Ecological risk assessments of key threats to Australia's tropical rivers: Overview, proposed framework and methodologies for the Tropical Rivers Inventory and Assessment Project

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GPO Box 461, Darwin NT 0801

June 2006

Registry File SG2004/0073

(Release status – unrestricted)

Australian Government

Department of the Environment and Heritage

Supervising Scientist

How to cite this report:

R van Dam, R Bartolo & P Bayliss 2006. Ecological risk assessments of key threats to Australia's tropical rivers: Overview, proposed framework and methodologies for the Tropical Rivers Inventory and Assessment Project. Internal Report 517, June, Supervising Scientist, Darwin. Unpublished paper.

Location of final PDF file in SSD Explorer

/Publications Work\Publications and other productions\Internal Reports (IRs)\Nos 500 to 599\IR517_TRIAP: Ecological risk assessments of key threats to Australia's tropical rivers (van Dam et al)

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Ecological risk assessments of key threats to Australia's tropical rivers: Overview, proposed framework and methodologies for the Tropical Rivers Inventory and Assessment Project

R van Dam, R Bartolo & P Bayliss

Background

The tropical rivers of northern Australia are under increasing pressure due to environmental threats and human activities. The objective of this sub-project (sub-project 2) of the *Tropical Rivers Inventory and Assessment Project* (TRIAP; www.nctwr.org.au/publications/tropical-rivers) is to develop a risk assessment framework applicable to the key focus catchments and significant locations that meet stakeholder needs, within the region of the TRIAP. In addition to providing a broad overview of the major pressures on tropical Australia's aquatic ecosystems, the key component of this study is more detailed risk assessments for the focus catchments, being the Daly River (NT), Flinders River (Qld) and Fitzroy River (WA). Throughout this sub-project, stakeholders will be involved in providing input and feedback.

This paper firstly describes the generic elements of ecological risk assessment then details the process that will be followed for the project and the approaches that will be used.

Ecological risk assessment

Overview

Ecological risk assessment (ERA) is the process of predicting or estimating the likelihood and magnitude of adverse ecological effects occurring as a result of one or more threats (also referred to as stressors – see *Terminology*, below) (US EPA 1998; Burgman 2005). It provides a structured, iterative approach for making rational and transparent decisions based on the best available knowledge and recognition of the associated uncertainties. A generic paradigm for ERA is shown in Figure 1, and is the basis for the framework developed for this project. Generally, ERA encompasses the following steps – *problem formulation/hazard identification*, *analysis*, which consists of effects (consequences) assessment and exposure (likelihood) assessment, and *risk characterisation* (Figure 1), and these are described further below. Additional steps, such as risk communication, risk reduction and monitoring are also critical in the overall decision making process and are necessary to complete the risk management cycle (Burgman 2005). Moreover, identification and quantification of the key uncertainties and knowledge gaps enables prioritisation of research and data acquisition, which, through iteration of the risk assessment, decreases uncertainty in the risk predictions.

Applications of ecological risk assessment are numerous and include assessments that range from: screening-level (qualitative) to detailed (quantitative) or a combination of both (ie. tiered ecological risk assessment); predictive to retrospective in temporal scale; local to global in spatial scale; and single threat to multiple threats (US EPA 1998; Burgman 2005). Increasingly, risk assessment is being used in a catchment or basin context, to assess, prioritise and manage multiple threats, pathways, ecological resources/assets and competing social values (Serveiss 2001; Hart 2004).

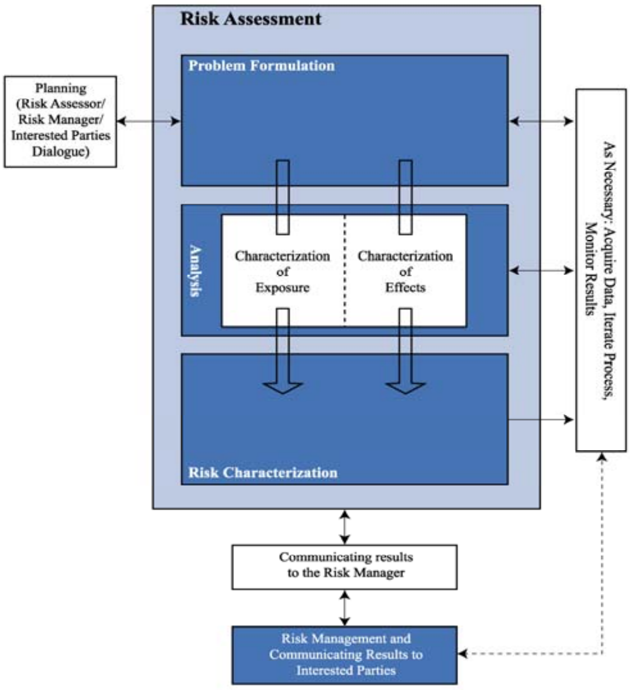

Figure 1 General framework for ecological risk assessment (modified from US EPA 1998)

Terminology

Consistency and clarity in terminology for risk assessment is crucial. Inconsistencies and lack of clarification can lead to miscommunication and incorrect interpretation amongst stakeholders. Table 1 lists definitions of common terms that are used and their intended use for this project.

