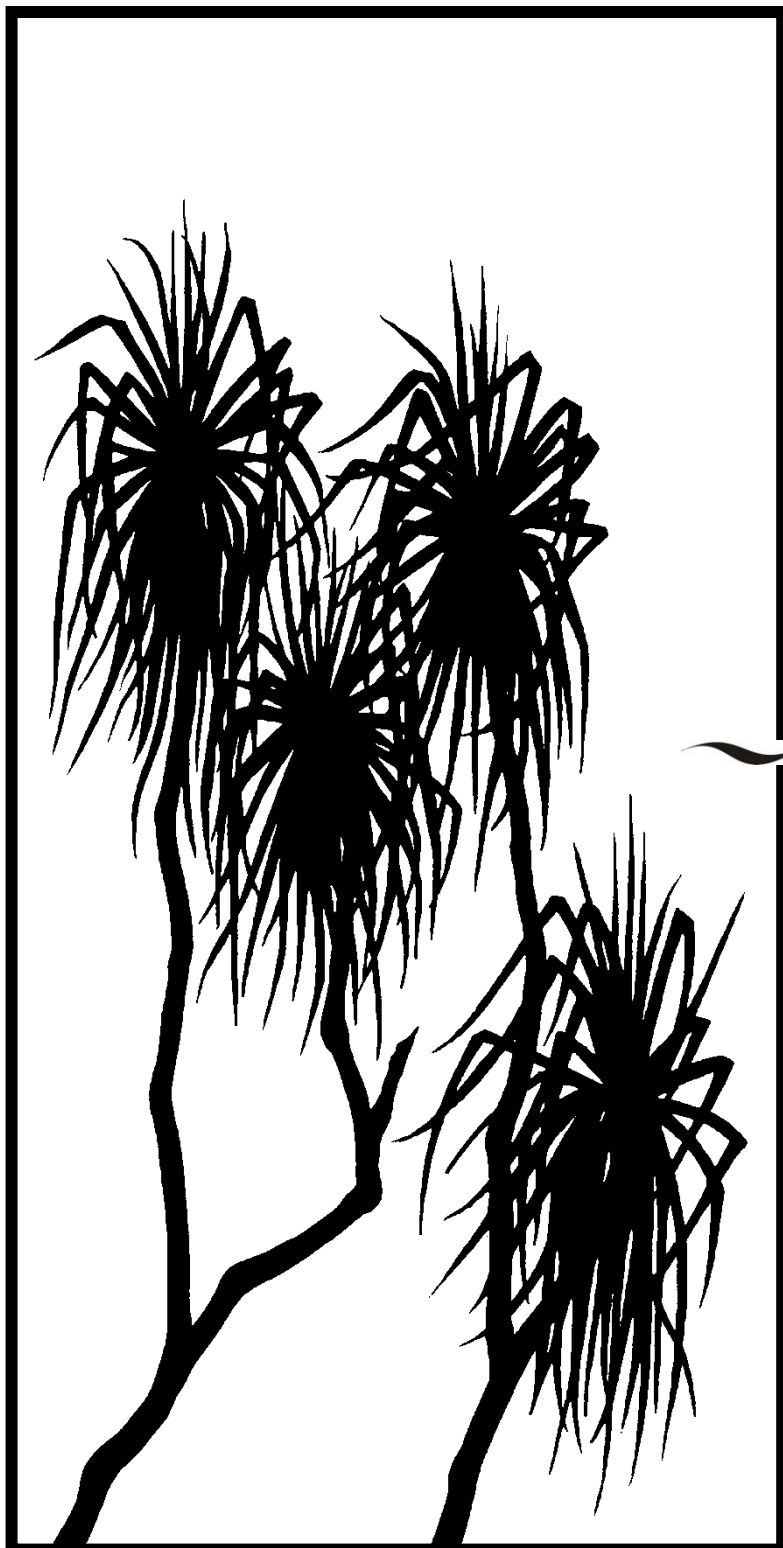




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Rehabilitation and closure
ecological risk assessment
for Ranger Uranium Mine:
Documentation of initial
problem formulation
activities

R Bartolo, S Paulka, R van Dam,
S Iles & A Harford

October 2013

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Rehabilitation and closure ecological risk assessment for Ranger Uranium Mine: Documentation of initial problem formulation activities

R Bartolo, S Paulka, R van Dam, S Iles & A Harford

Supervising Scientist Division
GPO Box 461, Darwin NT 0801

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Executive summary

Initial conceptual models (causal maps) of potential stressors and their pathways have been developed as part of the problem formulation phase of the ecological risk assessment focused on closure and rehabilitation of Ranger Uranium Mine. The conceptual models were drafted during a two day workshop with stakeholders who formed breakout groups around four themes (aquatic ecosystems; terrestrial ecosystems (Ranger Project Area); terrestrial ecosystems (landscape); and people), and were subsequently reviewed by a small review group and finalised by the breakout groups.

Components of the problem formulation that were undertaken include:

- Setting the spatial and temporal scales that are the focus of the ecological risk assessment. There are three temporal phases: i) decommissioning; ii) stabilisation and monitoring; and iii) post-closure. The five spatial scales defined are: i) the Ranger mine site (disturbed footprint); ii) the Ranger Project Area (RPA); iii) Magela Creek catchment; iv) Kakadu National Park; and v) the Alligator Rivers Region (ARR).
- Identify the key sources, stressors and ecological assets that will be examined for the decommissioning, stabilisation and monitoring, and the post-closure phases of Ranger uranium mine's closure. The values are documented in Pollino et al. (2013).
- Determine the ecological assessment endpoints. Numerous assessment endpoints were developed for the four themes.

For *aquatic ecosystems* three assessment endpoints were developed for both the on-site and off-site environment reflecting their different management goals:

- 1) Off-site water quality meets agreed closure criteria specified for water quality.
- 2) Habitat diversity of off-site aquatic ecosystems are comparable to the agreed reference condition.
- 3) Biodiversity (structure and function) of off-site/on-site aquatic ecosystems are comparable to the agreed reference condition.
- 4) On-site water quality is on a trajectory towards meeting agreed closure criteria specified for water quality on-site.
- 5) Habitat diversity of on-site aquatic ecosystems is on a trajectory towards meeting agreed closure criteria.
- 6) Biodiversity (structure and function) of on-site aquatic ecosystems are on a trajectory towards meeting agreed closure criteria.

The biodiversity assessment endpoints are proposed and not finalised as the ecological processes and functions that were identified during the workshop have not been drafted as conceptual models. The ecological processes and functions will be addressed in the near future by the Closure Criteria Working Group (CCWG).

For *terrestrial ecosystems (RPA)* three assessment endpoints were developed:

- 7) Erosion characteristics of the rehabilitated landform meet agreed closure criteria.
- 8) Wildlife on the rehabilitated site is on a trajectory towards meeting agreed closure criteria.
- 9) Vegetation on the disturbed sites of the RPA is on a trajectory towards meeting agreed closure criteria.

For *terrestrial ecosystems (landscape)* two assessment endpoints were developed:

- 10) Habitat diversity and ecosystem function within the landscape of the Magela Creek sub-catchment and broader Kakadu National Park is comparable to an agreed reference condition.
- 11) Aesthetic values meet the expectations of the stakeholders in the ARR.

For *people* four assessment endpoints were developed:

- 12) Landform is able to be accessed, and is readily traversable, by people.
- 13) Presence of culturally important species at right time and abundance.
- 14) Landform, vegetation and water bodies on-site meets agreed cultural closure criteria.
- 15) Return of traditional practices (e.g. burning, harvesting).

Develop conceptual models for the above-mentioned closure phases of the Ranger mine site:

- The aquatic ecosystems breakout group drafted one large conceptual model that included all sources, stressors, pathways, measurement points and assessment endpoints during the workshop. This large model needed to be reduced into ten sub-models in order to define differences in the pathways to measurement endpoints for each of the stressors.
- The terrestrial ecosystem (RPA) breakout group drafted four conceptual models during the workshop, with three being reviewed post workshop. The fourth model not revised to date, focused on 'protection of human health'. The human health model will be dealt with separately in the future, combining it with the human health model drafted by the people group.
- The terrestrial ecosystem (landscape) breakout group drafted three conceptual models during the workshop. These have been revised to two conceptual models as the sources and stressors were similar between two of the models that were output from the workshop, and review of the assessment endpoints indicated that the models were quite similar.
- The people breakout group drafted two conceptual models – one for cultural landscape and the other for human health. Currently, the group has focused on refining the cultural landscape model. The human health model will be dealt with separately in the future as discussed above. The original cultural landscape model, drafted during the workshop, has been split into four separate conceptual models, to reflect the revised assessment endpoints.

Communicate and document the outcomes from the problem formulation phase:

- A report was produced by Pollino et al. (2013) which details background material, and the values and draft conceptual models produced during the workshop. These are not reported in detail here.
- Revision of the conceptual models presented here and communication is ongoing.

Part of the problem formulation phase project included the development of an analysis plan (design, data needs, and methods for undertaking the risk analysis phase of the assessment), which was undertaken and reported by Pollino et al. (2013). It is recommended that the AS/NZS ISO 31000:2009 generic framework for risk management be adopted as it is considered best practice. The US EPA ecological risk assessment guidelines (US EPA 1998) can be used in conjunction with the ISO risk

management standard. Pollino et al. (2013) recognise there are many approaches for undertaking risk analysis, but they focused on Bayesian networks, a recommended approach in the ISO/IEC 31010 Standard which supports the risk management standard (it is focused on risk analysis techniques). Bayesian networks have also been identified as a potential tool by Energy Resources Australia (ERA).

1 Introduction

1.1 Project definition

Energy Resources of Australia (ERA) and the Supervising Scientist Division (SSD) are collaborating on an ecological risk assessment for the rehabilitation and closure of Ranger uranium mine. The risk assessment will be conducted in three phases. The three phases of the assessment are: (1) Problem formulation, (2) Risk analysis, and (3) Interpretation of results.

This project focuses on the problem formulation phase. The problem formulation, particularly the conceptual models, for the rehabilitation/closure risk assessments will inform the development of closure criteria and measures for monitoring the criteria.

Two experienced external facilitators, Carmel Pollino and Susan Cuddy, from CSIRO, guided and assisted in the problem formulation.

Outcomes of the project are:

- Stakeholder workshop facilitated by an external ecological risk assessment expert.
- Identification and agreement on key sources, stressors and ecological assets and ecological assessment endpoints to be examined for the three phases of Ranger's closure.
- Development of conceptual models (causal maps).
- An analysis plan (design, data needs, and methods for undertaking the risk analysis phase of the assessment).
- Traditional Ecological Knowledge (TEK) is addressed and incorporated throughout the problem formulation.

1.2 Focus of this project

There are specific temporal and spatial scales that are the focus of the ecological risk assessment.

The rehabilitation and closure of Ranger uranium mine will proceed in three temporal phases:

- *Decommissioning* – has commenced with the backfilling of Pit 3 and the decommissioning of the site will continue through to 2026.
- *Stabilisation and monitoring* – is the period post-decommissioning occurring over a decadal time frame. The site will be moving towards an ecosystem that could be considered for incorporation into the surrounding Kakadu National Park.
- *Post-closure* - is the period where monitoring has demonstrated that the closure criteria have been achieved, ERA have been issued a close-out certificate and released from their responsibility for the site, and the site has been returned to the traditional owners. In the short-term, from the perspective of traditional owners, this time frame is from issue of the close-out certificate to 7 generations (approximately 300 years). In the long-term this phase is ongoing to 10,000 years after the close-out certificate has been issued; specifically this time frame applies to the requirement for tailings containment.

There are five spatial scales defined for this ecological risk assessment as shown by Figure 1.1: the Ranger Mine site (disturbed footprint); the Ranger Project Area; Magela Creek catchment; Kakadu National Park; and the Alligator Rivers Region.

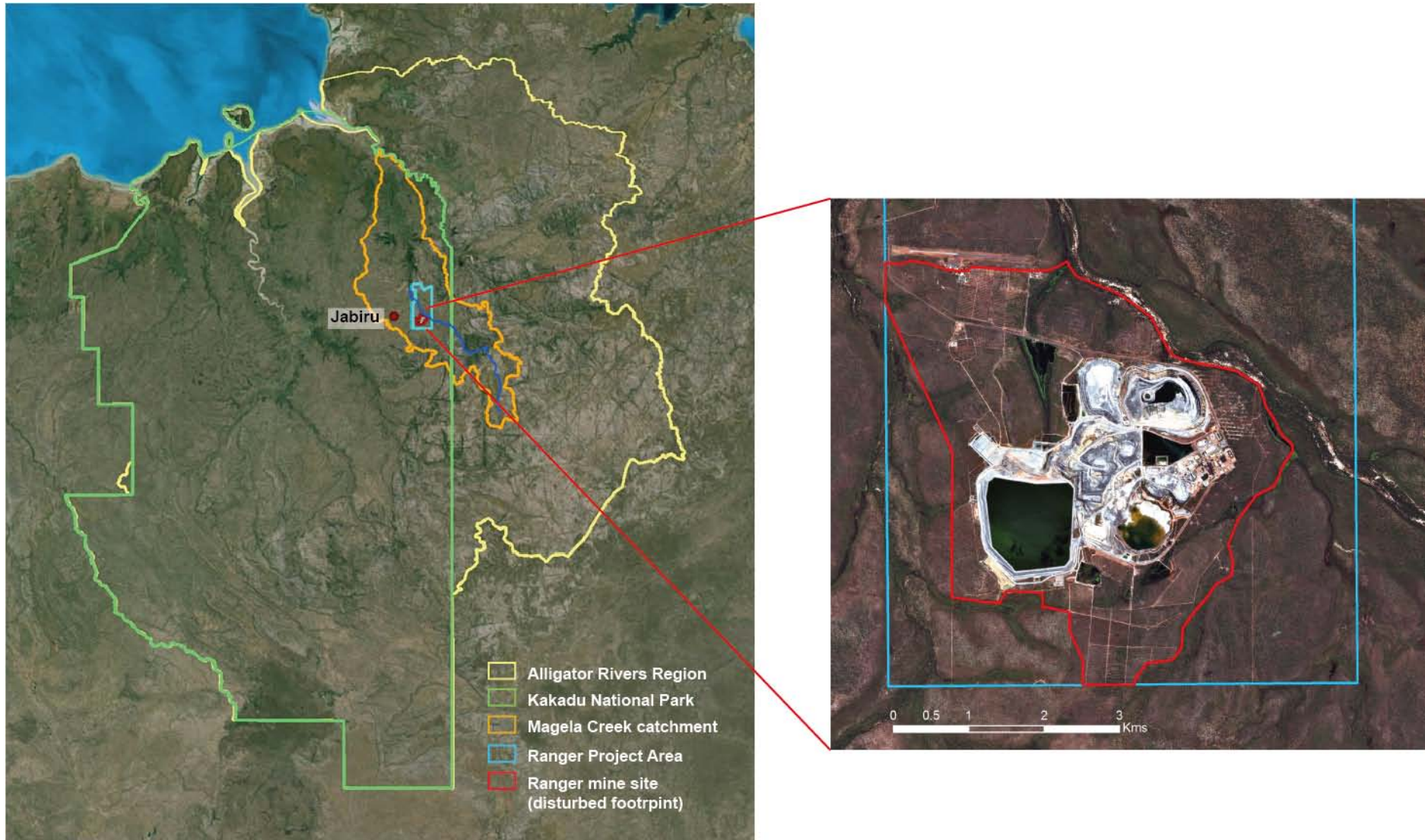


Figure 1.1 Spatial scales defined for the ecological risk assessment

1.3 Project background

ERA is required to close Ranger uranium mine by January 2026. ERA is conducting a major science and engineering study to develop a closure strategy. ERA and SSD have been conducting environmental studies for many years to ensure environmental protection during operations and rehabilitation and after closure. The study needs are identified by the Alligator Rivers Region Technical Committee (ARRTC) and are known as Key Knowledge Needs (KKNs).

Two of the ARRTC KKNs relate to Ecological Risk Assessments of Ranger's rehabilitation and closure. One relates to three phases (decommissioning, stabilization, long term post-closure) of rehabilitation and closure of the site itself (KKN 2.7.1; Box 1). The other relates to landscape scale risks of the closed site in the context of other relevant regional landscape process and threats (KKN 5.1.1; Box 2).

Box 1

KKN 2.7.1 Ecological risk assessments of the rehabilitation and post rehabilitation phases

In order to place potentially adverse on-site and off-site issues at Ranger during the rehabilitation phase within a risk management context, it is critical that a robust risk assessment framework be developed with stakeholders. The greatest risk is likely to occur in the transition to the rehabilitation phase, when active operational environmental management systems are being progressively replaced by passive management systems. A conceptual model of transport/exposure pathways should be developed for rehabilitation and post rehabilitation regimes and the model should recognise the potential that some environmental stressors from the mine site could affect the park and vice versa. Implicit in this process should be consideration of the effects of extreme events and climate change.

Conceptual modelling should be followed by a screening process to identify and prioritise key risks for further qualitative and/or quantitative assessments. The conceptual model should be linked to closure criteria and post-rehabilitation monitoring programs, and be continually tested and improved. Where appropriate, risk assessments should be incorporated into decision making processes for the closure plan. Outputs and all uncertainties from this risk assessment process should be effectively communicated to stakeholders.

Box 2

KKN 5.1.1 Develop a landscape-scale ecological risk assessment framework for the Magela catchment that incorporates, and places into context, uranium mining activities and relevant regional landscape processes and threats, and that builds on previous work for the Magela floodplain

Ecological risks associated with uranium mining activities in the ARR, such as current operations (Ranger) and rehabilitation (Nabarlek, Jabiluka, future Ranger, South Alligator Valley), should be assessed within a landscape analysis framework to provide context in relation to more diffuse threats associated with large-scale ecological disturbances, such as invasive species, unmanaged fire, cyclones and climate change. Most key landscape processes occur at regional scales, however the focus will be on the Magela catchment encompassing the RPA. A conceptual model should first be developed to capture links and interactions between multiple risks and assets at multiple scales within the Magela catchment, with risks associated with Ranger mining activities made explicit. The spatially explicit Relative Risk Model will be used to prioritise multiple risks for further qualitative and/or quantitative assessments. The conceptual model and risk assessment framework should be continually tested and improved as part of Best Practice. Where appropriate, risk assessments should be incorporated into decision making processes using advanced risk assessment frameworks such as Bayesian Networks, and all uncertainties made explicit. This risk assessment process should integrate outputs from KKN 1.2.1 (risks from the surface water pathway – Ranger current operations) and the new KKN 2.6.1 (risks associated with rehabilitation) to provide a landscape-scale context for the rehabilitation of Ranger into Kakadu National Park, and should be communicated to stakeholders.

Another driver for undertaking the risk assessment is updating the KKNs themselves. The KKNs for rehabilitation are based on the understanding of environmental risks and issues developed over several decades of studying the mine and surrounding environment. ARRTC wishes to base the next review of the KKNs on conceptual models and associated risks identified through a formal risk assessment process.

1.4 Project aims and objectives

The overall aim of this project was to complete the Problem Formulation phase (i.e., develop the conceptual models and framework) for the Ranger rehabilitation and closure ecological risk assessments (minesite and landscape scale) in advance of the risk analysis stage. Embedded in this was the need to include Traditional Ecological Knowledge through all phases of the project.