Risk assessments focus on how (or if) certain agents or processes might affect things that are valued and need to be protected. However, the terminology used to define these two components can differ between risk assessments. This project uses the terms *ecological asset* (or simply *asset*) to define an attribute of a natural ecosystem that the community values and wants to see protected, and *threat* to define an agent or process (including an action or activity) that could adversely affect the asset and its values. The term *value* (or *ecological value*) in this context refers to the specific reasons an asset is considered important. An asset can have multiple values, which can be vastly different for different stakeholders. For example, a series of permanent river pools on a seasonally flowing river might be valued by someone for its good recreational fishing, by someone else because it provides crucial habitat for a threatened species, and by someone else because it holds great spiritual value. This study focuses on ecological values whilst recognising their links with other values (eg cultural, economic) where they exist. Threats arise from *pressures* (or *environmental pressures*) We have chosen to use the terms *assets* and *threats* largely because they are consistent with the terminology used in the Integrated Natural Resource Management (INRM) planning processes currently underway in northern Australia and funded under the Natural Heritage Trust (NHT). This will hopefully facilitate the link between the assessments conducted under this project and the on-the-ground INRM programs. It is also important to note that threats arise from *pressures* (or *environmental pressures*), which are defined as human activities (eg. mining, urban development) and human-induced trends and patterns of environmental significance (eg. climate change and sea level rise) that have the potential to impact the natural environment.

Table 1 Definitions of terms used in risk assessment

Term	Definition	Reference	Context for this study
Ecological Assets	Attributes (eg. components, processes, functions, products) of natural ecosystems, which are valued by the community (eg. river, wetland, biodiversity, environmental flow, water supply, primary production).	Modified from Hart et al (2005)	Used as defined.
Ecological Values	Qualities or characteristics of ecological assets that make the community value and want to protect them (eg. an ecologically healthy river; a biologically productive wetland; an upland stream rich in endemic fauna and flora).	Modified from Hart et al (2005)	Used as defined.
Ecosystem services	The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life. They maintain biodiversity and the production of ecosystem goods (eg. seafood, forage timber, biomass fuels)	MEA (2003)	Relevant to, but not used to a great extent for, this study.
Endpoint	*Assessment endpoint* – explicit expression of the actual environmental value(s) to be protected (eg. invertebrate community diversity). *Measurement endpoint* – measurable responses to a threat that can be correlated with or used to predict changes in the assessment endpoints (eg invertebrate reproduction, macroinvertebrate monitoring).	US EPA (1998)	Used as defined.
Hazard	The potential, or capacity of a threat to cause adverse effects on man or the environment, under the conditions of exposure.	US EPA (1998)	Used as defined
Pressure	Any human activity that has the potential to impact the natural environment. "Pressures" here cover underlying or indirect pressures (ie. human activities themselves and trends and patterns of environmental significance) as well as proximate or direct pressures (ie. the use of resources and the discharge of pollutants and waste materials).	OECD (2003)	Used as defined.
Risk	The probability of occurrence of an adverse effect of specific magnitude and timeframe on man or the environment resulting from a given exposure to a stressor.	Adapted from US EPA (1998) & Burgman (2005)	Used as defined.
Stakeholder	An individual or a representative of a group affected by or affecting the issues in question.	Glicken (2000)	Used as defined.
Stressor	Any physical, chemical, or biological agent or process arising from a pressure, which can induce an adverse environmental response.	US EPA (1998)	Synonymous with *Threat*, and generally not used for this study.
Threat	As above for *Stressor*, OR An action or activity that has the capacity to adversely affect an ecological asset and its value.	 Hart et al (2005)	Used as defined.

The risk assessment process

The key steps in the ERA process are briefly explained below.

Problem formulation/hazard identification

This step involves the collation of existing information to determine the nature of the issue or problem. At the outset, decisions need to be made and clearly articulated on the specific objectives and scope of the risk assessment (eg. qualitative or quantitative analysis of a single or multiple threats to a single or multiple environmental assets; determination of spatial and temporal scale). These decisions will guide the type of data and information that need to be gathered, and help to identify knowledge gaps. Typically, existing information needs to be compiled for the following:

- the environment of interest, particularly its most important assets (and their values), or at least those that need to be protected or are potentially at risk;
- the threat(s) to which the environmental assets are, or may be, exposed; and
- the types of effects that the threats(s) may have on the environmental assets.

The synthesis of such information should be done in consultation with stakeholders through an agreed process. It is possible that the information may reveal that the scope and objectives need to be refined or more clearly articulated. This is one example of the iterative nature of ERA. Once the information on the relevant assets and threats has been acquired, the next step is to construct a hazard matrix, identifying specific threats that will potentially cause adverse effects on specific assets (or values) (see Table 2). A following step would be to identify the types of effects on the assets that could be caused by the threats, and based on this, determine relevant, and measurable endpoints on which the ERA will focus. Such endpoints are often referred to as *measurement endpoints* (US EPA 1998; see Table 1), and they represent measurable (and ecologically relevant) indicators of the environmental assets to be protected (US EPA 1998). The relevant information is then brought together to develop a conceptual model of the issue or problem. The conceptual model, which can be presented in numerous ways, but is often shown as a type of flow diagram, represents the current understanding of the relationships between the threat(s) and environmental asset(s), and is used to develop working hypotheses that guide the remainder of the risk assessment (Solomon et al 1996, US EPA 1998). Consequently, conceptual models are critically important components of risk assessments, as the assessments can only be as adequate and appropriate as the conceptual models on which they are based (Burgman 2005).

Analysis – effects (consequences) and exposure (likelihood) assessment

The analysis phase incorporates both effects assessment and exposure assessment. These are described separately, below. For both components, the most pertinent information sources and techniques should be used, although these will vary depending on the assessment. Some types and sources of information include (AS/NZS 2004a, b):

- past records, including relevant published literature;
- experiments and investigations;
- modelling;
- practice and relevant experience;
- the results of public consultation; and
- specialist and expert judgements.

Table 2 Example hazard matrix based on information for the Daly River, Northern Territory

Values	Threats							
	Groundwater extraction	Surface water extraction	Altered fire regime	Land clearance	Invasive flora	Invasive fauna	Water impoundment	Water quality
Water dependent ecosystems								
Biodiversity	✔	✔	✔	✔	✔	✔	✔	✔
Threatened species	✔	✔	✔	✔	✔	✔	✔	✔
Nurseries & refugia	✔	✔		✔	✔		✔	✔
Erosion control / sediment retention	✔	✔	✔	✔	✔	✔	✔	
Water regulation	✔	✔		✔	✔		✔	
Water supply								
Perennial flow of Daly R.	✔	✔						
L'stone & karst geology	✔			✔			✔	
Water quality	✔	✔	✔	✔	✔	✔	✔	✔
Riparian vegetation								
Monsoon vine thickets	✔	✔	✔	✔	✔	✔	✔	✔
Erosion control	✔	✔	✔	✔	✔	✔	✔	✔
Habitat for wildlife	✔	✔	✔	✔	✔	✔	✔	✔

Effects and exposure assessment are often carried out con-currently and in an iterative fashion: simple assessments are often performed initially, followed by more comprehensive (eg. quantitative) assessments if considered necessary (van Dam et al 1999). The outputs of the effects and exposure assessments should be cross-checked with stakeholders to ensure that data and information were used and interpreted appropriately.

Effects (consequences) assessment

Effects assessment aims to determine the impacts or consequences of the threat(s) on the measurement endpoints selected during problem formulation (van Leeuwen 1995, US EPA 1998). For example, reduced water quality (for whatever reason) might impact aquatic ecosystems as measured by reduced species diversity and abundance of macroinvertebrate and/or fish communities. It is desirable to quantify the magnitude of impact to the extent possible.

Exposure (likelihood) assessment

Data on the effects of a threat to an asset (or appropriate endpoint) provide little useful information without knowledge on the actual level of exposure of the asset to the threat. Thus, exposure assessment aims to determine the likelihood that the ecological asset(s) will be exposed to the threat, and therefore, that an effect will be realised. For a biological threat, such as an invasive weed, exposure assessment might involve integrating information on the source of the weed, the potential route of entry into the ecosystem of interest, rate of spread, habitat preferences, and associated distribution. Existing information (eg. remotely sensed imagery) or habitat suitability modelling can be used for such purposes.

Risk characterisation

This step integrates the outcomes of the effects (consequences) and exposure (likelihood) assessments in order to determine the level of risk (ie. consequences × likelihood). In general, there are three levels at which this analysis of risks can be undertaken: *qualitative*; *semi-quantitative*; and *quantitative*. Often, risk assessments are undertaken in a tiered manner, with initial screening-level qualitative or semi-quantitative analyses being done prior to more detailed quantitative analyses. The purpose of this is to first rank the threats and associated hazards so that more effort can be allocated to quantitative risk analyses for the most important (ie. highest priority) threats and associated hazards. This is the approach proposed for this study, and is described in more detail in the next section. Whilst the output of risk characterisation need not be a quantitative estimate of risk, sufficient information should, at the very least, be available for appropriate experts to make judgements based on a weight-of-evidence approach. In the event of insufficient information being available, it is possible to proceed with another iteration of one or more phases of the risk assessment process in order to obtain more information (US EPA 1998). Regardless of the approach, uncertainty associated with the risk assessment must always be described and, if possible quantified, while interpretation of the ecological significance of the conclusions must also be carried out (Pascoe 1993, US EPA 1993). In addition, the risks must be sufficiently well defined to support a risk management decision, as discussed below.