To achieve this aim, specific project tasks were identified:

- Determine the ecological assessment endpoints.
- Identify the key sources, stressors and ecological assets that will be examined for the decommissioning, stabilisation and monitoring, and the post-closure phases of Ranger uranium mine's closure.
- Develop conceptual models for the above-mentioned closure phases of the Ranger mine site.
- Communicate and document the outcomes from the problem formulation phase.
- Development of an analysis plan (design, data needs, and methods for undertaking the risk analysis phase of the assessment).

1.5 Report outline

This report is divided into four sections. Detailed background material is not presented in this report as this has been provided previously (Iles 2012, Bartolo et al. 2013, Pollino et al. 2013). Section 2 outlines the approach taken to develop the conceptual models. Section 3 presents the casual models and definitions of some terms used in the models. Section 4 provides a summary and recommendation for Phase 2 of the ecological risk assessment, the risk analysis phase.

2 Approach

A risk assessment framework was implemented for this project (see Pollino et al. 2013). The standard used for this project is the *AS/NZS ISO 31000:2009 Risk management-principles and guidelines*. Components specific to ecological risk assessment have been addressed by the *Guidelines for Ecological Risk Assessment* (US EPA 1998). These two frameworks are complementary as demonstrated by Pollino et al. (2013). A summary of the approach taken in this project is given by Figure 2.1.

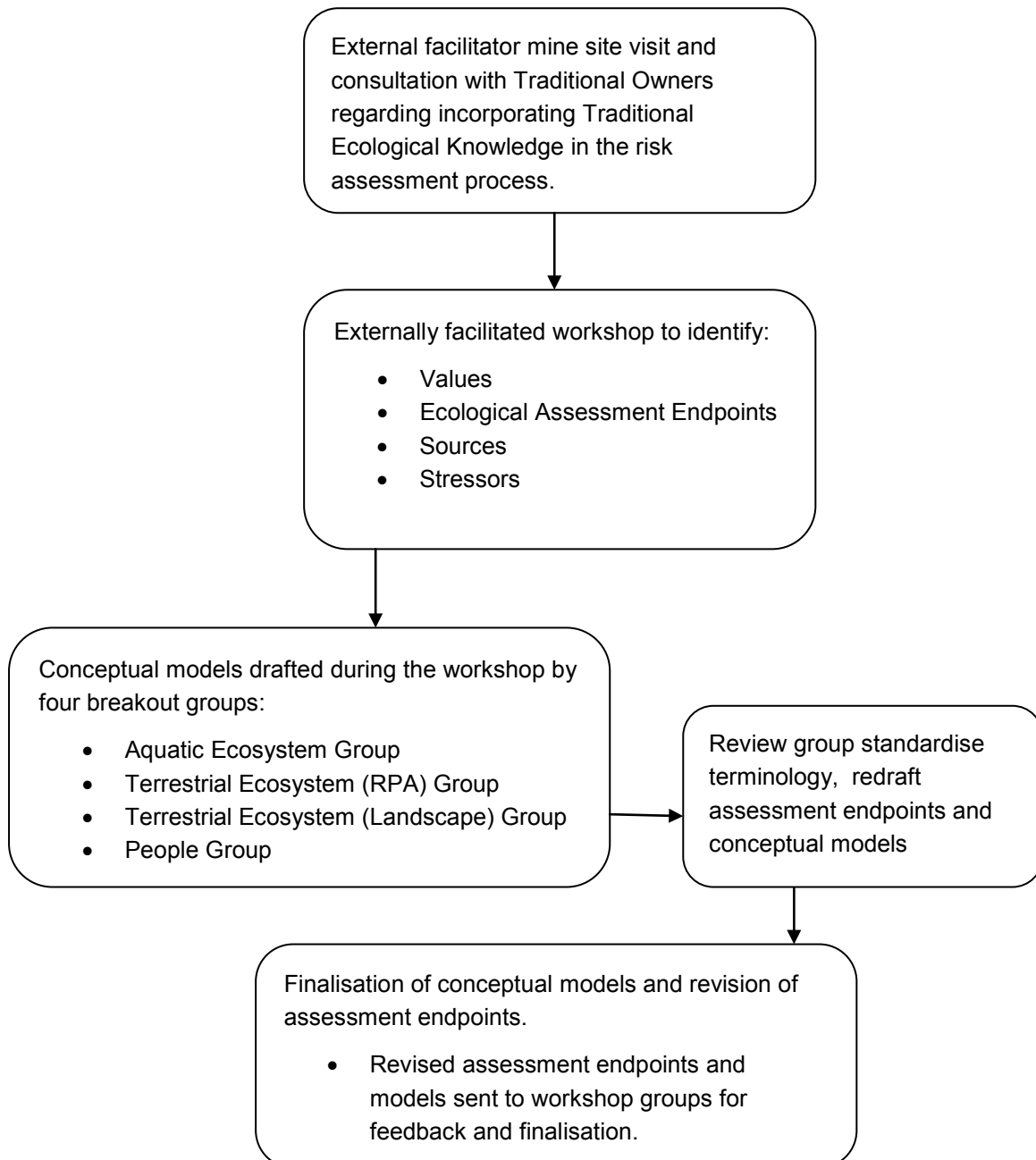


Figure 2.1 Overview of the approach for this project

2.1 Conceptual models workshop

In order to develop conceptual models for minesite rehabilitation and closure, a 2 day workshop with relevant stakeholders was externally facilitated by Carmel Pollino and Susan Cuddy from the CSIRO. Appendices 1 and 2 contain the workshop agenda and participants list. Prior to the workshop, the external facilitators met with Traditional Owners to ensure their concerns and views were included, and to capture information relevant to the incorporation of Traditional Ecological Knowledge (TEK) into the assessment framework.

Over the two day workshop the participants undertook exercises in context setting (spatial and temporal), determining values and drafting of conceptual models. Values and conceptual models were drafted in four key themes by breakout groups as follows:

- Aquatic Ecosystem
- Terrestrial Ecosystem (RPA scale)
- Terrestrial Ecosystem (Landscape scale)
- People

2.2 Review process post workshop to finalise assessment endpoints and conceptual models

The workshop provided no time for any refinement of the models or the development of consistency between models produced from each focus group.

After the workshop a smaller working group (ERA and SSD) was formed to progress and review each of the conceptual models. The aim of this review was to provide:

- Consistency in terminology and structure
- Review of the wording used to describe assessment endpoints, so that the assessment endpoints are measurable or can be related directly to a measurement endpoint.
- Consistency in models
- Removal of duplication
- Simplification where possible.

The review group identified that the workshop participants had identified numerous assessment endpoints that were closer to what are referred to as “management goals” by the US EPA (1998) and other key ecological risk assessment references (Suter II 1990, 1996, 2007). It was evident that clearer guidance on this issue should have been provided before or at the workshop.

Management goals – are statements about the desired condition of ecological values of concern. Management goals driving a specific risk assessment may come from the law, interpretations of the law by regulators, desired outcomes voiced by community leaders and the public, and interests expressed by affected parties.

Assessment endpoints – are explicit expressions of the actual environmental value that is to be protected, operationally defined by an ecological entity and its attributes. Their ability to support risk management decisions depends on whether they are measurable ecosystem characteristics that adequately represent management goals.

Defining assessment endpoints is a two-step process:

1. Identification of the specific valued ecological entity. This can be species (e.g. magpie geese), a community (e.g. benthic invertebrates), an ecosystem (e.g. billabong), a specified habitat (e.g. riparian forest), a unique place, or other entity of concern (e.g. scared site).
2. Identification of the characteristic about the entity of concern that is important to protect and potentially at risk. For example define what is important for magpie geese (e.g. nesting conditions), or a billabong (e.g. abundance of macrophytes).

The difference between assessment endpoints and management goals is that the former are neutral and specific, and as such they do not represent a desired achievement (goal). Assessment endpoints do not contain words like 'protect', 'maintain' or 'restore', or indicate directional change such as 'loss' or 'increase'.

Based on the information and guidance contained in the previously mentioned references, the assessment endpoints were redefined. Table 2.1 provides the original and revised assessment endpoints.

It should be noted that several of the assessment endpoints refer to the closure criteria or trajectories towards closure criteria. While this does not meet the exact definition of an assessment endpoint, it was decided that the specific details of which parameter should be used in the endpoints, and their threshold values, will be set by the Closure Criteria Working Group (CCWG). When these are finalised then the assessment endpoints can be adjusted to be more specific.

In addition to the review of assessment endpoints, a review of terminology was conducted. It was noticed that the focus groups used different terminology to describe common sources, stressors and pathways used in the conceptual models. The review group has developed a set of standard terminology (see Table 2.2). This is not an exhaustive list and can be added to or changed if required.

A revised set of conceptual models, along with a summary paper detailing (i) how each model was modified to incorporate the new assessment endpoints and (ii) the changes to consistent terminology, were provided to each of the four focus groups. Focus group members were asked to review the models with the following objectives:

- The values identified are represented in the models.
- Review of the updated assessment endpoints (specifically, do they meet the definition of an assessment endpoint as provided).
- Identify any components that have been omitted from the workshop or review.
- Review the linkages between sources, stressors and pathways are correct.

Details of each of the conceptual models developed, and changes made as part of the review process, are provided in the subsequent sections.

Table 2.1 Original and reviewed assessment endpoints

Assessment endpoints from workshop	Re-defined assessment endpoint
Aquatic ecosystems	
Protect and Rehab/Restore Aquatic Ecosystems	Protection of off-site aquatic ecosystems <ul style="list-style-type: none">Off-site water quality meets agreed closure criteria specified for water quality.Biodiversity (structure and function) of off-site aquatic ecosystems are comparable to the agreed reference condition.Habitat diversity of off-site aquatic ecosystems are comparable to the agreed reference condition
	Restoration/rehabilitation of on-site aquatic ecosystems <ul style="list-style-type: none">On-site water quality is on a trajectory towards meeting agreed closure criteria specified for water quality on-site.Biodiversity (structure and function) of on-site aquatic ecosystems are on a trajectory towards meeting agreed closure criteria.Habitat diversity of on-site aquatic ecosystems is on a trajectory towards meeting agreed closure criteria.
Terrestrial ecosystems (RPA)	
Landform similar to surrounds (topography, erosion rate, stability)	Erosion characteristics of the rehabilitated landform meets agreed closure criteria
Vegetation similar to surrounds (sustainable)	Vegetation on the disturbed sites of the RPA is on a trajectory towards meeting agreed closure criteria.
Faunal community similar to surrounds	Wildlife on the rehabilitated site is on a trajectory towards meeting agreed closure criteria.
Protection of Human Health	Covered under people section
Terrestrial ecosystems (Landscape)	
Protect the landscape of the ARR	Habitat diversity and ecosystem functions within the landscape of the Magela Creek sub-catchment and broader KNP is comparable to an agreed reference condition
Protect the diversity of habitats across the terrestrial landscape of the ARR	
Protect the aesthetic values of the ARR	
Aesthetic values meet the expectations of the stakeholders in the ARR	
People	
Re-creation of a cultural landscape in which TOs can resume traditional practices	Re-creation of a cultural landscape in which TOs can resume traditional practices
Accessible and traversable by people	Landform is able to be accessed, and is readily traversable, by people

Assessment endpoints from workshop	Re-defined assessment endpoint
Traversable surface	
Abundance of keystone species	Presence of culturally important species at right time and abundance
Landform design as close as practical to pre-mining topography	Landform, vegetation and water bodies on-site meets agreed cultural closure criteria.
Re-establishment of water bodies	
Return of traditional practices	Return of traditional practices (e.g. burning, harvesting)
Harvest of acceptable feral/invasive species	
Safe potable water	<i>Covered under human health (next end point)</i>
Protection of human health both on and off the rehabilitated site	Protection of human health on the rehabilitated site <ul style="list-style-type: none"> • Radiation doses to people from the rehabilitated site are less than the dose limits • Rehabilitation works do not negatively impact of worker safety (as measured by LTIFR and AIFR)
Meets drinking water quality guidelines	
Meets radiation protection standards	Protection of human health off the rehabilitated site
Meets recreational water quality guidelines	<ul style="list-style-type: none"> • Water resources¹ used for drinking continue to meet drinking water limits for mine derived contaminants. • Water resources¹ used for recreation continue to meet recreational water quality limits for mine derived contaminants. • Radiation doses to people from the rehabilitated site are less than the dose limits
Meets LTIs and MTCs associated with rehab works	

¹ Water resources that are considered important to be identified and added as specific locations to this assessment endpoint. This endpoint has been made generic as this stage since the important resources are not yet known.

Table 2.2 Standardised terminology for sources, pathways and stressors

Sources/Processes	Transport mechanism/pathways	Stressors
Surface water	Surface water	Trace metals (dissolved)
Groundwater	Ground water	Trace Metals (particulate)
Waste rock - exposed	Atmospheric	Solutes - major ions
Waste rock - buried	Biota - trophic transfer	Radionuclides
Buried tailings/brine	Human/non-human vector	Suspended sediment
Soil		Bed load
Sediment		Organic chemicals
Biota - flora		Nutrients
Biota - fauna		Change in flow regime
Kakadu National Park		Weeds
Ranger Project Area		Feral animals
Climate - extreme rain		Native pests
Climate - extreme wind		Soil erosion
Climate – hot days		Subsidence
Exhalation		Slope failure
		Channel erosion
		Fire
		Radiation
		Habitat / veg loss
		Physical barriers
		Hunting
		Water deficit / stress
		Water surplus / logging
		Plant disease
		Hazardous terrain
		Inappropriate surface material
		Ineffective consultation

3 Causal conceptual models

3.1 Aquatic ecosystem

The aquatic ecosystems breakout group drafted one large conceptual model that included all sources, stressors, pathways, measurement points and assessment endpoints during the workshop. The end point of this large model was identified as a management goal and needed to be broken down into six separate assessment endpoints. In addition it was not possible to include all sources and stressors for one endpoint in the one model as this created a problem for tracing of pathways and would subsequently create issues when the risk analysis phase commenced.

The assessment endpoints for the off-site risks now include “*Off-site water quality meets agreed closure criteria specified for water quality*” and “*Habitat diversity of off-site aquatic ecosystems are comparable to the agreed reference condition*”. The on-site assessment endpoints include “*On-site water quality is on a trajectory towards meeting agreed closure criteria specified for water quality on-site*” and “*Habitat diversity of on-site aquatic ecosystems is on a trajectory towards meeting agreed closure criteria*”.

At this stage, the initial values relating to ecological processes and ecological function that were identified during the workshop have not been progressed into conceptual models. A draft paper outlining how ecological processes may be addressed is included in Appendix 3. The assessment endpoints currently proposed are, “*Biodiversity (structure and function) of off-site aquatic ecosystems are comparable to the agreed reference condition*” and “*Biodiversity (structure and function) of on-site aquatic ecosystems are on a trajectory towards meeting agreed closure criteria*”. Feedback is being sought on these proposed assessment endpoints and a set of measurements endpoints needs to be defined. It is likely that these additional assessment and measurement endpoints could then be incorporated into the current sub-models.

At the completion of the review 10 sub-models (Figures 3.1-3.10) had been produced that were based on stressors that have common pathways and measurement endpoints for four of the six assessment endpoints.

Terminology has been standardised according to a list of terms produced by a review group. For example, the source ‘*contaminated soil*’ is now referred to as ‘*soil*’. Table 3.1 outlines the changes in terminology used in the revised model for the assessment endpoints. Unless specified in Table 3.1, the terms have remained the same between the workshop output and the revision of the models. Also listed in Table 3.1 are 3 sources and 1 stressor that were not included in any of the sub-models. The three sources did not neatly fit into the sub-models because they could be seen as mechanisms that activate sources.

Transport pathways were moved from between sources and stressor to between stressors and measurement endpoints.

In reviewing the conceptual models, it was clear that ecological processes were not clearly defined and that there is clarity required on this. A small focus group from the Aquatic Ecosystems breakout group have drafted a paper discussing ecological processes and how these can be measured (Appendix 3). This aspect of the conceptual models will be further addressed through the CCWG.

Table 3.1 Revisions and status of terminology in the model for aquatic ecosystems endpoints

Terminology from Workshop	Standardised terminology	Status in revised models
Source		
Vehicle-People	Kakadu National Park	The source has also been changed to Kakadu National Park to acknowledge stressor being carried from off-site
Contaminated soils	Soils	Changed to soils as this encompasses both contaminated and uncontaminated soils
Contaminated sediments	Sediments	Changed to sediments as this encompasses both contaminated and uncontaminated sediments
Untreated mine waters	Surface waters	Changed to surface waters as this encompasses all contaminated and uncontaminated waters on-site
Treated mine waters	Surface waters	Changed to surface waters as this encompasses all contaminated and uncontaminated waters on-site
Industrial areas fuel stores	Plant and Mill areas	Changed to be more descriptive
Extreme Climate Events	Not included in any sub-model	This source was not used in any of the sub-models. It is likely to be a mechanism that triggers other sources
Physical disturbance	Not included in any sub-model	This source was not used in any of the sub-models. It is likely to be a mechanism that triggers other sources
Meandering creek	Not included in any sub-model	This source was not used in any of the sub-models. It is likely to be a mechanism that triggers other sources
Stressors		
Sediments SPM	Suspended sediments	Changed for consistent terminology
Inorganics_metals	Trace metals (dissolved) Trace metals (particulate)	Changed for consistent terminology. As split into dissolved and particulate fractions.
Inorganics_solutes	Solutes – major ions	Changed for consistent terminology

Terminology from Workshop	Standardised terminology	Status in revised models
Invasive species	Weeds Feral animals	Split into two stressor as each will have specific assessment endpoints
High/Low flow	Not included in any submodel	This stressor did not fit well in any of the sub-models
Transport pathways		
Biota_transfer Vehicles_people	Human/Non human vector	Changed to include both pathways in one.