Proposed ERA framework and method for TRIAP

As mentioned above, the risk assessments will adopt an *assets* and *threats* approach, with the key ecological assets, and threats to these assets, being described and inter-linked through conceptual models. Generically, the risk assessment framework will follow that described above. The workplan tasks (see Attachment 1) reflect this framework. Specific aspects of the risk assessments are detailed below.

Scope of risk assessment

We propose to adopt a hierarchical (ie. tiered) approach to the risk assessments, with analyses at increasing levels of detail/quantification as spatial scale becomes smaller. Several assessments are proposed, as follows:

Northern Tropical Rivers Study Area

- Hazard assessment of threats to the aquatic ecosystems of the tropical rivers

Daly River

- Semi-quantitative risk assessment of multiple threats to multiple assets
- Quantitative risk assessment of 1–2 key threats to selected assets

Fitzroy River

- Semi-quantitative risk assessment of multiple threats to multiple assets
- Quantitative risk assessment of 1–2 key threats to selected assets

Flinders River

- Semi-quantitative risk assessment of multiple threats to multiple assets
- Quantitative risk assessment of 1–2 key threats to selected assets

The focus for the ecological assets and their values will be on those that are directly related to the surface water ecosystems (ie. the river and its associated surface wetlands). Socio-cultural and economic assets and values will also be identified, although they will not be assessed except where there is large overlap with ecological assets and values. This decision was based largely on funding constraints, but also following discussions with numerous stakeholders.

In general, the assessments will focus on the risks posed by current land and water use. With the possible exception of the quantitative risk assessments, no future or potential land and water use and associated threat scenarios will be developed or tested.

The risk assessment framework and associated risk analysis approaches that will be adopted for this project are not new and have been well described elsewhere (eg. US EPA 2003; Bayliss et al 2004; Hart et al 2005). Thus, it is not the intention of the project to develop a new risk assessment framework for application to tropical rivers.

Objectives of risk assessment

The objectives of the project are three-fold:

1. to identify and describe the key threats to the aquatic ecosystems of the tropical rivers;
2. to identify, and where possible, quantify the risks of key threats to key ecological assets of the aquatic ecosystems of the selected focus catchments;

and in doing so,

3. illustrate the application and utility of ecological risk assessment as a decision making tool for natural resource management.

Problem formulation/hazard identification

Within the above-defined scope of the assessments, data collation will focus on the key assets and threats for the area of interest. Thus, the aim of this phase is to identify and describe: (i) the key assets (mostly ecological, but capturing a number of overlapping values of socio-cultural and economic importance) and threats to the aquatic ecosystems at the study area and focus catchment scale; and (ii) the interactions between the ecological assets and threats (ie. an initial description of how the threats might impact on the assets and also how the threats themselves might affect each other). The assets data will be derived largely from Sub-project 1 (*Inventory and mapping*), whilst the threats data are being collated as part of this project. Identification of assets and threats within the focus catchments will be undertaken through a combination of consultations with stakeholders and reviews of existing reports and management plans. Both spatial and non-spatial data related to assets and threats will be collated, and all spatial data will be linked to the inventory GIS. The initial outputs of this task will be a description of the key assets and threats, and a matrix of assets and threats that will be used as the basis for (i) constructing the conceptual models (see below) and (ii) focusing data/information searches.

Tropical Rivers Study Area

Ecological assets and threats information for the whole of the study area will be drawn mostly from broad scale national datasets and existing national scale reporting efforts. Examples of both reporting efforts and specific spatial datasets include:

- National Land and Water Resources Audit (NLWRA);
- State of the Environment (SoE) Reporting;
- GEODATA TOPO 250K Series 2 (GeoScience Australia); and
- Vegetation of the Australian Tropical Savannas (CRC-Tropical Savannas).

This information will be synthesised to provide a narrative and spatial overview of the key pressures and threats to the tropical rivers, including a matrix of threats against the catchments across the whole study area.

Focus catchments

The need for workshops with a broad range of stakeholders for the focus catchments will be determined on a case-by-case basis following consultation with key government stakeholders. To date, consultations with stakeholders from the Daly and Fitzroy Rivers have strongly indicated that there is unlikely to be a need for up-front stakeholder workshops to identify and agree on key assets and threats, as this process has occurred in both catchments for various purposes over the last few years. Consequently, it is considered appropriate to use the information produced from previous consultation processes, as long as stakeholders are kept abreast of progress and have the opportunity to verify/confirm the appropriate usage and interpretation of data/information (ie. through regular consultation and communication).