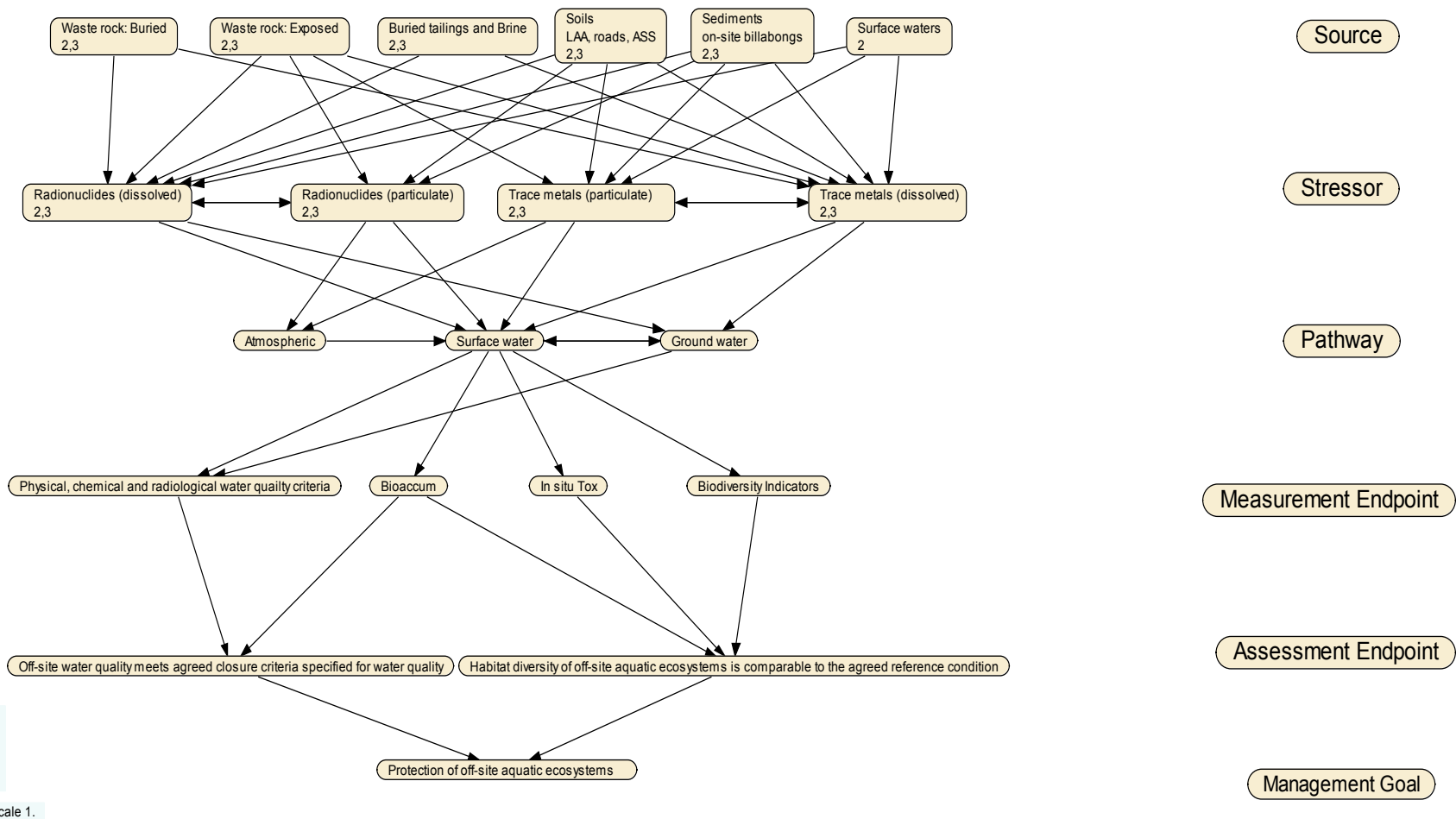


Figure 3.1 Sub-model for the protection of off-site aquatic ecosystems from metals and radionuclides

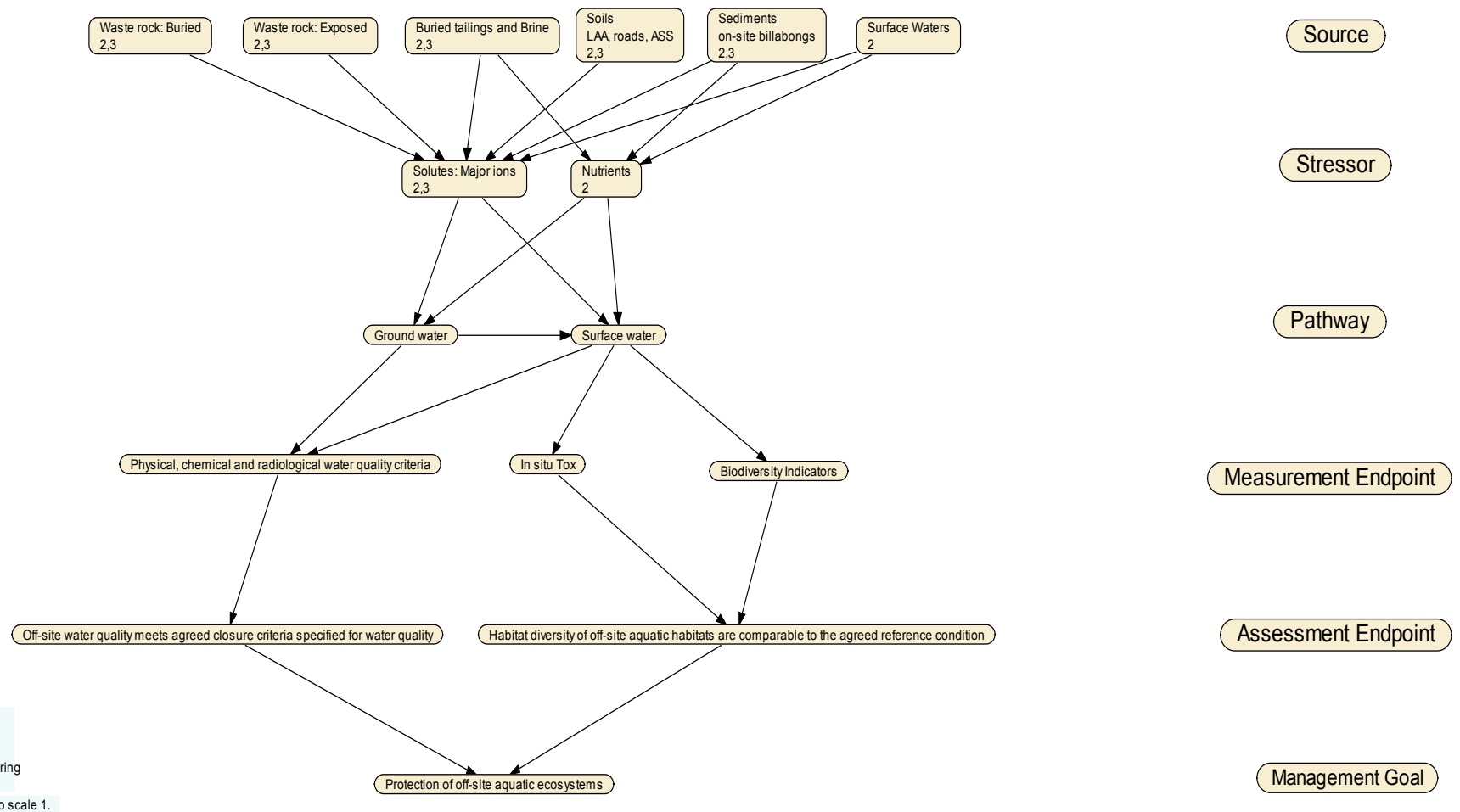


Figure 3.2 Sub-model for the protection of off-site aquatic ecosystems from solutes and nutrients

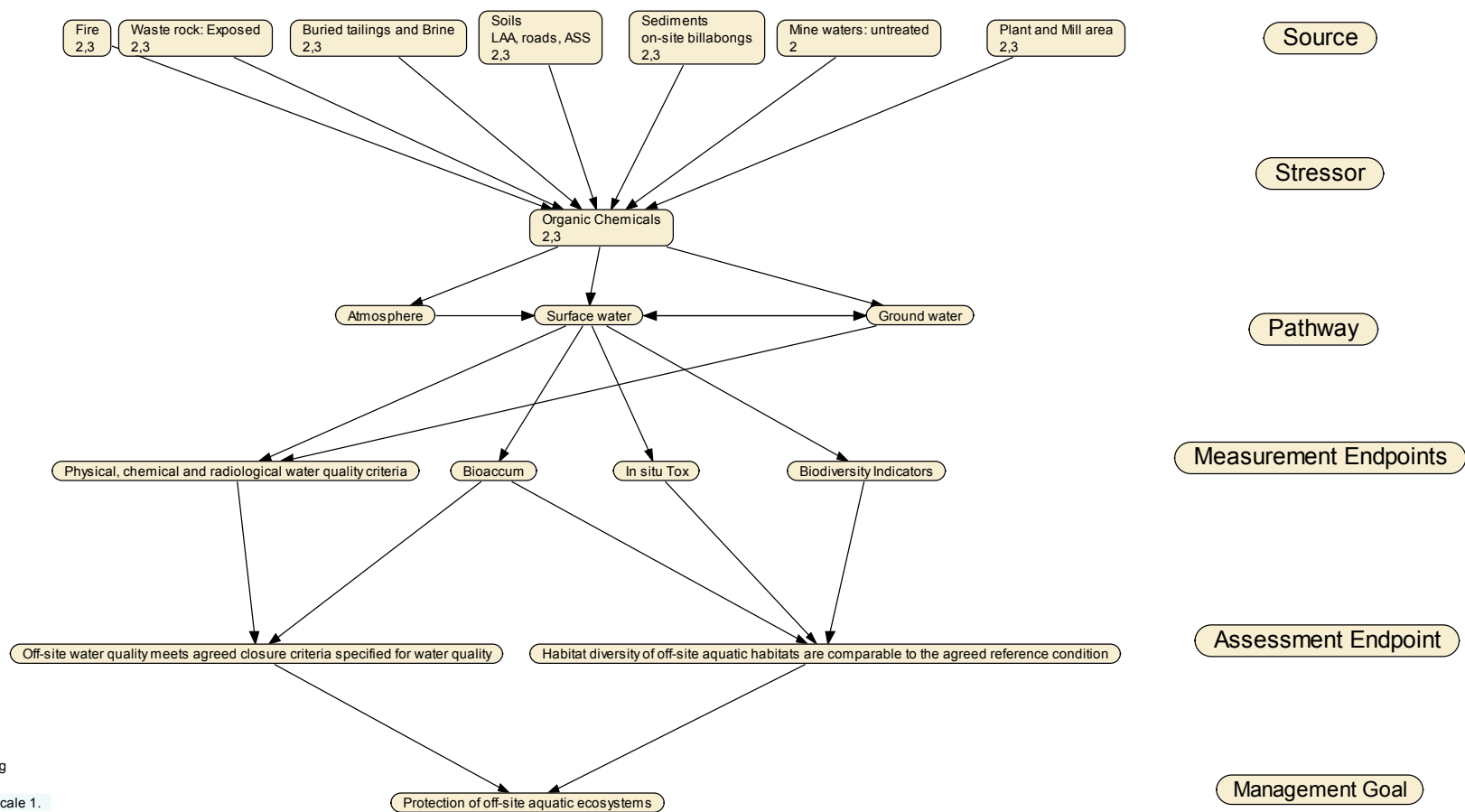


Figure 3.3 Sub-model for the protection of off-site aquatic ecosystems from organic chemicals

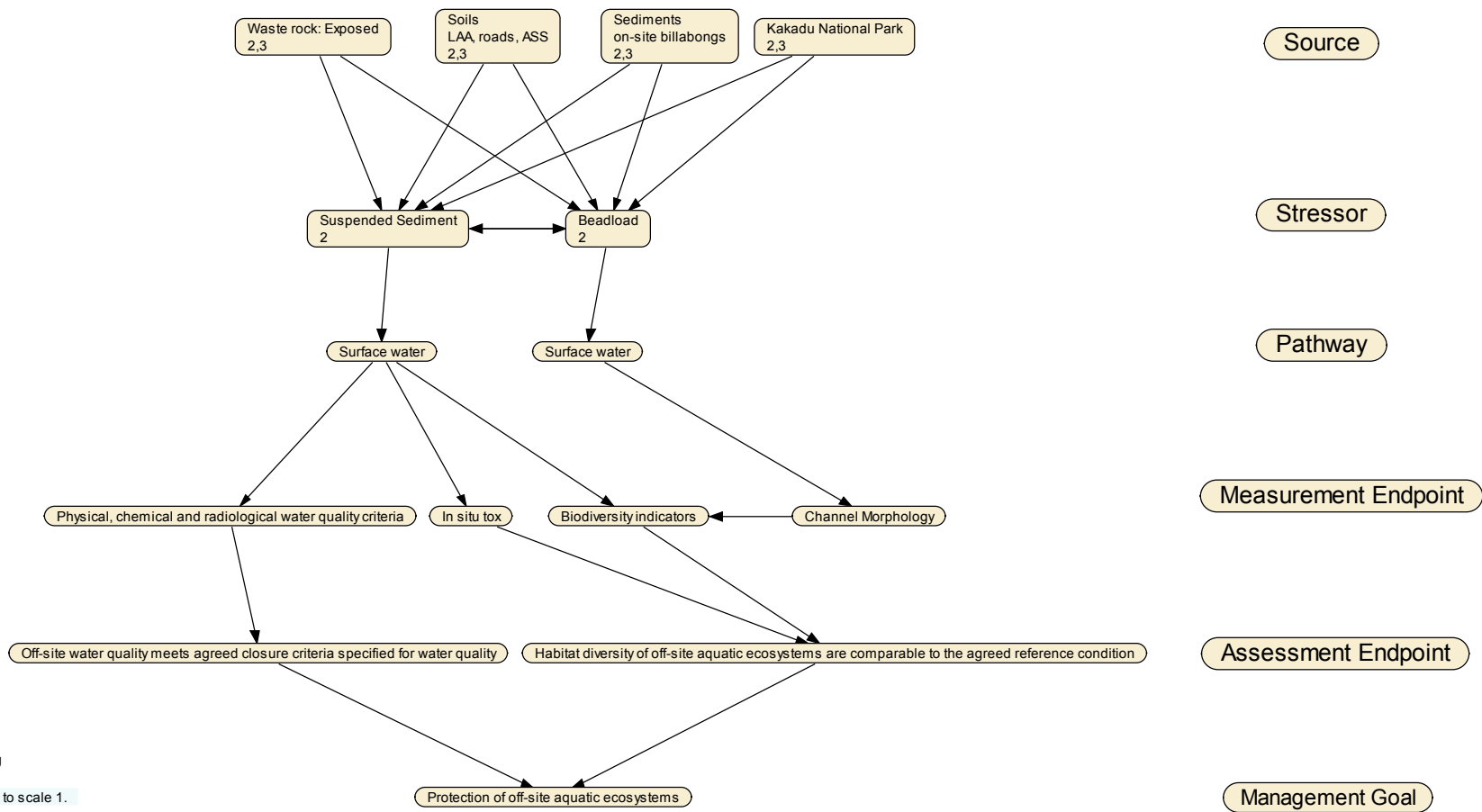


Figure 3.4 Sub-model for the protection of off-site aquatic ecosystems from suspended and bedload sediments

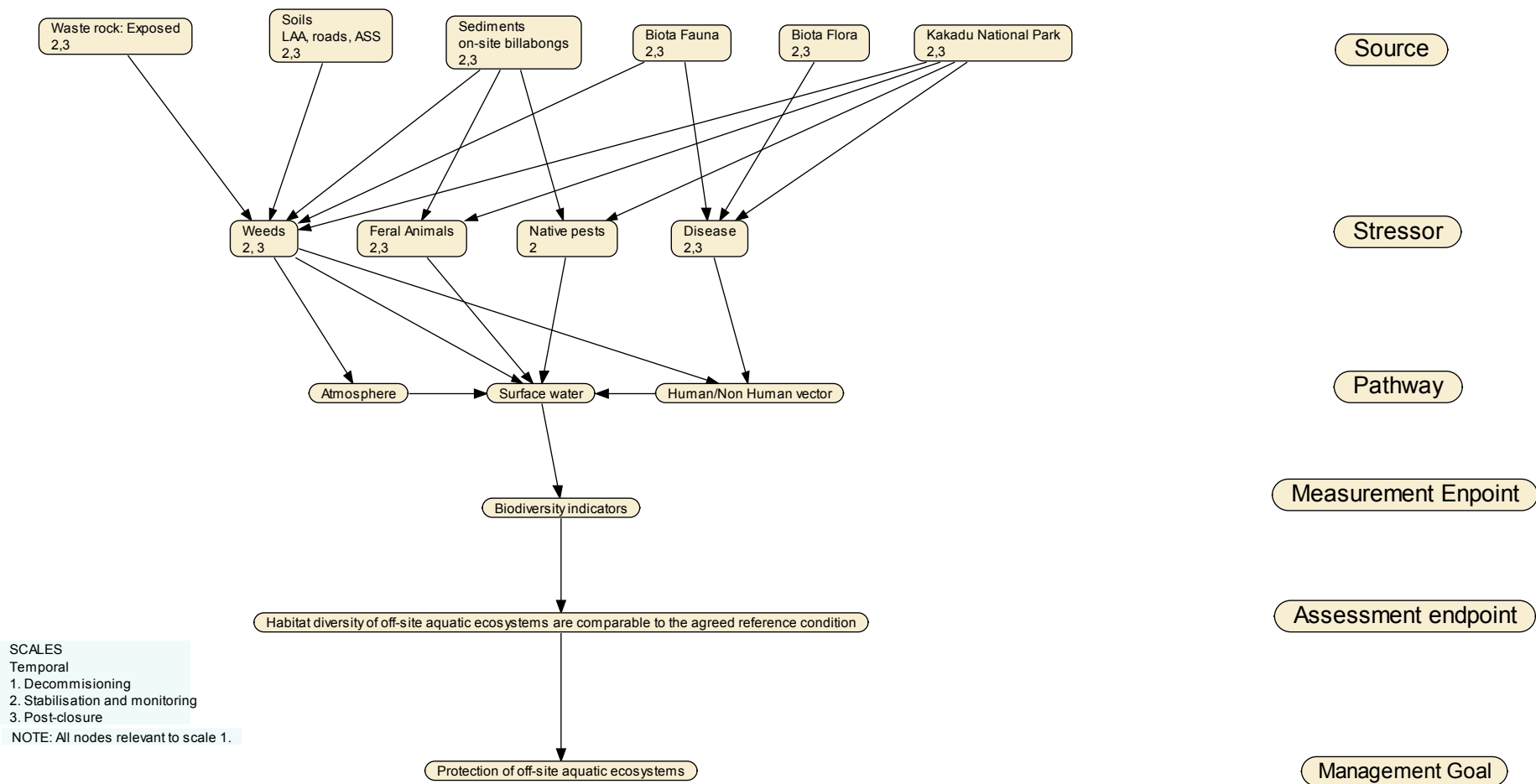


Figure 3.5 Sub-model for the protection of off-site aquatic ecosystems from invasive species