Ecological assets and threats information for the focus catchments will be drawn from the national scale sources where relevant, but also from more detailed, finer scale datasets held by the relevant government jurisdictions and other organisations (eg. local research institutions, non-government organisations – NGOs, NRM bodies). For example, key reports and spatial datasets for the Daly River catchment include:

- Draft Conservation Plan for the Daly Basin Bioregion, August 2003 (NT DIPE);
- Daly River Community Reference Group Draft Report, November 2004;
- Environmental Water Requirements of the Daly River, July 2004 (NT DIPE);
- Inventory and risk assessment of water dependent ecosystems in the Daly basin, Northern Territory, 2001 (ERISS);
- Aquatic conservation values of the Daly River Catchment, Northern Territory, September 2005 (WWF);
- Mapping of locations of weeds surveyed from 1999 to 2003 (Daly_point_220801_g94); and
- Mapping of *Mimosa pigra* from 2003 aerial survey (Daly_mimosa_survey_g9)

The assets and threats information for each catchment will be used to construct a hazard (or threat) matrix (see Table 2). The assets and threats information and hazard matrices will be distributed to key stakeholders for comment, with the primary aim to ensure that the key information has been captured, and that is has been appropriately represented and interpreted. Once this process has been completed, the information will be used to construct a conceptual model for each focus catchment, representing the interactions between key assets and threats. The final form of the models is yet to be determined, but for practical reasons, may involve disaggregation of the complex systems into a series of simpler, more useable sub-models. The conceptual models, which will also be fed through a stakeholder consultation/feedback phase, will drive the subsequent semi-quantitative and quantitative risk analyses.

Analysis and risk characterisation

Tropical rivers study area

A semi-quantitative approach to determining an overall hazard/risk ranking for each of the study area catchments will be developed that relies heavily on the GIS but also on other available information on the severity and extent of the pressures and threats. A spatially explicit methodology, which the use of GIS lends to, is a practical means by which to characterise ecological risk. A spatially explicit ERA can be defined as estimating the differences in risk for different locations (Woodbury 2003). In a spatial context and of relevance to this particular project is the fact that water catchments are increasingly being used as the unit for integrated landscape assessment and management (Aspinall and Pearson 2000).

The use of GIS facilitates the incorporation of multiple anthropogenic and natural threats at the regional level. Within this context, GIS and spatial analysis have been used in various ERA applications (Hession et al 1996; Kienast et al 1996; Hogsett et al 1997; Aspinall and Pearson 2000; Gordon and Majumder, 2000; Diamond and Serveiss 2001; Ferdinands et al 2001; Gustafson et al 2001; McDonald and McDonald 2002; Preston and Shackelford 2002; Rouget et al 2002; Xu et al 2004; Billington 2005). Also, see Bayliss et al (2006) for an ecological risk assessment of Magela floodplain from landscape-wide risks such as invasive species (wetland weeds & pig rooting damage) and uncontrolled fire. The landscape risk assessments were conducted spatially and combined with point-source risks to downstream surface water quality from three major pollutants released from Ranger uranium mine.

In this project, we will adopt the Relative Risk Model (RRM) (Landis and Wiegers 1997) to assess, semi-quantitatively, ecological risks at the regional scale. The RRM is a robust methodology that incorporates spatial variability at a large scale to examine the interaction of multiple threats to habitats, and their effects (impacts) on assessment endpoints. The method has been shown to direct the focus of investigative studies and data collection and the decision making process (Landis and Wiegers 1997). Figure 2 illustrates the difference between a risk assessment in the 'traditional' local site application and a regional level. Landis and Wiegers (1997) define the following terms used in the RRM as follows:

- Sources – group of stressors (threats); and
- Habitats – group of receptors; where the receptors reside.