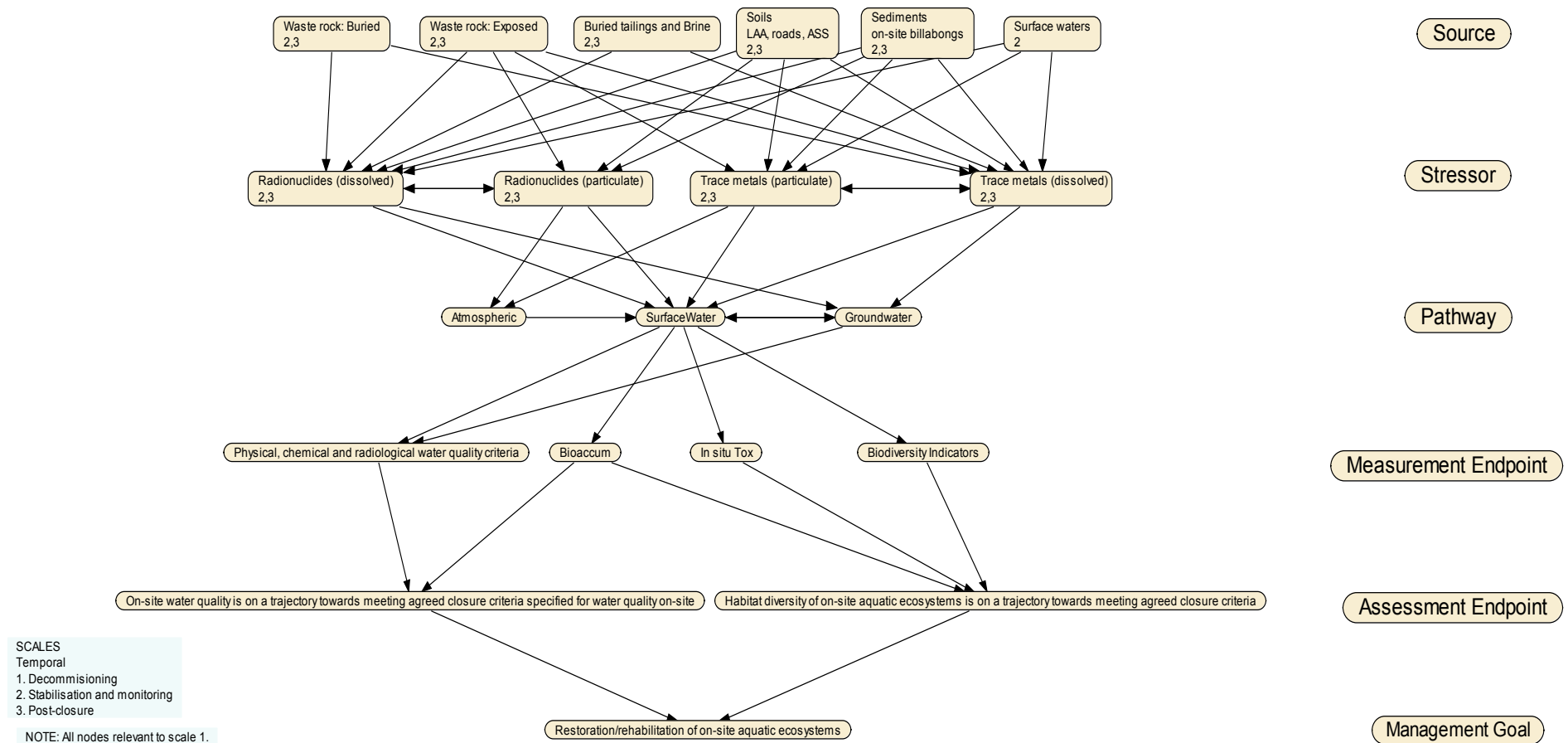


Figure 3.6 Sub-model for the protection of on-site aquatic ecosystems from metals and radionuclides

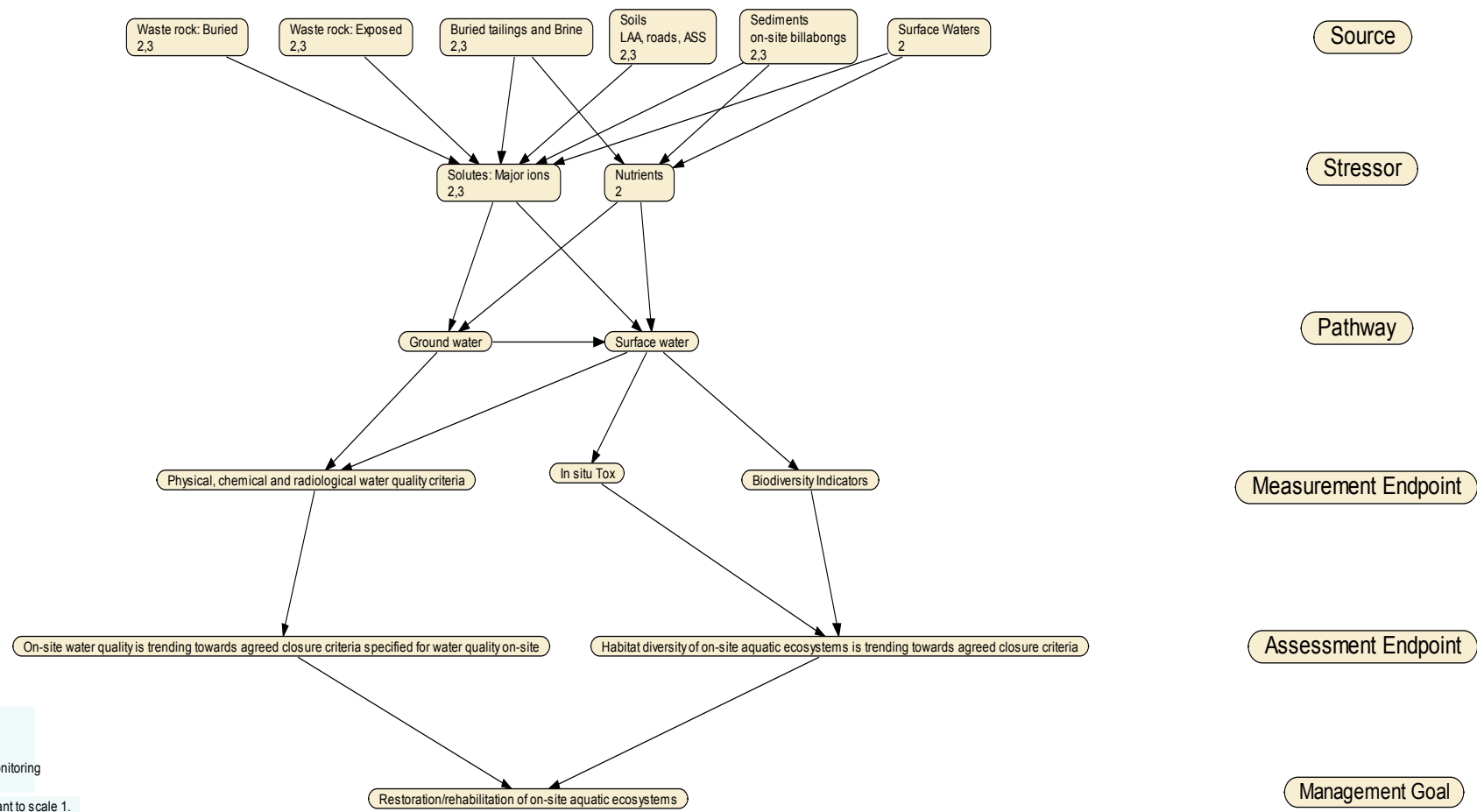


Figure 3.7 Sub-model for the protection of on-site aquatic ecosystems from solutes and nutrients

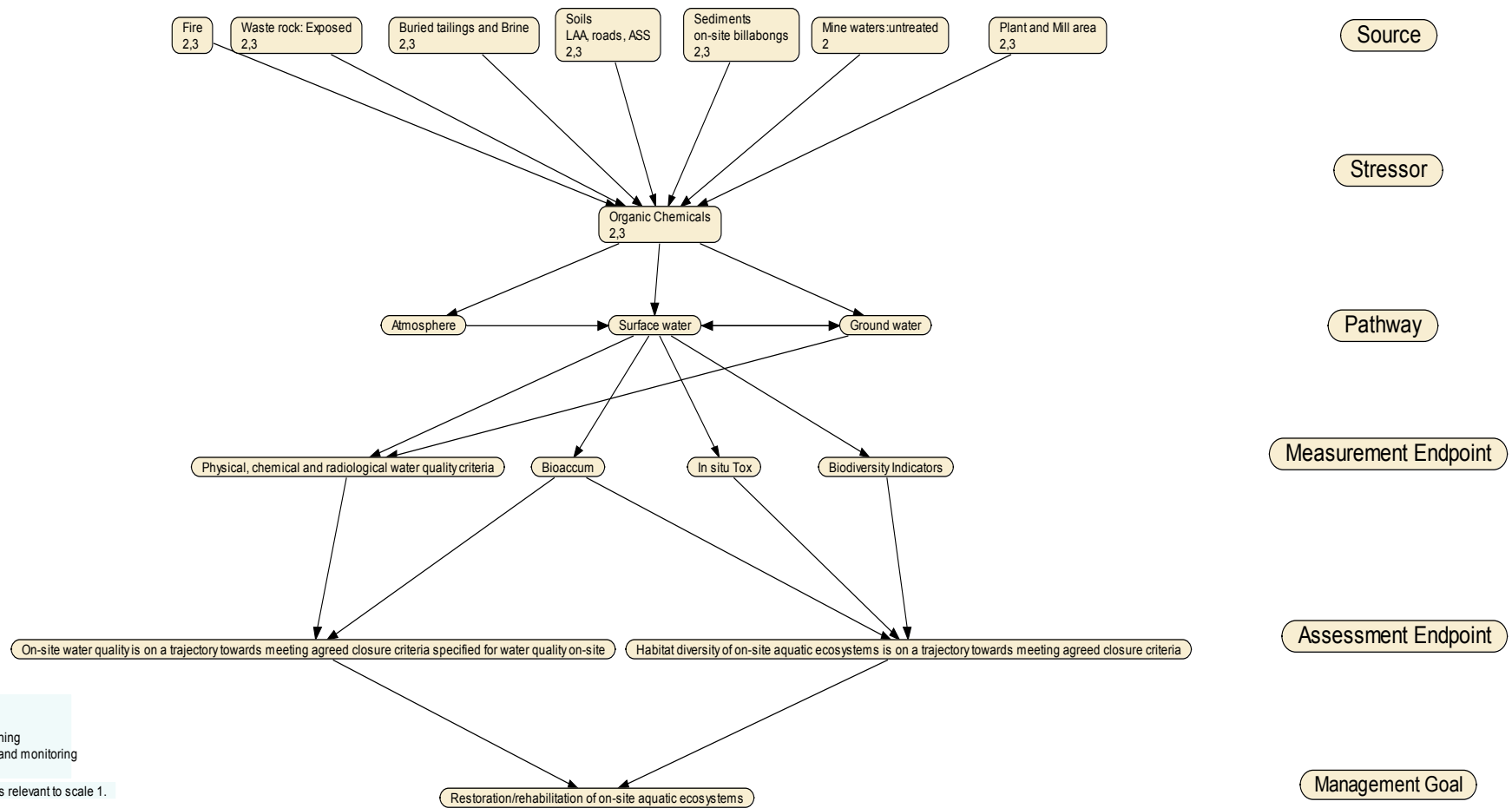


Figure 3.8 Sub-model for the protection of on-site aquatic ecosystems from organic chemicals

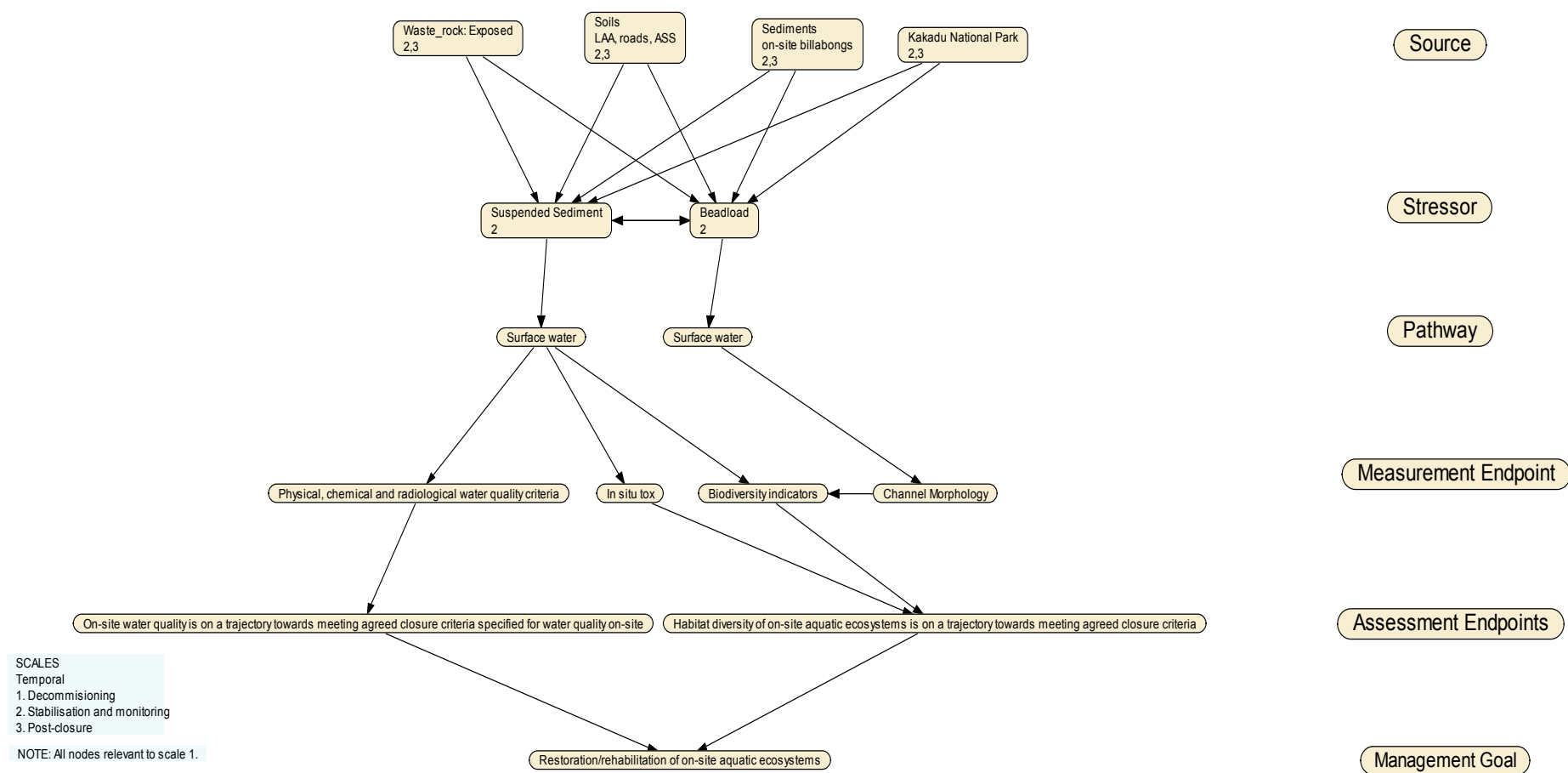


Figure 3.9 Sub-model for the protection of on-site aquatic ecosystems from suspended and bedload sediments

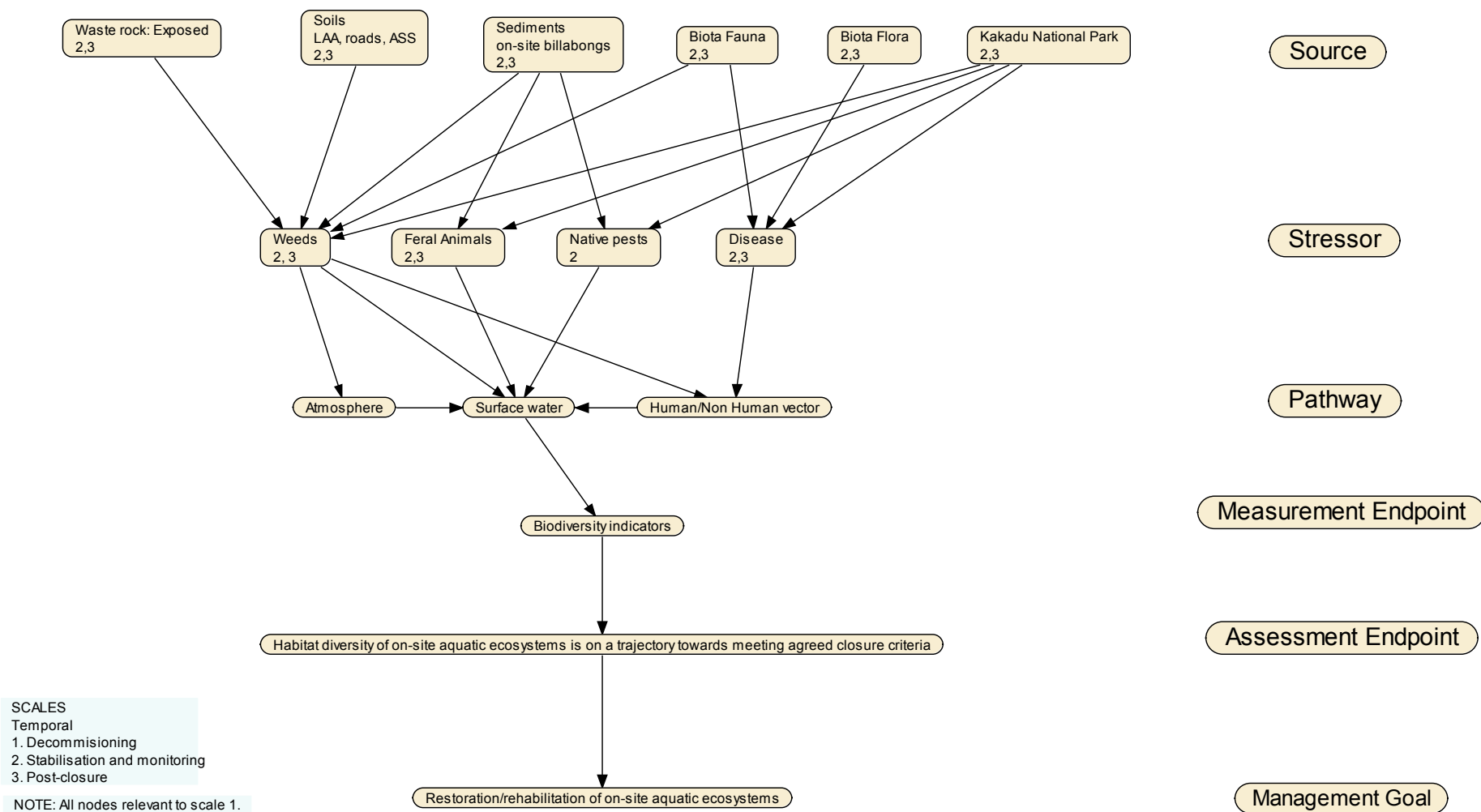


Figure 3.10 Sub-model for the protection of on-site aquatic ecosystems from invasive species

3.2 Terrestrial ecosystem

3.2.1 Ranger Project Area

The terrestrial ecosystem (RPA) breakout group drafted four conceptual models. Three of these models had the assessment endpoints revised to be more specific and measurable, and have also been updated with the standardised terminology. The model focused on ‘protection of human health’ will be dealt with separately in the future, combining it with the human health model drafted by the people group.

The assessment endpoint *‘Landform similar to surrounds (topography, erosion rate, stability)’* has been revised to *‘Erosion characteristics of the rehabilitated landform meet agreed closure criteria’* (see Figure 3.11).

Terminology has been standardised according to a list of terms produced by a review group. Table 3.2 outlines the changes in terminology used in the revised model for the assessment endpoint: *‘Erosion characteristics of the rehabilitated landform meets agreed closure criteria’*. Unless specified in Table 3.2, the terms have remained the same between the workshop output and the revision of the models. Measurement endpoints have been revised based on the measurement endpoints derived from the workshop.

Table 3.2 Revisions and status of terminology in the model for erosion characteristics of the rehabilitated landform meets agreed closure criteria

Terminology from Workshop (including definition by breakout group)	Standardised terminology	Status in revised models
Source or Management Case		
Natural geological/extreme event driven (Management Case) Earthquake (Management Case)	This is not specifically included in the list for sources	Revised to <i>‘Natural geological process or event’</i> which could include events such as earthquakes.
Climate Change (Management Case) Extreme rainfall events (Source)	Climate – extreme rainfall	Revised to <i>‘Climate Change – Extreme rainfall’</i> as <i>‘Extreme rainfall events’</i> was included as a source and <i>‘Climate Change’</i> was included as a management case in the workshop model.
Sea Level Rise (Management Case)	This is not specifically included in the list for sources	Suggested revision is <i>‘Climate Change – Sea Level Rise’</i> treated as a source.
The following are listed as one Management Case: Poor design Inadequate characterisation of materials Quantity and Quality Conflict between stakeholders	This is not specifically included in the list for sources	Suggested revision is <i>‘Poor design of final landform’</i> treated as a source.
Stressor		
Lack of stability (originally included as a source)	This is not specifically included in the list for sources or stressors.	Suggested revision is to move to Stressor group.