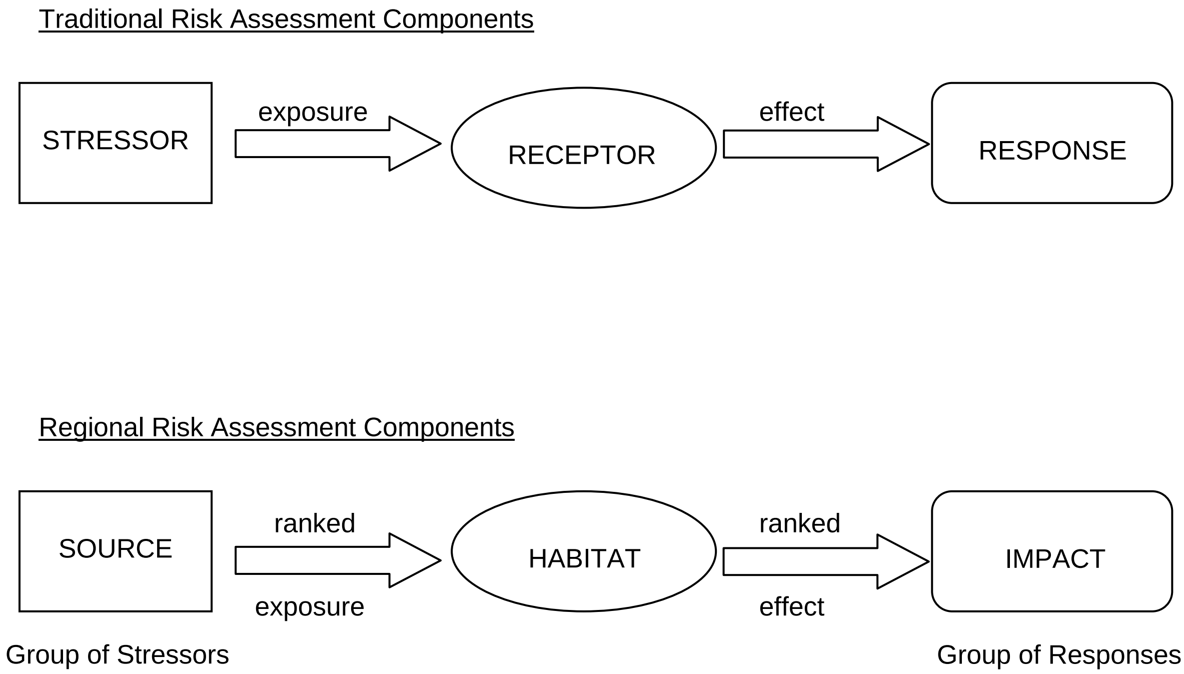

Figure 2 Comparison of risk components applied at the traditional and the regional levels (Landis and Wiegers 1997). *Source* in the context of this project equates to a *group of threats* and *habitat* can be related to a *group of assets.*

The RRM has been applied successfully in numerous studies and environments including: the marine environment of a fjord in Alaska (Wiegers et al 1998); Mountain River catchment in Tasmania, Australia (Walker et al 2001); an Atlantic Rain Forest reserve in Brazil (Moraes et al 2002); the Codorus Creek Watershed, Pennsylvania (Obery and Landis 2002); a near shore marine environment, Cherry Point, USA (Hayes and Landis 2004); and threats to sensitive species from military land uses in New Mexico and Texas (Andersen et al 2004).

Relative risk estimates are determined by combining source and habitat ranks. The results of the RRM are 'relative' so that one risk region can be compared with another and the results should not be used outside of this comparative context. In the process, risk characterisation results in a comparison of risk estimates among sub-regions, sources, habitats and endpoints to identify: the sub-regions where most risk occurs; the sources contributing the most risk; the habitats where most risk occurs; and the ecological assets most at risk in the study area.

The steps that will be undertaken in this project in applying the RRM are:

1. Determining the Assessment Endpoints (assets) based on stakeholder input;
2. Describing the Habitats to be examined;
3. Determining the Sources of Threats;
4. Creating a spreadsheet of the conceptual model for ranking purposes;
5. Identifying and creating risk areas;
6. Ranking of Threats based on a 2-point scheme (0, 2, 4, 6);
7. Ranking of Habitats based on the proportion of a particular habitat within a risk region;
8. Relative Risk Calculations; and
9. Risk Characterisation, including sensitivity and uncertainty analyses (via Monte Carlo simulation).

Some of the advantages of the RRM as suggested by Landis and Wiegers (1997) include: few assumptions are required; the impacts of ranking decisions upon the final outcome can be examined by quantifying uncertainties in rankings via a sensitivity analysis; rule driven approaches can be easily incorporated into the ranking system; and the rankings are testable hypotheses. Limitations in using the RRM are that the approach uses an additive model, although some threats may have multiplicative effects on the impact to an asset (Andersen et al 2004), and threats and habitats are ranked on their relative likelihood of occurrence, opposed to their relative consequence of occurrence (Walker et al 2001). Points of caution include firstly, ranks may be misinterpreted (eg. should not be used in regression analysis) and end users may rely on the ranking system without validating the projected risks (Landis and Wiegers, 1997). Additionally, the geographic extent of the habitat will influence the magnitude of the effects, particularly with different size populations (Hayes and Landis 2004), and variable distances between sources and effects will add complexity and so increase uncertainty.

Concordant with the broad scale of this analysis, the habitat of interest is simply the entire riverine ecosystems (including wetlands) of the catchment. The risk sub-regions at the continental scale will be the catchments themselves. Any pressure on the catchment that has the potential to impact on the riverine ecosystems is included in the analysis. The GIS will be used to determine the pressures that occur in each of the catchments, and where possible, the areal extent of those pressures. In addition, the pressures will be ranked according to their perceived severity in terms of the potential magnitude of impact on the riverine ecosystems.

This will be based on existing information; for example, a pressure that is listed under the EPBC Act as a Key Threatening Process will be ranked higher in terms of its severity than a pressure that is not listed as such. Outputs from applying the RRM at the continental scale will include (but are not limited to) maps illustrating catchments where the highest risk estimates occur, the habitats where most risk occurs, and the spatial distribution of pressures and threats.