Terminology from Workshop (including definition by break out group)	Standardised terminology	Status in revised models
Failure of re-vegetation	This is not specifically included in the list for sources or stressors. Assumed that it is defined as habitat/vegetation loss in this context. Habitat/vegetation loss is included in the list of stressors.	Suggested revision is to move to Stressor group.
Meander of Magela	This is not specifically included in the list for sources or stressors.	Suggested revision is to move to Stressor group.
Changes in groundwater level	This is not specifically included in the list for s stressors, but is included as both a source and transport mechanism /pathways in those lists.	Suggested revision is to move to Stressor group.
Transport pathway/Change Process		
Wave erosion Tidal erosion Not clear as to whether these were stressors or transport pathway/change process in the model.	This is not specifically included in the list for Transport mechanism/pathways.	Currently left as ' <i>Wave erosion/tidal erosion</i> ' in the revised model and moved to transport pathway/change process. The group will need to decide whether this is appropriate.
Erosion (soil) Gullies, rills etc Not clear as to whether these were stressors or transport pathway/change process in the model.	' <i>Soil erosion</i> ' is included in the list for Stressors.	Changed to ' <i>Soil erosion</i> ' in the revised model and moved to transport pathway/change process. The group will need to decide whether this is appropriate.
Subsidence	' <i>Subsidence</i> ' is included in the list for Stressors.	Currently left as ' <i>Subsidence</i> ' in the revised model and moved to transport pathway/change process. The group will need to decide whether this is appropriate.
Slope failure	' <i>Slope failure</i> ' is included in the list for Stressors.	Currently left as ' <i>Slope failure</i> ' in the revised model and moved to transport pathway/change process. The group will need to decide whether this is appropriate.
Erosion (channel)	' <i>Channel erosion</i> ' is included in the list for Stressors.	Changed to ' <i>Channel erosion</i> ' in the revised model and moved to transport pathway/change process. The group will need to decide whether this is appropriate.

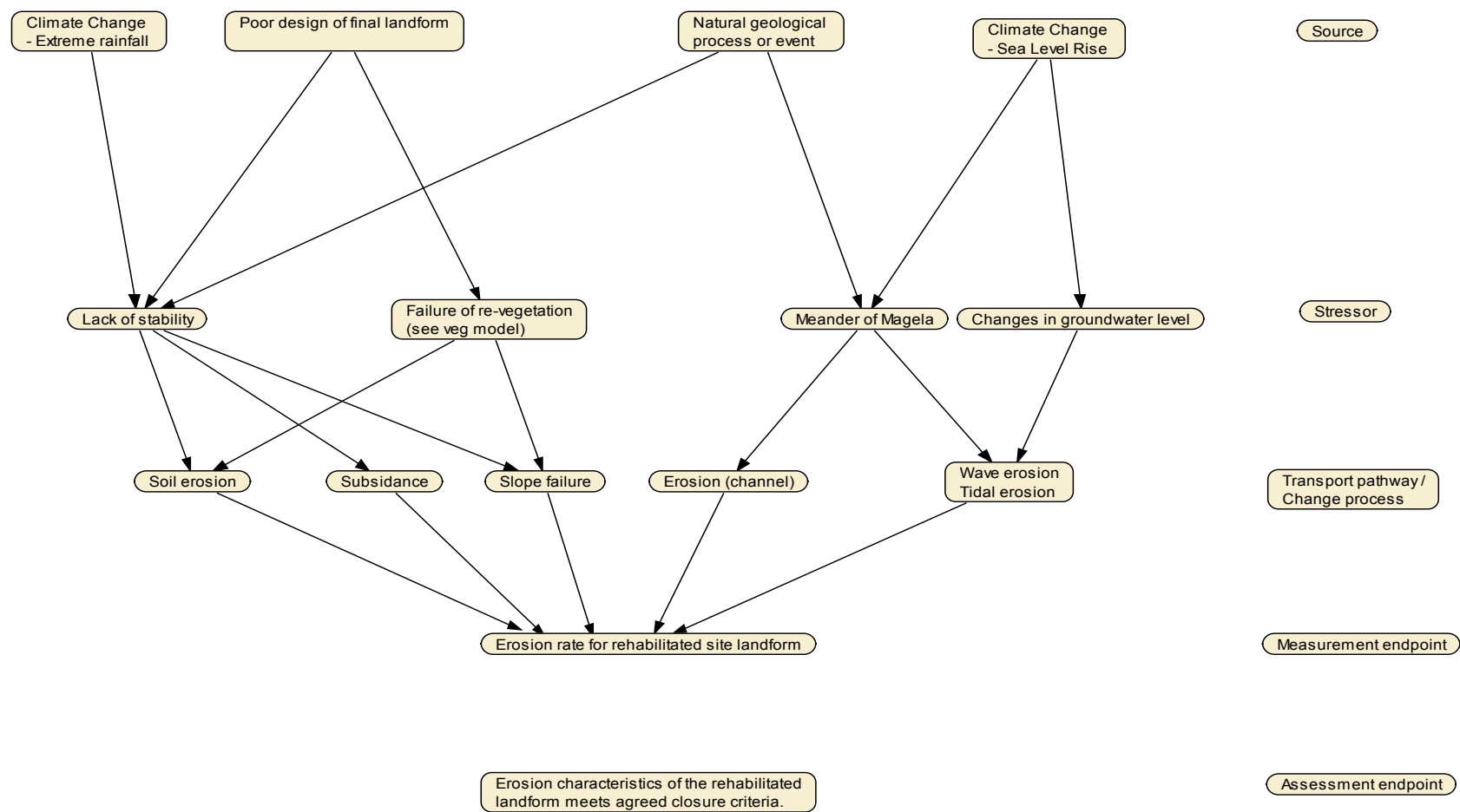


Figure 3.11 Conceptual model for erosion characteristics of the rehabilitated landform.

The model for ‘*Faunal communities similar to surrounds*’ has a revised assessment endpoint: ‘*Wildlife on the rehabilitated site is on a trajectory towards meeting agreed closure criteria*’ (see Figure 3.12). Unless specified in Table 3.3, the terms have remained the same between the workshop output and the revision of the models.

Table 3.3 Revisions and status of terminology in the model for wildlife on the rehabilitated site is on a trajectory towards meeting agreed closure criteria

Terminology from Workshop (including definition by break out group)	Standardised terminology	Status in revised models
Source or Management Case		
Sources: Water quality Bioaccumulation in food	This is not specifically included in the list for sources, although ‘ <i>surface water</i> ’ and ‘ <i>groundwater</i> ’ could be used as in place of water quality. ‘ <i>Ranger Project Area</i> ’ describes the source for the terrestrial environment at the onsite scale.	Revised to ‘ <i>Ranger Project Area</i> ’ which covers the original sources and management cases without the need for requiring a series of sub-models to simplify exposure pathways for multiple sources and management cases in the model.
Failure of revegetation (see reveg model) (Management Case)	This is not specifically included in the list of sources.	Suggested revision is ‘ <i>Failure of revegetation (see reveg model)</i> ’ treated as a ‘Transport pathway/Change process’.
Human (Management Case)	This is not specifically included in the list for sources.	Suggested revision is ‘ <i>Human</i> ’ treated as a ‘Transport pathway/Change process’ and use the standardised terminology ‘ <i>Human/non-human vector</i> ’.
Management Cases: Material characteristics (Physical and Chem) Soil/Substrate Contamination (non-rad)	This is not specifically included in the list for sources.	Suggested revision is ‘ <i>Material characteristics (Physical and Chem)</i> ’ and ‘ <i>Soil/Substrate Contamination (non-rad)</i> ’ are treated as a ‘Transport pathway/Change process’, and suggested standardised terminology is ‘ <i>surface water</i> ’ and ‘ <i>biota-trophic transfer</i> ’ as material of concern is predominantly transported by surface water. Is there a need to include ‘ <i>atmospheric</i> ’ and ‘ <i>ground water</i> ’?
Stressor		
Adverse radiological conditions	External gamma exposure	Revised to ‘ <i>External gamma exposure</i> ’. Group to review whether this encapsulates adverse radiological conditions.
Lack of habitat (food,shelter, etc)	Habitat/Vegetation loss	Revised to ‘ <i>Habitat/Vegetation loss</i> ’.
Competition with ferals	Feral animals & weeds	Revised to ‘ <i>Feral animals & weeds</i> ’.
Fire beyond background	Fire	Revised to ‘ <i>Fire</i> ’. It is assumed that fire as a stressor implies that fire is beyond background frequency and intensity.
Toxicity to fauna	Contaminants	Revised to ‘ <i>Contaminants</i> ’.
Transport pathway/Change Process	Note: No transport pathways/Change processes were included in the original models.	

Terminology from Workshop (including definition by break out group)	Standardised terminology	Status in revised models
Failure of revegetation (see reveg model)	This is not specifically included in the list for transport pathway/change processes	Suggest inclusion in this model as a change process.
	Human/non-human vector	Include as stated.
	Biota-trophic transfer	Include as stated.
	Surface water	Include as stated.

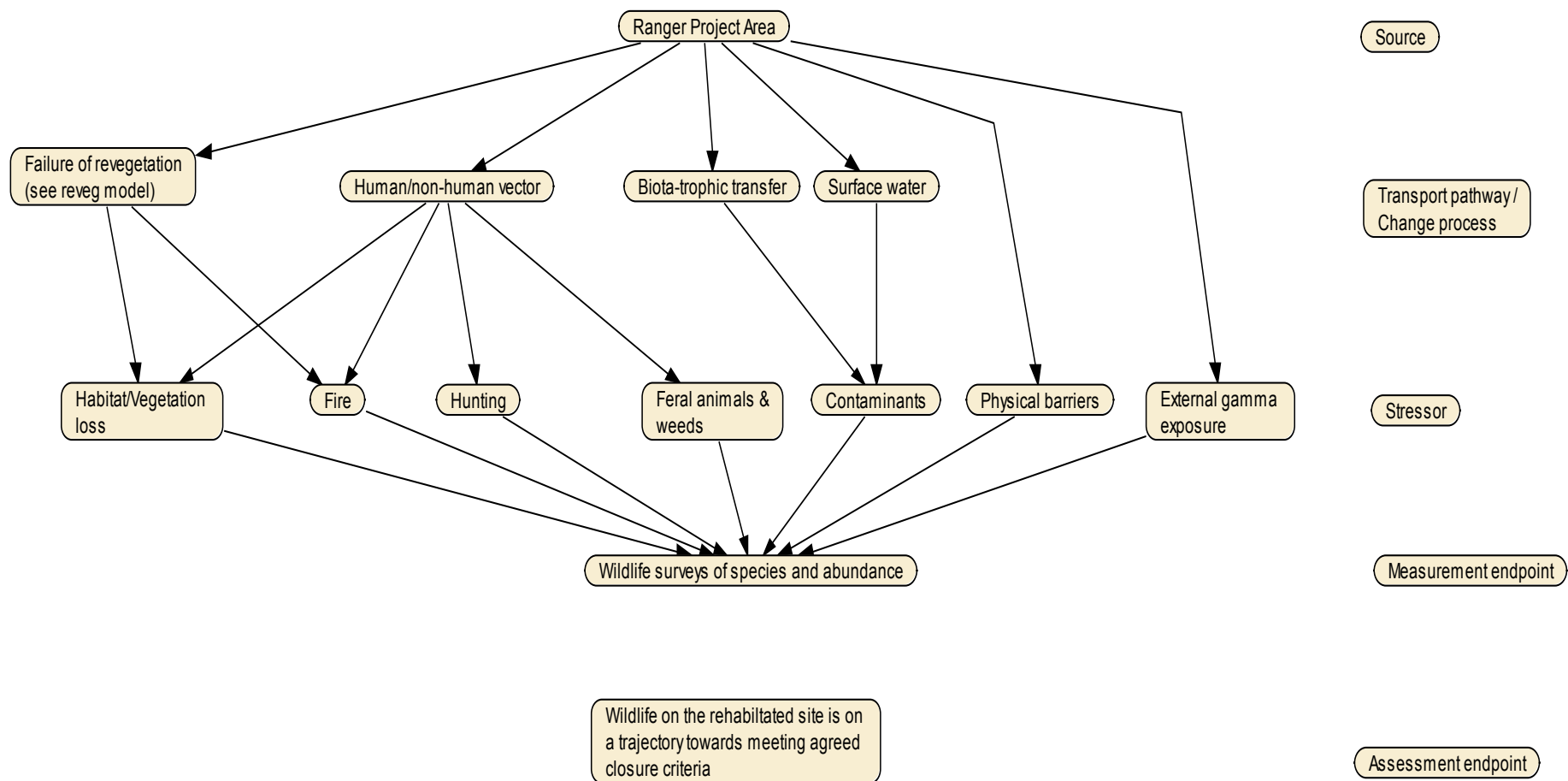


Figure 3.12 Conceptual model for wildlife on the rehabilitated site.

The model for '*Vegetation community similar to surrounds*' has a revised assessment endpoint: '*Vegetation on the disturbed sites of the RPA is on a trajectory towards meeting agreed closure criteria*' (see Figure 3.13). Unless specified in Table 3.4, the terms have remained the same between the workshop output and the revision of the models.

Table 3.4 Revisions and status of terminology in the model for vegetation on the disturbed sites of the RPA is on a trajectory towards meeting agreed closure criteria

Terminology from Workshop (including definition by break out group)	Standardised terminology	Status in revised models
Source or Management Case		
Climate Change (Management Case)	Climate - hot days Climate – extreme rain Climate – extreme wind	Revised to ' <i>Climate – Extreme rainfall & wind</i> ' as ' <i>Cyclones and Extreme rainfall</i> ' was included as a source. Also ' <i>Climate Change – hot days</i> ' was included as a source, as a surrogate to replace ' <i>Drought/Low rainfall</i> ' which was included as a source.
Management Cases: Resourcing Park Management-resources	These are not specifically included in the list of sources.	Suggested revision is to remove both of these from the model. ' <i>Resourcing</i> ' is not linked to any other components in the model and it is unclear what the term refers to. Similarly, ' <i>Park Management – resources</i> ' is not clearly linked to the model except for ' <i>Limited seed stock</i> ' which is suggested to be included as a source as shown by the original model.
Limited seed stock (Source) Failure of irrigation – mech & tech (Source)	These are not specifically included in the list for sources.	Suggested revision is to include ' <i>Limited seed stock</i> ' and ' <i>Failure of irrigation – mech & tech</i> ' as sources because results of these sources are key stressors in both the original and revised models.
Lack of faunal activity (Source)	This is not specifically included in the list for sources.	Suggested revision is to remove ' <i>Lack of faunal activity</i> ' from the revised model. From the linkage to ' <i>Disease and Pests</i> ' it is unclear as what to what this term refers to. Does it refer to predation?
Source: Soil condition Weathering of rock No initial soils-rock as initial substrate	' <i>Soil</i> ' is included in the list for sources.	Suggested revision is use ' <i>Soil</i> ' as the source.
Source: Landform design - Construct of substrate - Waste holding cap	This is not specifically included in the list for sources. ' <i>Waste rock- exposed</i> ' and ' <i>Waste rock – buried</i> ' are on the source list.	Suggested revision is to replace ' <i>Landform design</i> ' with standardised terminology ' <i>Waste rock – exposed & buried</i> '. Does ' <i>buried tailings/brine</i> ' need to be included also?
Weeds (Source)	This is not specifically included in the list for sources, but is included in the list for stressors.	Suggested revision is to treat ' <i>Weeds</i> ' as a stressor.

Terminology from Workshop (including definition by break out group)	Standardised terminology	Status in revised models
Humans (Source)	This is not specifically included in the list for sources, but is included in the list for transport mechanism/pathways.	Suggested revision is ' <i>Human</i> ' treated as a 'Transport pathway/Change processes and use the standardised terminology ' <i>Human/non-human vector</i> '. This also recognises the transport of material by non-human vectors which were not accounted for in the original model.
	Ranger Project Area	Not included in the original model as it is assumed this was implicit due to the spatial scale of the model. However for humans to be a transport mechanism they need to be originating from a source. Is the source the RPA or KNP, or both?
Stressor		
Lack of water for growth	Water deficit/stress	Revised to ' <i>Water deficit/stress</i> '.
Waterlogging	Water surplus/logging	Revised to ' <i>Water surplus/logging</i> '.
Feral grazing	Feral animals	Removed from revised model as there were no links to sources in the original model.
Lack of plants: Species selection, Diversity, Abundance	This is not specifically included in the list for stressors.	Suggested revision is to include ' <i>Lack of plant species: Diversity & Abundance</i> ' as a stressor
Poor recruitment	This is not specifically included in the list for stressors.	Suggested revision is to remove ' <i>Poor recruitment</i> ' from the revised model as it can be covered by the stressor ' <i>Lack of plant species: Diversity & Abundance</i> '.
Increased competition	This is not specifically included in the list for stressors.	Suggested revision is to remove ' <i>Increased competition</i> ' from the revised model. Does this relate to weeds? If so, it is covered by the stressors ' <i>Weeds</i> '.
Landform stability	This is not specifically included in the list for stressors. ' <i>Slope failure</i> ', ' <i>Soil erosion</i> ' and ' <i>Subsidence</i> ' are included in the list for stressors.	' <i>Landform stability</i> ' has been included in the revised model as a stressor. Does this need to be replaced by ' <i>Slope failure</i> ', ' <i>Soil erosion</i> ' and ' <i>Subsidence</i> ' and do each of these have different linkages to the sources?
Radiation exposure Toxic effects from contaminated soils Lack of microbial activity	This is not specifically included in the list for stressors. However ' <i>External gamma exposure</i> ' and ' <i>Contaminants</i> ' are included on the list of stressors.	Suggested revision is to replace 'Radiation exposure, Toxic effects from contaminated soils, Lack of microbial activity' with ' <i>External gamma exposure</i> ' and ' <i>Contaminants</i> '.
Transport pathway/Change Process		
	Note: No transport pathways/Change processes were included in the original models.	
	Human/non-human vector	Suggested revision is to add to revised model.

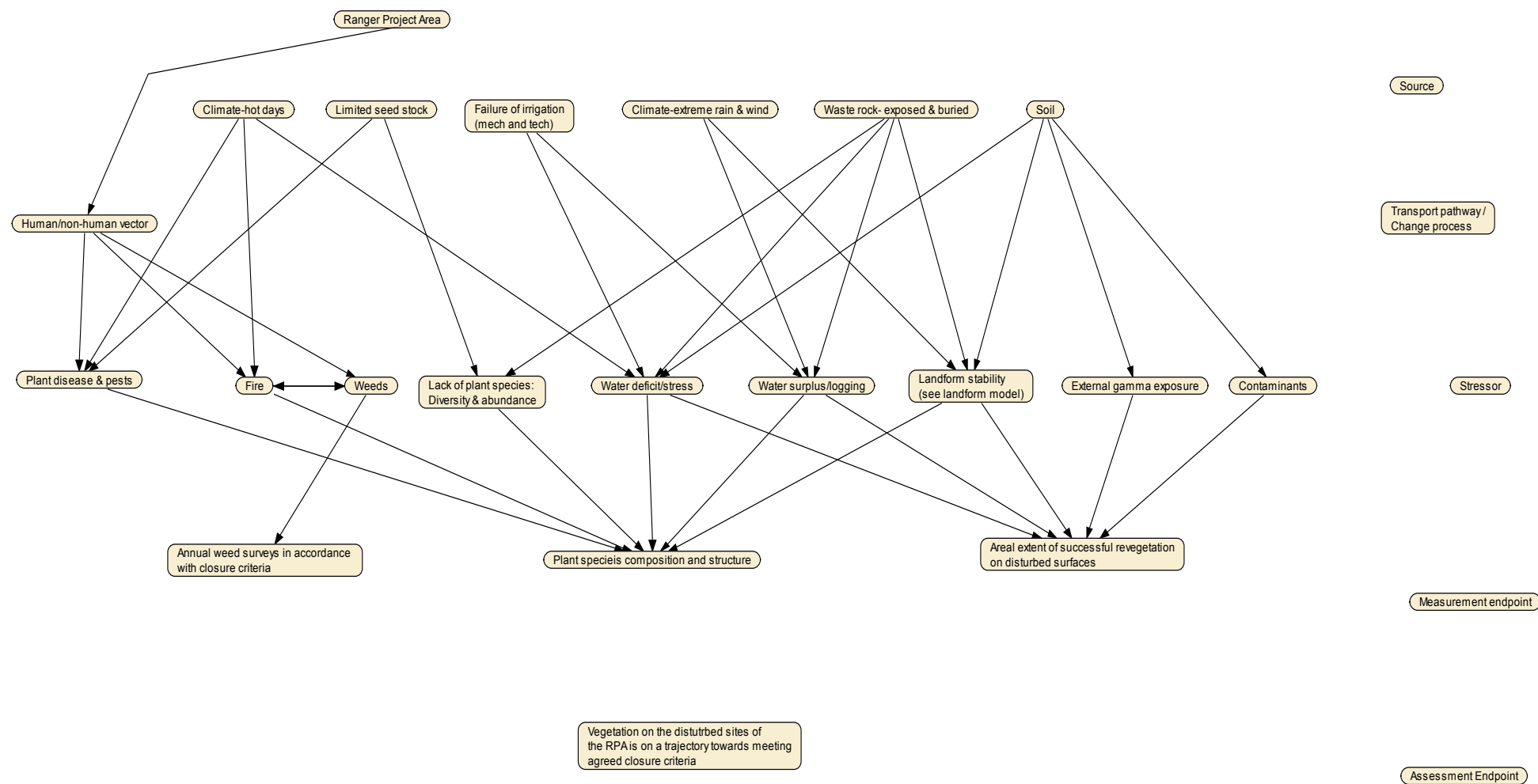


Figure 3.13 Conceptual model for vegetation on the disturbed sites of the RPA.

3.2.2 Landscape

The terrestrial ecosystem (landscape) breakout group drafted three conceptual models. These have been revised to two conceptual models. The models for *Protect the landscape of the ARR* and *Protect the diversity of habitats across the terrestrial landscapes of the ARR* were collapsed into one model for a revised assessment endpoint: *Habitat diversity and ecosystem functions within the landscape of the Magela Creek sub-catchment and broader KNP is comparable to an agreed reference condition* (see Figure 3.14). This was undertaken as the sources and stressors were similar between the two models that were output from the workshop, and review of the assessment endpoints indicated that the models were quite similar.

The definitions of components in the terrestrial ecosystem models as shown in Table 3.5 were largely derived from the definition of terms developed by the landscape terrestrial working group during the workshop.

Terminology has been standardised according to the list of terms produced by a review group. For example, the source *‘offsite’* is now referred to as *Kakadu National Park*. Table 3.6 outlines the changes in terminology used in the revised model for the assessment endpoint: *Habitat diversity and ecosystem functions within the landscape of the Magela Creek sub-catchment and broader KNP is comparable to an agreed reference condition*. Unless specified in Table 3.6, the terms have remained the same between the workshop output and the revision of the models. There were no links between the stressor *‘floristic composition during minesite revegetation’* and any stressors that were directly linked to a measure of effect. This stressor may be poorly defined and either needs to be revised by the group or removed from the model. In the revised model it is linked to the stressors *‘fire’* and *‘weeds’*.

Measurement endpoints have been revised based on the measurement endpoints derived from the workshop.

Table 3.5 Definition of source and stressor components of the models for 1) *habitat diversity and ecosystem functions within the landscape of the Magela Creek sub-catchment and broader KNP is comparable to an agreed reference condition* and 2) *aesthetic values meet the expectations of the stakeholders in the ARR*.

Component in conceptual model	Definition as used in the model
Source	
Unsuitable growth medium	Landform substrate that is not suitable for survivability of plant species
Climate Change – Extreme or decrease in rainfall	Increase in extreme precipitation events or decrease in seasonal rainfall which impacts on rainfall variability.
Floristic composition during minesite revegetation	Floristic composition of revegetation becomes a source of fuel load for fires, or enables establishment of weeds, or becomes dominated by a small number of species.
Stressors	
Solutes	Radionuclides, inorganic toxicants & organic toxicants
Sediment	Runoff & erosion from landform into ARR
Weeds	Weeds offsite (terrestrial & aquatic) – Spread to onsite from wind, non-human and human vectors Weeds onsite (terrestrial & aquatic) – Effect of final landform floristic composition on final landscape. Also spread to offsite via non-human and human vectors. Aquatic weeds affect terrestrial fauna.

Component in conceptual model	Definition as used in the model
Fire	Fire can be any or all of the following: stressor, value, biophysical, cultural. Fire offsite – Unmanaged fire from KNP and ARR. Fire onsite – Fire originating onsite and spreading offsite.
Feral animals	Feral animals offsite – unmanaged feral animals offsite Feral animals onsite – Potential refuge for feral animals
Rainfall variability	Combination of high frequency, high intensity, low frequency or low intensity. Can affect floristic and fuel loads.
Line of sight-physical barriers	Visibility from point x to point y in the landscape

Table 3.6 Revisions and status of terminology in the model for spatial pattern of the landscape in the ARR is comparable to the habitat diversity and ecosystem functions previously documented for the ARR

Terminology from Workshop (including definition by break out group)	Standardised terminology	Status in revised models
Source		
Offsite - Kakadu National Park (KNP) and the Alligator Rivers Region (ARR)	Kakadu National Park	Revised to standardised terminology
Climate Change	Climate – extreme rainfall Climate – extreme wind Climate – hot days	Revised to ' <i>Climate Change – Extreme or decrease in rainfall</i> ' <i>Hot days not included, question to focus group; Is this required?</i>
Unsuitable growth medium	NIL	Remains as is
Stressors		
Solutes - Radionuclides, inorganic toxicants & organic toxicants	Solutes – trace metals Solutes – major ions Radionuclides	Currently left as ' <i>solutes</i> ' in the revised model. The group will need to decide whether the pathways need to be split up and in addition, a more appropriate measure of effect needs to be derived.
Sediment - Runoff & erosion from landform into ARR	Suspended sediment Bedload	Currently left as ' <i>sediments</i> ' in the revised model. The group will need to decide whether the pathways need to be split up and in addition, a more appropriate measure of effect needs to be derived.
Rainfall variability - High frequency, high intensity, etc Can affect floristic composition and fuel loads	Maybe linked to ' <i>water deficit/stress</i> ' and ' <i>water/surplus</i> '	Currently left as ' <i>rainfall variability</i> ' in the revised model. The group will need to decide whether the pathways need to be split up and in addition, a more appropriate measure of effect needs to be derived.

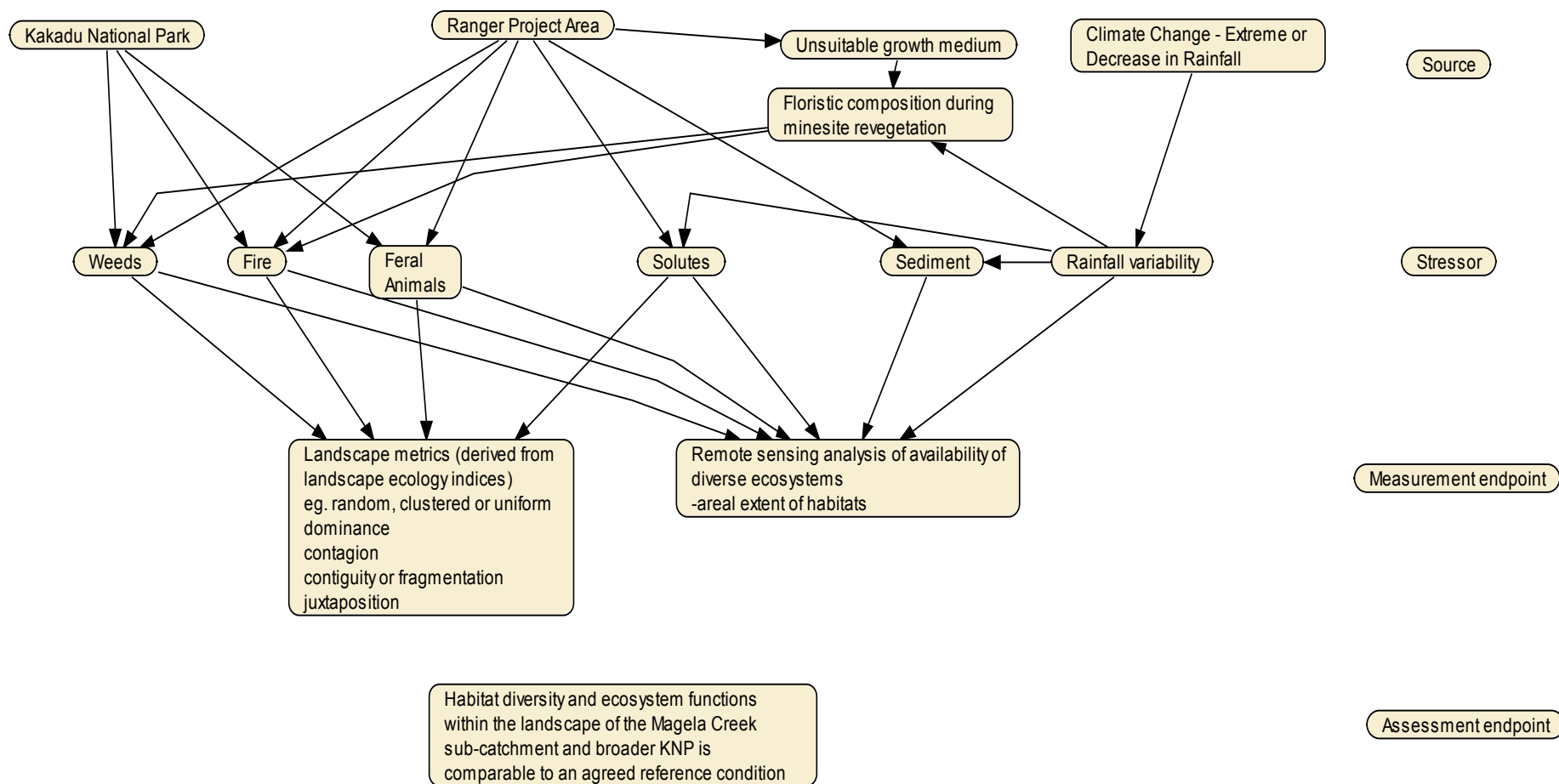


Figure 3.14 Conceptual model for spatial pattern of the landscape in the ARR.

The model for *Protect the aesthetic values of the ARR* has a slightly revised assessment endpoint: *Aesthetic values meet the expectations of the stakeholders in the ARR* (see Figure 3.15). It is documented (Suter 1990) that aesthetics cannot be given a clear operational definition prior to surveys of stakeholders and that aesthetic values may also conflict with ecological values. Until the aesthetics are parameterised from the stakeholders' perspective, this assessment endpoint and subsequent measures of effects cannot be reviewed any further.

Table 3.7 outlines the changes in terminology used in the revised model for this assessment endpoint. Unless specified in Table 3.7, the terms have remained the same between the workshop output and the revision of the models.

Table 3.7 Revisions and status of terminology in the model for aesthetic values meet the expectations of the stakeholders in the ARR

Terminology from Workshop (including definition by break out group)	Standardised terminology	Status in revised models
Stressors		
Line of sight – Visibility from point x to point y	Physical barriers	Currently noted as Line of Sight – physical barriers. The group will need to decide whether this is an appropriate representation of the stressor.
Solutes - Radionuclides, inorganic toxicants & organic toxicants	Solutes – trace metals Solutes – major ions Radionuclides	Currently left as ' <i>solutes</i> ' in the revised model. The group will need to decide whether the pathways need to be split up and in addition, a more appropriate measure of effect needs to be derived.
Sediment - Runoff & erosion from landform into ARR	Suspended sediment Bedload	Currently left as ' <i>sediments</i> ' in the revised model. The group will need to decide whether the pathways need to be split up.

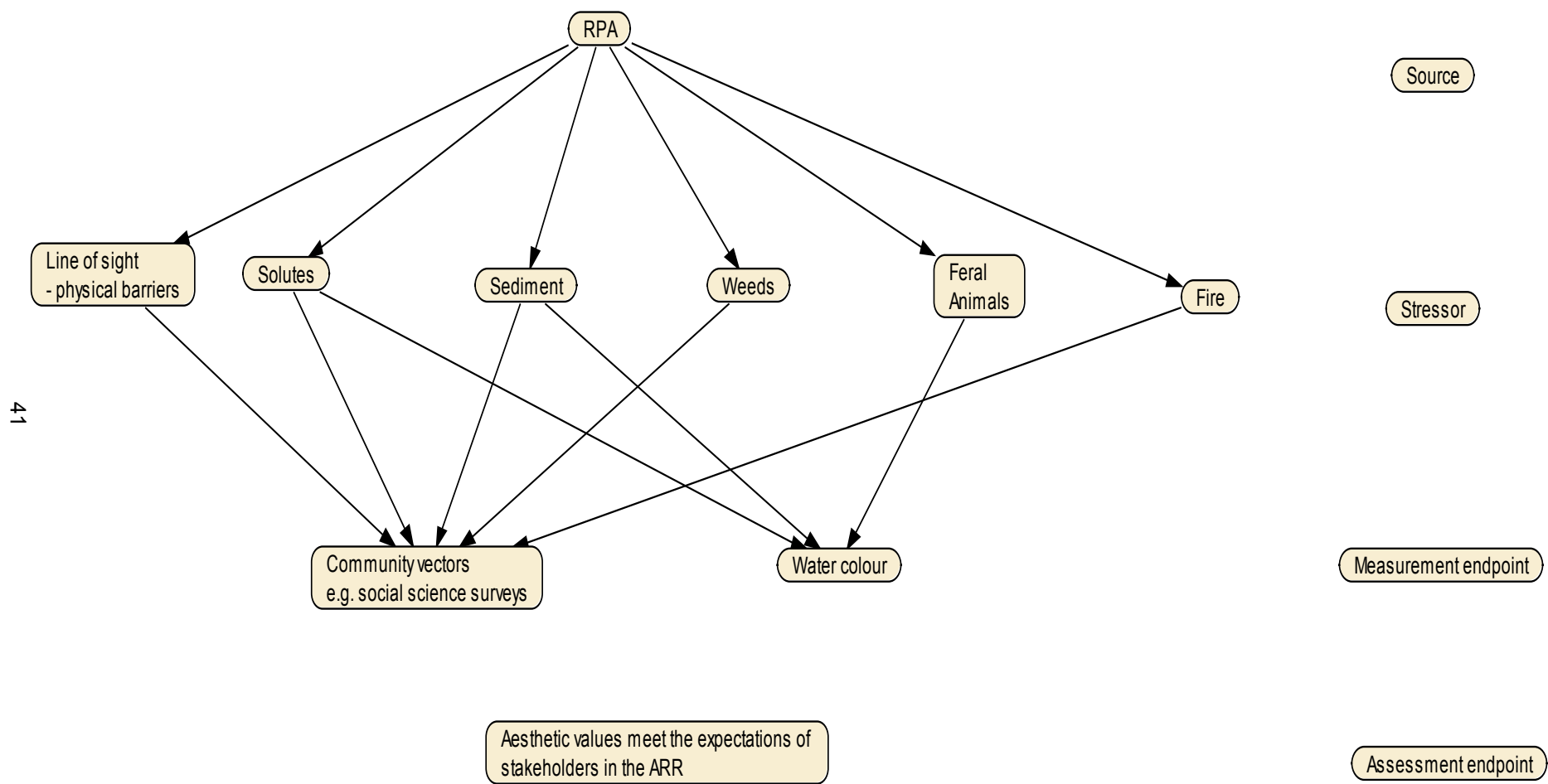


Figure 3.15 Conceptual model for aesthetic values meeting the expectations of stakeholders in the ARR.

3.3 People: Cultural and Socio-economic

The people breakout group drafted two conceptual models – one for cultural landscape and the other for human health. The review focused on refining the cultural landscape model. The human health model will be dealt with separately in the future, combining it with the human health model drafted by the terrestrial ecosystems (Ranger Project Area) group.

The original cultural landscape model, shown in Figure 3.16, has been split into four separate conceptual models, to reflect the revised assessment endpoints. The revised assessment endpoints are as follows:

- landform is able to be accessed, and is readily traversable, by people
- presence of culturally important species at right time and abundance
- landform, vegetation and water bodies on-site meets agreed cultural closure criteria
- return of traditional practices (e.g. burning, harvesting).

The revised assessment endpoints capture the key elements of the sub-assessment endpoints that were captured in the terminal node (last box) of the original model (Figure 3.16). Those that are not captured are *Safe potable water* and *Re-establishment of water bodies*. The first one is more related to human health and, as noted, is not covered at this stage, but could potentially be captured in the *Return of traditional practices* assessment endpoint if the presence of safe potable water was to be deemed necessary for traditional owners to undertake certain activities. The second one would be covered in the *Landform, vegetation and water bodies on-site meets agreed cultural closure criteria* assessment endpoint.

Tables 3.8 and 3.9, outline key changes in terminology for sources and stressors (respectively) used in the revised models compared to the original model, as well as new terms introduced during the revision of the models. Measurement endpoints for each of the models have been added, as they were not specifically addressed during the workshop.

The four revised models are presented in Figures 3.17–3.20. A key outcome of the revision of the cultural models was that most are critically linked to a number of the other assessment endpoints. For example, the presence of important species at the right time and abundance will be highly dependent on the success of revegetation and aquatic ecosystem rehabilitation and establishment, and associated wildlife recolonisation, all of which are issues addressed by other models. Thus, in a number of cases, these other models were linked to the cultural models, rather than trying to fully duplicate these models (or variations thereof) within the cultural models.

The revised models presented here are in draft form only, and will require further input and revision. For example, the *Presence of culturally important species at right time and abundance* model will only be able to be finalised once the important species, and their requirements, are identified. Similarly, the *Return of traditional practices* model will only be able to be finalised once specific traditional practices, and their requirements, are identified.