Focus catchments

Semi-quantitative risk analysis

The semi-quantitative risk analyses for the focus catchments will be undertaken using the type of standard matrix approach detailed in AS/NZS (2004a, b) and shown in Figure 3 and within the RRM framework. In this process, values need to be assigned to what would normally be qualitative scales for both *consequences* and *likelihood* to produce a more expanded ranking scale. These scales will be underpinned by various data and information, including that contained within the GIS and will be based on a 2-point scale as described above (Obery and Landis 2002). For example, the consequences scale will be based on an analysis of data/information on documented effects of the threats to the types of assets being assessed (eg. see example provided above for the whole-of-study area analysis), while the likelihood scale will primarily be based on GIS modelling to determine the extent or likelihood of exposure of the assets to the threats. Risks will be spatially analysed for derived sub catchments at the focus catchment scale as has been reported in the literature (Hession et al 1996; Obery and Landis 2002).

For both the consequences and likelihood analyses, there will be a description of, and, where possible, an attempt to quantify, the associated level of confidence in the outputs. The inclusion of spatial data in ecological risk assessment contributes to the overall uncertainties inherent in site specific through to regional scale risk assessments (Woodbury 2003). Uncertainty has been addressed in numerous studies (Clifford et al 1995; Hogsett et al 1997; Landis and Wiegers 1997). The uncertainty in this instance arises from an inability to fully resolve the spatial heterogeneity of parameters such as land use and vegetation due to scale (Obery and Landis 2002), error propagation through analysis (Woodbury 2003), and aggregation of spatial data (Hession et al 1996; Woodbury 2003). Hayes and Landis (2004) used Monte Carlo analysis to describe uncertainty in their rank-based regional risk assessment. In this project a number of approaches will be tested to describe and measure uncertainty based on the RRM literature.

Likelihood Label	Consequences Label				
	I	II	III	IV	V
A	Medium	High	High	Very high	Very high
B	Medium	Medium	High	High	Very high
C	Low	Medium	High	High	High
D	Low	Low	Medium	Medium	High
E	Low	Low	Medium	Medium	High

NOTE: The relationship between consequence and likelihood will differ for each application: the level of risk assigned to each cell needs to reflect this.

Figure 3 Example matrix for determining level of risk (from AS/NZS 2004a)

The outputs of the semi-quantitative risk analysis will include:

- Identification of relative risks of the threats to multiple assets (ie. across all the assets, which threats pose the most risk), and to individual assets (ie. for individual assets, which threats pose the most risk);
- Identification of the relative vulnerability of the assets (ie. the assets least/most at risk);
- Identification of the cumulative risks of the threats to the assets; and
- Description of the degree of uncertainty in the overall assessment; and
- Description of the applications of semi-quantitative risk outputs to catchment management and NRM bodies (ie. how do they inform risk management/risk reduction?).

Quantitative risk analysis

The quantitative ecological risk analysis (QERA) will flow from the semi-quantitative risk analysis. A few key threats and assets will be selected for quantitative analysis based on outcomes of the semi-quantitative risk assessment, a process essentially and appropriately driven by stakeholder views. Depending on results of the RRM at regional (catchment-subcatchment) scales, the conceptual model for each selected threat will be reaffirmed and, if necessary, revised. A Bayesian Network (BN) will then be developed that explicitly identifies links between hypothesised causes and effects, and highlights complexities and uncertainties in the system. The influence of different interventions used to manage risks to the chosen ecological endpoints (usually a condition metric along the species-population-habitat continuum) will be examined using "what if" scenario simulation. Uncertainty will be incorporated into the risk assessment using Monte Carlo simulation and sensitivity analysis. Hence, the BN will form the start of an adaptive Decision Support System (DSS) framework that can be improved over time, especially with additional and/or better information flowing from targeted and well-designed future monitoring programs.

However, apart from the Daly River focus catchment (see below), at this stage we cannot be prescriptive about the QERA methodologies to be adopted in the other three focus catchments and, hence, the details of their associated work plan. The methods used will ultimately depend on the nature of the threats that are eventually selected for quantitative analysis, the type, coverage, quantity and quality of available data, and their linkages to other research projects (eg. NAIF). Regardless, the following generic approach will be adopted in all focus catchments: (i) where adequate empirical data exist frequentist approaches will be used, unless there are better existing statistical and/or ecological models; (ii) where there is combined reliance on empirical data and expert opinion/knowledge, and/or where decisions need to be made in the face of uncertainty, Bayesian networks will be employed; and (iii) where possible and desirable, the quantitative risk assessment will be spatially explicit with respect to assets and threats, in order to provide a better basis for on-ground management. Irrespective of what final quantitative methods will be used within the above mentioned analytical and DSS framework, all approaches will be consistent with the most recent national and international guidelines with respect to robustness, transparency, coherency and reliability (eg. see US EPA 1998, 2003; Cain 2001, AS/NZS 2004a, b; Burgman 2005). Needless to say, all uncertainties will be made explicit and their influence on the outcomes of all assessments examined by sensitivity analysis. In summary, we will highlight the benefits of using spatially explicit QERA methods and Bayesian Networks as decision making and communication tools for environmental managers, methodologies that recognise the dual nature of probability, that is chance (via frequentist statistics) and belief (via Bayesian statistics and expert opinion).