Temporal scales: stabilisation & post-closure phases
 Spatial scales: Minesite, RPA (except for fire)

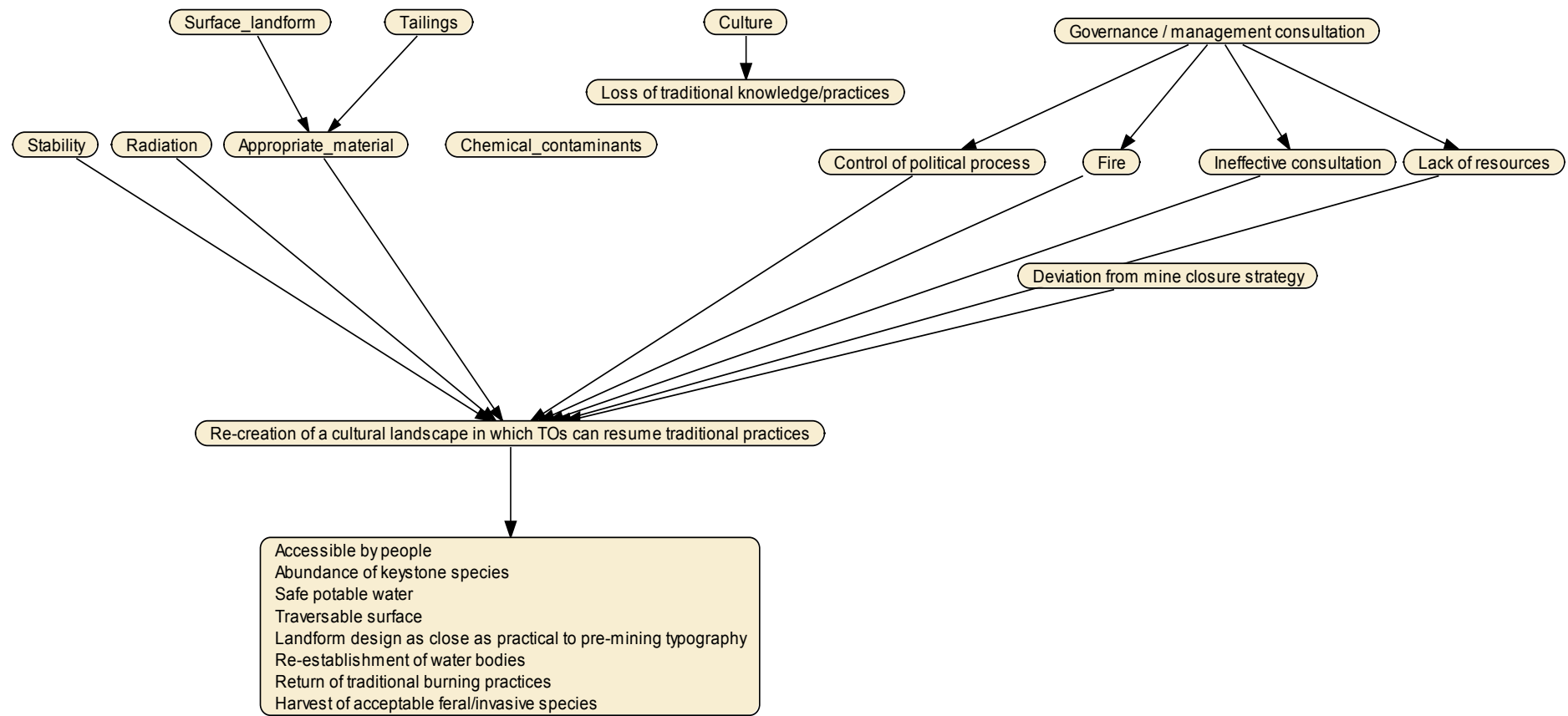


Figure 3.16 Conceptual model for cultural values developed during the workshop.

Table 3.8 Revisions and status of terminology for Sources in the cultural values models

Terminology from Workshop (including definition by break out group)	Standardised or new terminology	Status in revised models
Surface landform	Waste rock - exposed	Revised to standardised terminology
Tailings	Buried tailings/brine	Revised to standardised terminology
Governance/management consultation	Nil	Not included. Several of the stressors arising from this Source were deemed to be outside the scope of this assessment, while several others were retained (see Stressors, below)
	Mine rehabilitation plan: <ul style="list-style-type: none"> • landform design characteristics • revegetation plan • water body establishment/ rehabilitation plan 	New sources added to one model to reflect importance of rehab plans properly reflecting cultural values, and subsequent communication of expectations and what can be achieved
	Waste rock - buried	Included in the site accessibility/ traversability model due to potential radiation does issues
	Buried tailings/brine	Included in the site accessibility/ traversability model due to potential radiation does issues
	Climate – extreme rain	Included in the site accessibility/ traversability model due to potential effects on landform stability and topography
	Kakadu National Park	Included in the site accessibility/ traversability model as a source of potential weed invasion and infestation of the rehabilitated mine site
	Ranger Project Area	Included in the site accessibility/ traversability model as a source of potential weed invasion and infestation of the rehabilitated mine site

Table 3.9 Revisions and status of terminology for Stressors in the cultural values models

Terminology from Workshop (including definition by break out group)	Standardised or new terminology	Status in revised models
Stability	Slope failure	Revised to standardised terminology
Radiation	Radiation dose	Revised to standardised terminology
Appropriate material	Inappropriate surface material	Revised to standardised terminology
Chemical contaminants	Solutes – trace metals Solutes – major ions Organic chemicals	Not directly used in revised models, but are indirectly captured through other models feeding into the revised models (as indicated in the models)
Control of political process	Nil	Deemed to be outside the scope of this assessment
Fire	Fire	Not directly used in revised models, but is indirectly captured through other models feeding into the revised models (as indicated in the models)
Ineffective consultation	Ineffective consultation	Used as is
Lack of resources	Nil	Deemed to be outside the scope of this assessment
Deviation from mine closure strategy	Nil	Not included in revised models, but captured through the inclusion of relevant mine rehabilitation plan components as sources
	Physical barriers	Included in the site accessibility/ traversability model.
	Soil erosion	Included in the site accessibility/ traversability model.
	Weeds	Included in the site accessibility/ traversability model.

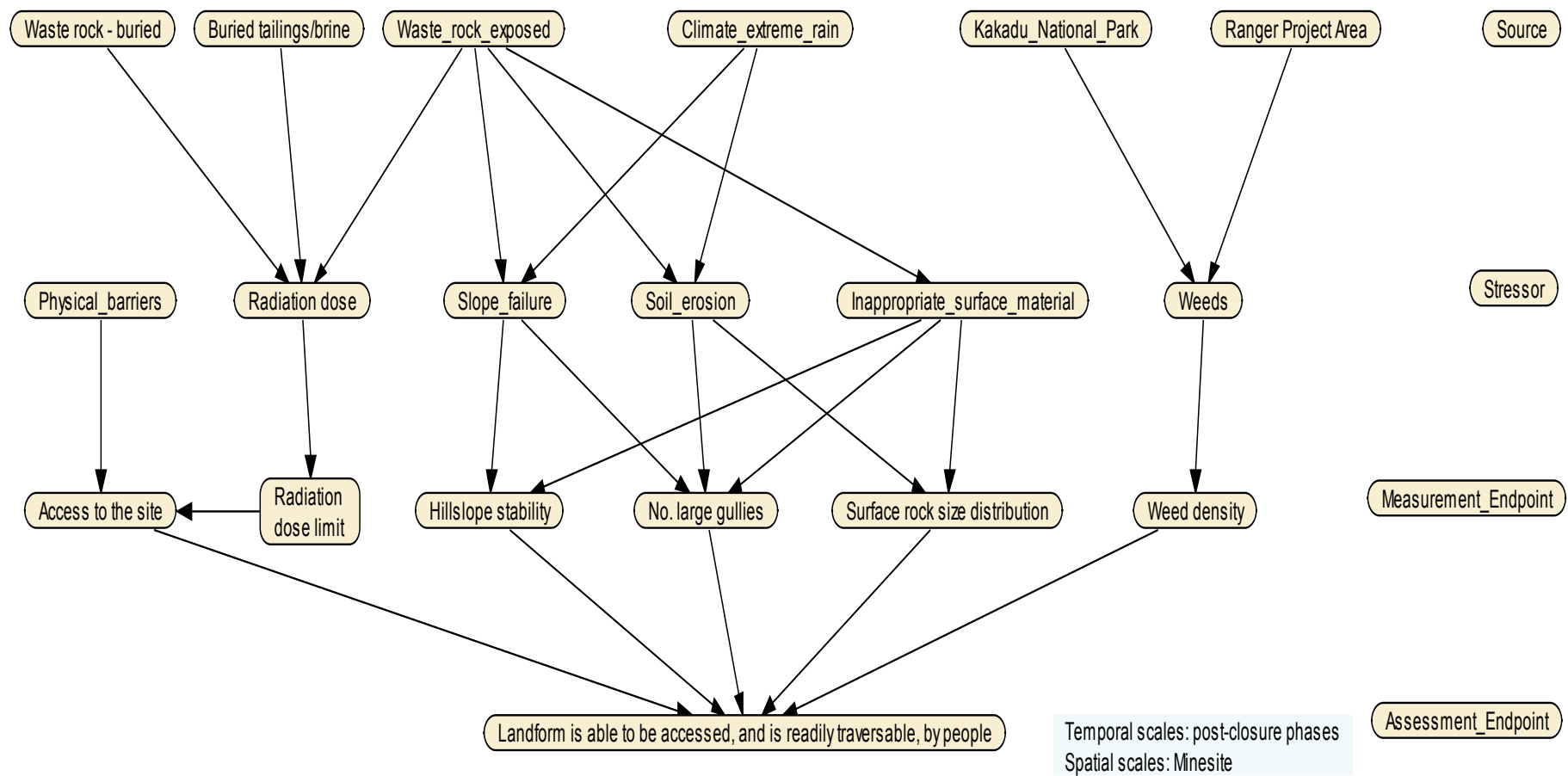


Figure 3.17 Revised conceptual model for the assessment endpoint, *Landform is able to be accessed, and is readily traversable, by people*.

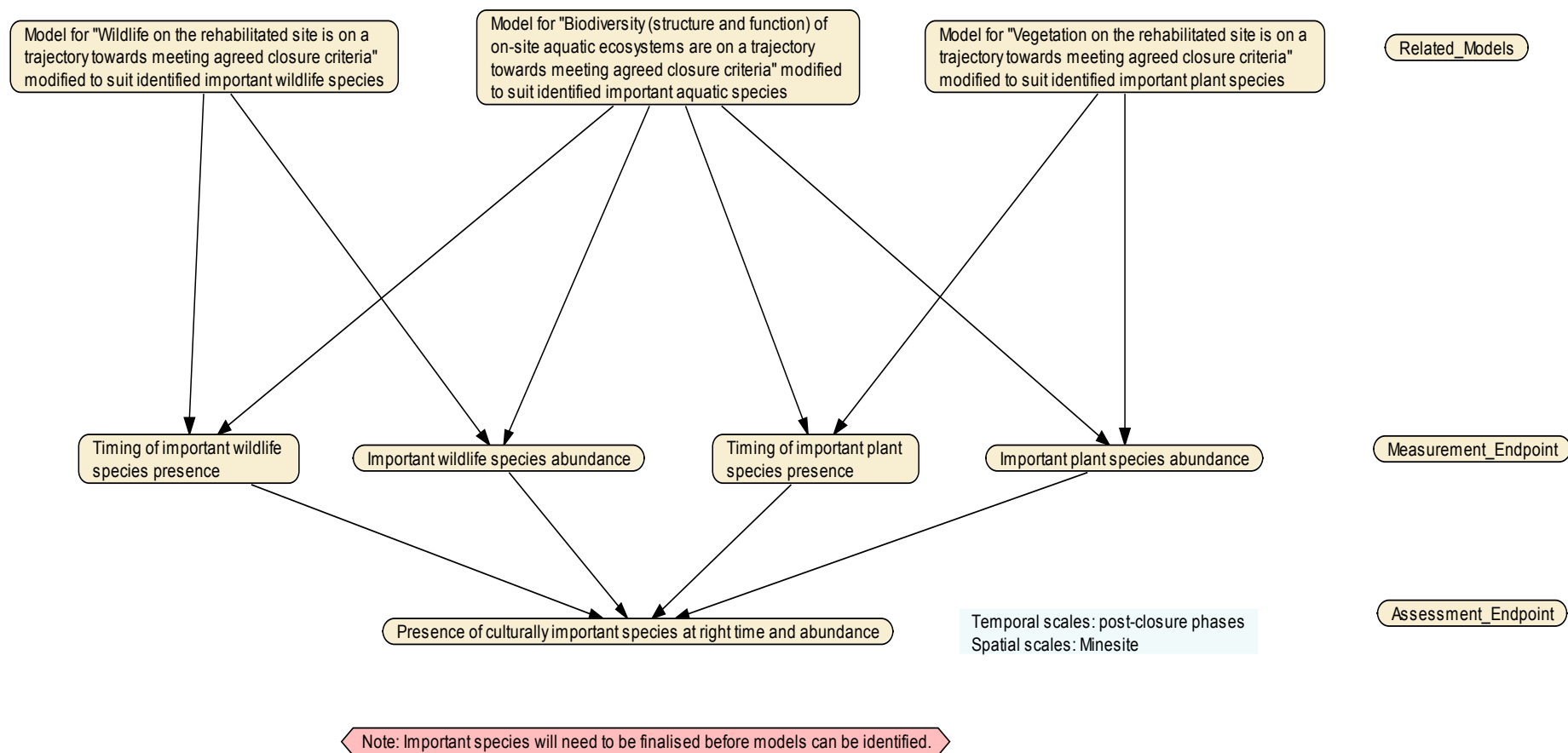


Figure 3.18 Revised conceptual model for the assessment endpoint, *Presence of culturally important species at right time and abundance*.

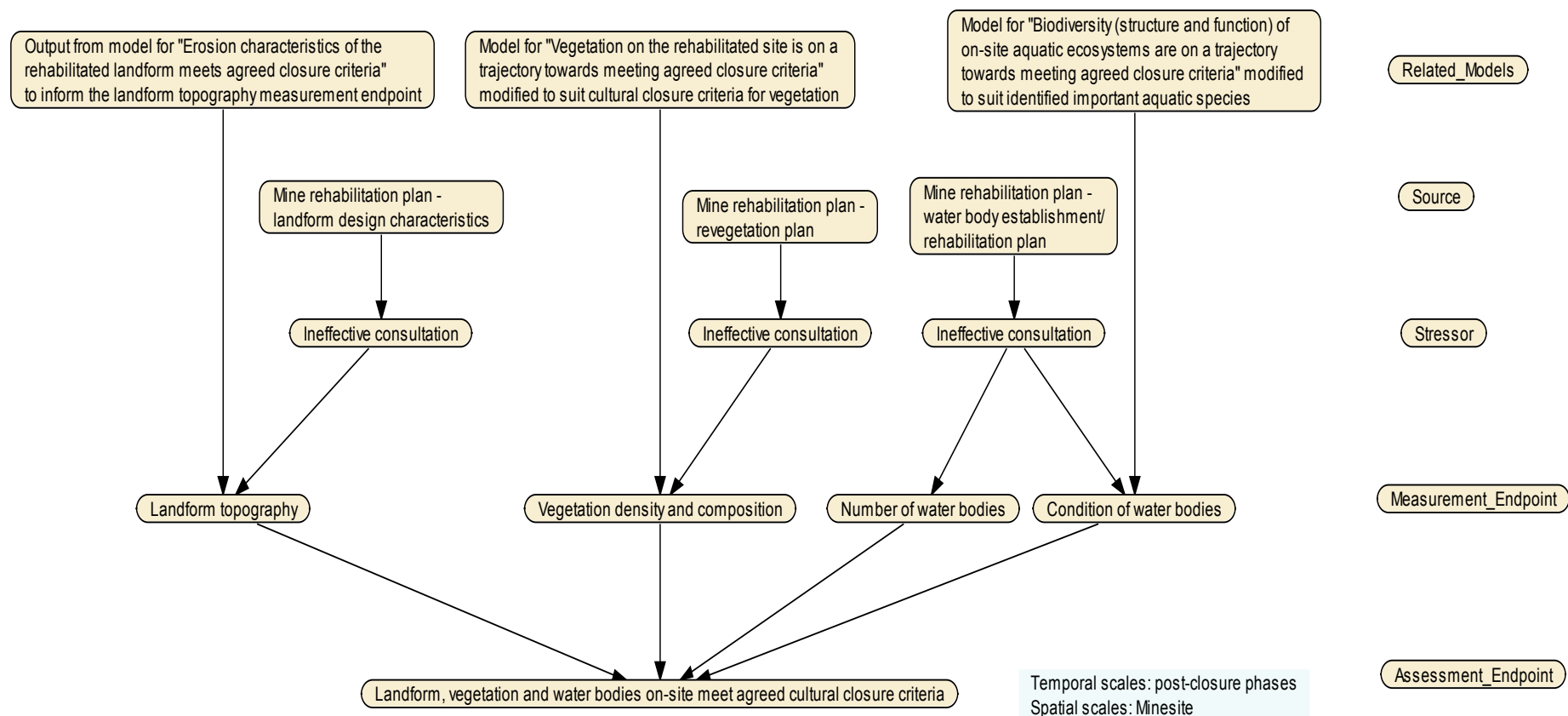


Figure 3.19 Revised conceptual model for the assessment endpoint, *Landform, vegetation and water bodies on-site meets agreed cultural closure criteria*.

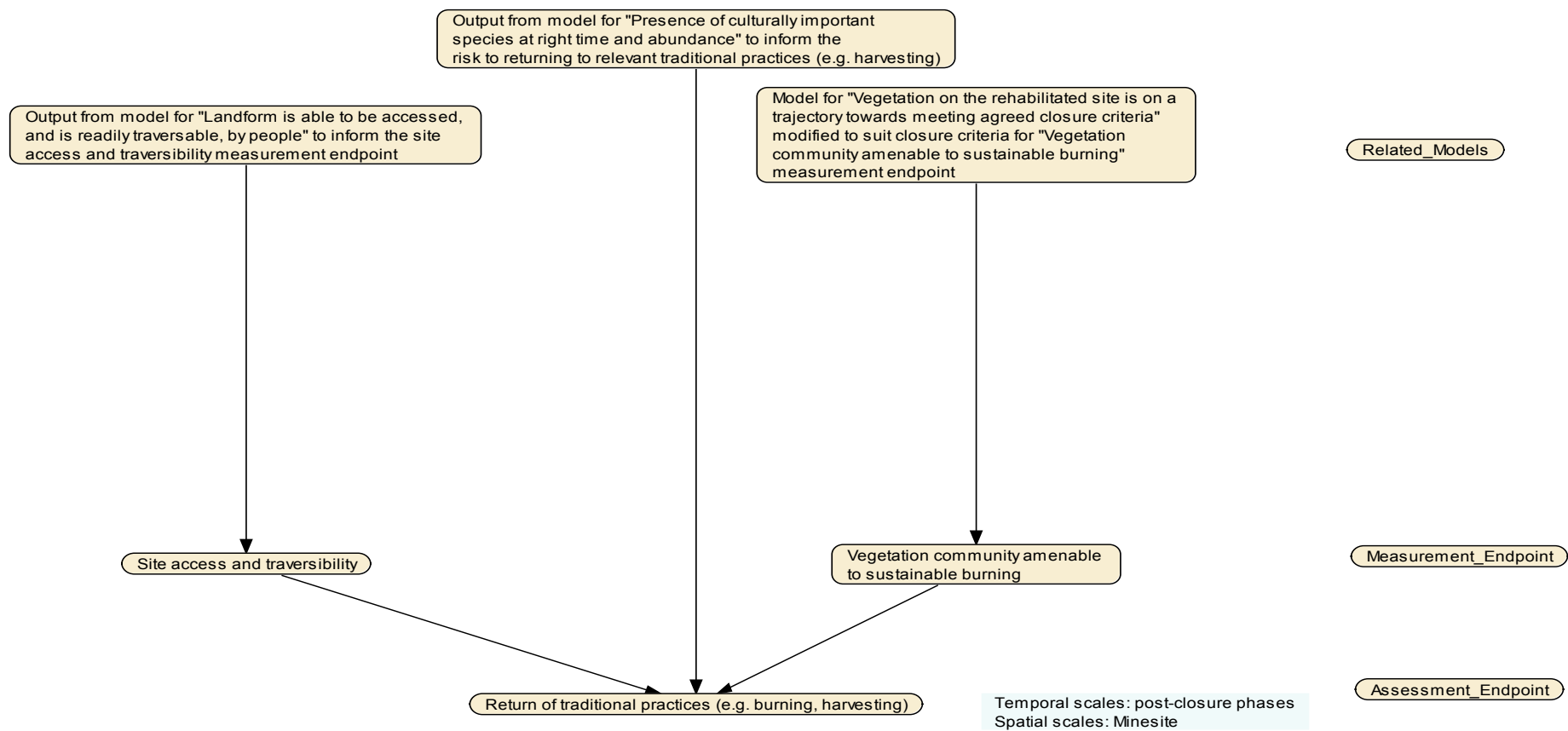


Figure 3.20 Revised conceptual model for the assessment endpoint, *Return of traditional practices (e.g. burning, harvesting)*.

4 Summary

The main objective of this project was to complete the Problem Formulation phase (i.e. develop the conceptual models and framework) for the rehabilitation/closure ecological risk assessments for Ranger (the minesite and landscape scale risk assessments), and to include TEK throughout this phase.

In meeting this objective a number of tasks were undertaken during a stakeholder workshop and subsequent reviews by small focus groups and the breakout groups from the workshop and are summarised as follows:

- Identify the key sources, stressors and ecological assets that will be examined for the decommissioning, stabilisation and monitoring, and the post-closure phases of Ranger uranium mine's closure. The values are documented in Pollino et al. (2013).
- The key values identified by the workshop participants were formulated into ecological assessment endpoints. Post-workshop, these endpoints were modified into fifteen assessment endpoints covering four themes:
 - 1) Off-site water quality meets agreed closure criteria specified for water quality.
 - 2) Habitat diversity of off-site aquatic ecosystems are comparable to the agreed reference condition.
 - 3) Biodiversity (structure and function) of off-site aquatic ecosystems are comparable to the agreed reference condition.
 - 4) On-site water quality is on a trajectory towards meeting agreed closure criteria specified for water quality on-site.
 - 5) Habitat diversity of on-site aquatic ecosystems is on a trajectory towards meeting agreed closure criteria.
 - 6) Biodiversity (structure and function) of on-site aquatic ecosystems are on a trajectory towards meeting agreed closure criteria.
 - 7) Erosion characteristics of the rehabilitated landform meet agreed closure criteria.
 - 8) Wildlife on the rehabilitated site is on a trajectory towards meeting agreed closure criteria.
 - 9) Vegetation on the disturbed sites of the RPA is on a trajectory towards meeting agreed closure criteria.
 - 10) Habitat diversity and ecosystem functions within the landscape of the Magela Creek sub-catchment and broader KNP is comparable to an agreed reference condition
 - 11) Aesthetic values meet the expectations of the stakeholders in the ARR.
 - 12) Landform is able to be accessed, and is readily traversable, by people.
 - 13) Presence of culturally important species at right time and abundance.
 - 14) Landform, vegetation and water bodies on-site meets agreed cultural closure criteria.
 - 15) Return of traditional practices (e.g. burning, harvesting).
- Nineteen conceptual models were redrafted by the review group and finalised by the focus groups. There are three assessment endpoints that are yet to have models redrafted and finalised; two models for aquatic ecosystems and one for human health. These will be addressed in the near future; the first two upon completion of the ecological processes definition; and the last by combining the human health models drafted by both the terrestrial (RPA) and people breakout groups.

- A report was produced by Pollino et al. (2013) which details background material, and the values and draft conceptual models produced during the workshop. Revision of the conceptual models presented here and communication is ongoing through the CCWG processes.

In reviewing the conceptual models, it was clear that ecological processes were not clearly defined and that there is clarity required on this. Ecological processes are specifically mentioned in the Environmental Requirements for the operation and closure of the Ranger Uranium mine. A small focus group from the aquatic ecosystems breakout group have drafted a paper discussing ecological processes and how these can be measured (Appendix 3). This aspect of the conceptual models will be further addressed through the CCWG.

Once the causal models are finalised, they will be used as the basis for scoping the risk analysis phase of the risk assessment. The risk analysis phase of the rehabilitation risk assessment will commence in 2013–14. Progress to date has been hampered due to staff availability (resourcing) for the project, both within SSD and ERA. Part of the problem formulation phase project included the development of an analysis plan (design, data needs, and methods for undertaking the risk analysis phase of the assessment), which was undertaken and reported by Pollino et al. (2013). It is recommended that the AS/NZS ISO 31000:2009 generic framework for risk management be adopted as it is considered best practice. The US EPA ecological risk assessment guidelines (US EPA 1998) can be used in conjunction with the ISO risk management standard. Pollino et al. (2013) recognise there are many approaches for undertaking risk analysis, but they focused on Bayesian networks, a recommended approach in the ISO/IEC 31010 Standard which supports the risk management standard (it is focused on risk analysis techniques). Bayesian networks have also been identified as a potential tool by Energy Resources Australia (ERA). Bayesian networks are probabilistic graphical networks, which can be used to directly apply the conceptual model from the problem formulation in a modelling platform for quantifying risks and associated uncertainties.

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Appendix 1: Workshop Agenda for the Ranger Mine closure causal maps 2-day workshop (25-26 February 2013)

Day 1 (25/02/2013)

Time	Topic / objective	Notes
9.30-10.00	Introduction	
	Role, Organisation, Interest/role in mine closure planning	What do participants anticipate getting OUT of the workshop (as well as putting INTO the workshop); measures of success by which we can judge the success of the workshop
10.00-10.30	Context for workshop; and workshop overview	
	Closure planning process Requirements for risk assessment	Shelly – closure context and goals and decisions about what Risk Assessment is intended / must achieve; policy/legal/reputation compliance requirements; evaluation criteria
	Agree on objectives and outcomes for workshop	Carmel –language and concepts; workshop process and outcomes
	Agree on how we meet workshop objectives (agenda)	Carmel – what process will we use (brainstorming, break-out groups, prioritisation); rules of 'play', including how to resolve/arbitrate differences of opinion
10.30-11.20	Mine closure – risk assessment objectives	
	Overview the objectives; and discussion around the scales	Scope and scales (time, space, interacting scales that we need to consider?)
11.20-11.30	Break	
11.30-1.00p	Defining values	
	Existing (already documented) and new ones	Brainstorming (post-it notes) - Need to distinguish between values and drivers
1.00-1.45	LUNCH BREAK	Over lunch, project team (Carmel, Sue, Rick, Renee, Shelly) create 'straw man' with values grouped into 4 groups, e.g. Park v. Mine interests OR value types OR mine closure phases OR exposure/threats (least preferred as models non-integrated)
1.45-3.00	Role of values in risk assessment	
	To define, and agree as a workshop 'team', on the core set of values	Split into break-out groups to workshop the 'groups' of values. What is role of each value? What is missing from the assessment by not including it? Can it be measured? How relevant is to mine closure? Can multiple values be combined? <i>May need to rank values</i>
3.00-3.15	BREAK	

Time	Topic / objective	Notes
3.15-4.15	Defining assessment endpoints	
	List of core values converted into assessment endpoints	Convert each of the 'core' values into assessment endpoints (e.g. indicators) Still in groups
4.15-4.20	Wrap up	Carmel, and Shelly

Day 2 (26/02/2013)

Time	Topic / Objective	Note
9.00-10.00	Refresh / review	
	Assessment endpoints	Review progress
	Refresh of causal mapping needs	Carmel – use the one that Carmel & Sue put together night before from Day 1
10.00-10.15	Break	
10.15-2.30p	Development of causal maps	
10.15a – 12.30p	What are the key threats to endpoints?	For each threat, identify – sources (mine derived v. non-mine), <ul style="list-style-type: none"> - relevant scale (decommissioning, stabilization and monitoring, post-closure / mine site, KNP); - mobilisation processes, - transport and exposure pathways; - interactions; - <i>available knowledge base; key uncertainties</i>
12.30-1.45	LUNCH	
1.45-2.30	Continue threats session	Causal diagrams
2.30-4.00	Collation / synergies	
	Groups come together (models by scale by value)	Synergies; can we collapse these 'models' down? What is best way to finalise the presentation of these 'models'? (don't need to do on the day, part of consequent write-up)
	BREAK SOMEWHERE	
4.00-4.30	WRAP UP	
	Gaps; where to from here	Carmel
	Wrap up, Next steps	Shelly – e.g. data identification and collation; Approval/sign-off process re outcomes of workshop

Appendix 2: Workshop Attendees

Name	Organisation	Breakout Group
Carmel Pollino	CSIRO	Facilitator
Sue Cuddy	CSIRO	Facilitator
Michelle Iles	Energy Resources Australia	Aquatic
Sharon Paulka	Energy Resources Australia	Terrestrial (RPA)
Nicole Jacobsen	Energy Resources Australia	People
Linda Pugh	Energy Resources Australia	Terrestrial (Landscape)
Daniel McIntyre	Energy Resources Australia	Terrestrial (Landscape)
Mark Lewty	Energy Resources Australia	Terrestrial (RPA)
Steve Winderlich	Kakadu- Parks Australia	People
Howard Smith	Northern Land Council	People
Adam Thompson	Northern Land Council	People
Geoff Kyle	Gundjeihmi Aboriginal Corporation	People
Sally-Anne Stromhayer	Department of Resouces (NT)	Terrestrial (RPA)
David Mulligan	Alligator Rivers Region Technical Committee	Terrestrial (RPA)
Keith Tayler	Supervising Scientist Division-Office of the Supervising Scientist	Terrestrial (RPA)
Rick van Dam	Supervising Scientist Division-Environmental Research Institute of the Supervising Scientist (ERISS)	People
Renee Bartolo	ERISS	Terrestrial (Landscape)
Chris Humphrey	ERISS	Aquatic
Wayne Erskine	ERISS	Terrestrial (RPA)
Kate Turner	ERISS	Aquatic
Andreas Bollhoefer	ERISS	Aquatic
Andrew Harford	ERISS	Aquatic
Amy George	ERISS	Aquatic
Tim Whiteside	ERISS	Terrestrial (Landscape)
Che Doering	ERISS	Aquatic

Appendix 3: Measuring Ecological processes for the Ranger Uranium Mine Ecological Risk Assessment – Draft discussion paper

The Environment Requirements for closure of the Ranger Uranium mine includes the following;

*“d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including **ecological processes**.”*

Consequently, “*ecological processes*” was flagged as a necessary ‘Assessment Endpoint’ in the Ranger Closure and Rehabilitation Ecological Risk Assessment workshop of 25-26 February 2013. However, the conceptual model developed for the Ecological Risk Assessment method is designed for the assets or components (e.g. biodiversity) which are sustained by ecological processes. Thus, ecological processes are a suitable endpoint, but their value is derived from the direct assessment and measure of key ecological components. Ecological processes require further definition, delineation and prioritisation to be successfully incorporated into the current Risk Assessment Framework. Consequently, discussions concerning the concepts of Ecological Processes, and how to measure them, were continued the day after the ARRTC 30 meeting. The meeting included 4 key ecologists; Paul Boon (ARRTC independent member), Chris Humphrey (ERISS), Amy George (ERISS) and Kyla Clarke (ERA).

Ecological processes are essential in conservation and rehabilitation programs because such programs will ultimately fail if the ecological processes that support assets are not established or maintained. Consequently, ecological processes are a fundamental requirement in the Australian Ramsar Ecological Character Description methodology (Department of the Environment, Water, Heritage and the Arts 2008). A number of recent papers have aimed to define, or at least list, ecological processes, the threats to these process and/or management strategies to preserve ecological processes (McGregor et al. 2008, Bennett et al. 2009, Cork et al. 2009, McDonald & Williams 2009). These papers listed a number of ecological processes but sometimes without a specific definition of ecological processes. Nevertheless, Trail (2007) defined ecological processes as:

“The interactions and connections between living and non living systems, including movements of energy, nutrients and species.”

Most simplistically, ecological processes are the dynamic forces within an ecosystem between and within organisms, populations and communities (Aust Heritage Commission 2008). As such, the definition of ecological processes embeds concepts relevant to both biotic and abiotic components that interact to form a functional ecosystem. The Department of the Environment, Water, Heritage and the Arts (2008) lists 7 broad categories of ecological processes (Table 1). Each of these processes has numerous measurement endpoints and the ability to measure these processes varies markedly. The challenge for any ecological risk assessment is appropriately mapping ecological components with key ecological processes supporting them and providing the justification for them through identifying ecological values, benefits and services. This allows an evaluation of what is currently measured and identification of possible additional measures to be developed within a monitoring program.

Some of the data that informs an ecological process may be readily measurable but how the different components integrate to affect the overall ecosystem needs to be assessed using available data. Ecological processes are both temporally and spatially dynamic and measuring environmental change is paramount to knowing the status of ecological processes. Monitoring programs are useful for this when they generate information on ecological trajectories (Bennett et al. 2009). Thus, reference approach needs to reflect trajectories as well as the spatial representation of processes and the relative role of key components in maintaining structural heterogeneity. Examining ecological process is about similarity in process rather than simply similarity in structure. Measuring and comparing ecological processes is difficult and Bennet et al. (2009) have recommended that one of the first steps is to identify the key ecological processes that sustain an ecosystem. Hence, ecological processes that are to be assessed as part of Ranger's environment requirements will need to be clearly identified. Ideally, this should be an outcome of this risk assessment processes that identifies the most important processes that can sustain an ecosystem on the post-rehabilitated mine site. The Kakadu National Park Ramsar Site Ecological Character Description (BMT WBM 2010) may provide a starting point since the ecological character description (ECD) is described from critical and supporting ecological components, processes, and services for the region. However, the list of processes does not fully capture the spatial representation of the links between measured data and large-scale ecological processes since the ECD focuses on large-scale components and processes only.

Assessment Endpoints

The Risk Assessment currently proposes Assessment Endpoints as; “*Biodiversity (structure and function) of off-site aquatic ecosystems are comparable to the agreed reference condition*” and “*Biodiversity (structure and function) of on-site aquatic ecosystems are on a trajectory towards meeting agreed closure criteria*”. However, a key conclusion of the 23 May meeting was that structural biodiversity was better viewed as a Measurement Endpoint that informs functional biodiversity (aka ecological processes). This is because “biodiversity” is something that can be measured and has a direct relationship to ecological processes.

Measurement Endpoints

As shown in Table 1, Ecological processes can be split into abiotic and biotic processes. Specifically, abiotic processes include:

- Formation of habitat structure
- Geochemical processes (soil/sediment and aquatic)
- Hydrological processes
- Climatic processes
- Natural disturbance regimes

Biotic processes include:

- Movement of organisms, including recruitment and/or regeneration
- Primary production
- Predation, herbivory, competition, parasitism and mutualism

The ECD does not split processes. Rather it groups all processes together, but recognizes that they may be physical, chemical or biological. The measurement endpoints are more

closely aligned with ecological components which are always physical, chemical or biological parts of the ecosystem (e.g. habitats, species, nutrients) (Department of the Environment, Water, Heritage and the Arts 2008).

Measured v Derived data

It is noteworthy that some data previously collected for biodiversity assessments, may also inform ecological processes. For example, the identification of species during biological monitoring surveys can be used to derive information on the organism traits that have a more direct relationship to their function in the ecosystem. Similarly, size structure data gathered on fish communities during biological monitoring studies in the ARR may be used to inform ecological processes associated with reproduction/recruitment and dispersion/migration of fish.

Table 1 Examples of Ecological Processes modified from Department of the Environment, Water, Heritage and the Arts (2008)

Process	Examples
Climate ^a	Precipitation Temperature Evaporation Wind
Geomorphology ^a	Topography/morphology Connectivity of surface waters Water source Soils Sedimentation Erosion
Hydrology ^a	Water balance (water flowing in, water flowing out) Groundwater infiltration and seepage Surface–groundwater interactions Tidal regime Inundation regime (volume, frequency, duration, height and seasonality [timing] of inundation)
Energy and nutrient dynamics	Primary production Nutrient cycling (nitrogen, phosphorus) Carbon cycling Decomposition Oxidation–reduction
Processes that maintain animal and plant populations	Reproduction Regeneration Dispersal Migration Pollination
Species interactions	Competition Predation Succession Herbivory Diseases and pathogens
Physical processes	Stratification Mixing Sedimentation Erosion Evaporation Infiltration
Natural disturbance regimes ^b	Fire Floods and drought Cyclones Extreme temperatures Disturbance regimes (i.e. the combination of frequency, duration, intensity and extent of disturbance) have greater long-term influence than single events

^a For some wetlands these processes may be viewed as components or broken down into their components.

^b Not included in Australian Heritage Commission (2002)

Table 2 Ecological components modified from Department of the Environment, Water, Heritage and the Arts (2008)

Component	Examples	Measured
Physical form	Area of the wetlands and creeks Wetland form (e.g. depth, shape and bathymetry [the study of underwater depth]) Landform topography	Yes – Remote sensing Yes? HGCP will know Yes – Landform modelling
Soils and sediments	Site and soil/sediment profile characterisation (e.g. using the Australian Soil and Land Survey Field Handbook McDonald et al. 1990). Soil profile classification (e.g. using Isbell 2002) – most profiles should fall into the Hydrosol Soil Order and classification to the Sub-Order or Great Group level will be sufficient in most cases. Soil physical properties (e.g. structure, texture, consistency and profile) Soil chemical properties (e.g. organic content, nutrients, sulfides, acid neutralising capacity, salts and pH) Soil biological properties (e.g. soil organisms such as bacteria and fungi, invertebrates – shellfish, mites and worms)	Not sure what this means? Probably (HGCP) not sure? Probably (HGCP) Yes – to some extent but focusing mostly on metals Some information being generated from the sed U tox project. CDU have done some LAA bacterial work
Physicochemical water	Nutrients (e.g. nitrogen, phosphorus) Electrical conductivity Cations and anions Turbidity Temperature Dissolved oxygen pH Nutrient cycling Light attenuation	Yes – possibly limited sampling? Without much spatial or temporal solution. Yes Yes Yes – especially in Magela and Gulungal Yes Yes – not sure how extensive Yes Not sure Limited but can be inferred from turbidity
Biota	Wetland plants Vertebrate fauna (e.g. fish, amphibians, reptiles, waterbirds, mammals) Phytoplankton, including diatoms Aquatic macroinvertebrates	Remote sensing. Ecological surveys Yes – fish channel billabongs and shallow lowland billabongs Much historical (1978-81) data. . More limited recently, GTB study and some during recessional flow sampling Yes – year recessional flow sampling in creeks. Intermittent billabong sampling

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