We propose to use the Daly River catchment in the NT to test the utility of various QERA approaches. Three key threats to a range of key natural assets were chosen *a priori* from previous stakeholder consultations and community-based preliminary risk assessments (see CRG Report 2004). Additionally, the chosen assets and, hence, ecological endpoints are likely "at risk" from multiple regional stressors and so will comprise ideal candidates to assess the utility of Relative Risk Models (see above). Nevertheless, before we begin we will consult with NTG stakeholders (mainly DPIFM and NRETA; with cross-reference to the CRG Report 2004) to confirm or re-confirm choice of key threats, appropriateness of the conceptual models and ecological endpoints. Potential key threats to be assessed are described below.

Land clearing

First-cut ERA conceptual models (CRG Report 2004) identified land clearing as a potential key threat to the condition of riparian habitats, in-stream water quality, in-stream and floodplain environmental flows and, hence, the "condition" of associated biotic habitats. In turn changes in habitat condition will ultimately affect species or population level ecological endpoints. Land clearing will lead to loss of vegetation cover and, hence, increased erosion rates. This in turn will influence sediment, chemical and nutrient loads and concentrations, and flow (via less vegetation more ground & surface water flows). The combined "downstream" effects of land clearing are hypothesised to affect a range of ecological endpoints, such as primary and secondary aquatic production and productivity, habitat condition and ultimately biodiversity (eg. habitat diversity, species community structure & composition, species by populations). Needless to say, the direction and magnitude of all hypothesised landuse affects on aquatic ecosystems will depend strongly on end landuse type. For example, cleared native vegetation may be replaced with annual pastures, horticulture crops or commercial forests, and non-native vegetation cover classes may either ameliorate or accelerate negative land clearing effects.

Barramundi & in-stream impacts

The correlation between increasing environmental flow and increased commercial fisheries production are well known (eg. total prawn catch, barramundi year class strength, growth rates of crabs) from some catchment to coast studies are well known (eg. see Griffith 1987, Sawynok 1998 & Staunton-Smith 2004 for barramundi, Glaister 1978 for prawns, and Loneragan & Bunn 1999 in general), and can be indirectly used to predict the tradeoffs between reduced flow from extractions on fisheries revenue. Although the main value of barramundi in the Daly River catchment is recreational fishing, it cannot be underestimated in terms of generating economic revenue and external non-monetary benefits. NT Fisheries have offered access to their time series catch data on the "Barramundi Classic Tournament" series (1981-2006) for the Daly River. Long-term catch-effort and length frequency data will be analysed for trends in relation to effort (harvesting impact *per se*) and long-term flow patterns (as potentially affecting fecundity, survival & dispersal processes via habitat change). Hence, the relative importance of changes in water quality, flow and fishing effort on the "barramundi" ecological endpoint will be assessed simultaneously and their relative effects ranked. An attempt will be made to link the results of this single-species analysis with work recently commenced by CDU on fish biodiversity in the Daly River. A Bayesian Network will be constructed using empirical data and expert opinion (via recreational fishers & NTG fisheries scientists) to examine potential causal links between changes in river flow (here predicted increases) and possibly quality, to changes in barramundi populations and, hence, recreational catch after variations in effort and management regimes are factored out.

Magpie geese & floodplain impacts

Bayliss et al (2006) showed with CUSUM and time series analysis a strong relationship between apparent 20-year population cycles of magpie geese (*Anseranus semipalmata*) across the NT and a similar periodicity in flow cycles for the Katherine River and Magela Creek, two stream gauging stations with the longest flow records in the NT. The time lag between geese numbers and flow is about a year, which concords with ecological relationships found between regional geese population dynamics and regional rainfall (Bayliss 1989). Bayliss et al (2006) also found similar relationships between long-term flow and long-term population trends of fish-eating egrets and rainbow fish (see Humphrey et al 2006) on the Magela Creek floodplain and associated billabongs, respectively. The Daly River floodplain encompasses key wet season nesting and dry season refuge habitats for magpie geese in the NT (30% of the NT population, respectively; see Bayliss & Yeomans 1990a&b). Hence, decadal trends in river flow at the nearest long-term stream gauging station (& hence by inference floodplain overflow) will be matched by time series analysis to spatial and temporal trends in nesting success and population size. As for barramundi, a Bayesian Network will be constructed using empirical data and expert opinion (indigenous & non-indigenous geese hunters & NTG wildlife scientists) to examine potential causal links between changes (here increases) in flow to changes in magpie geese populations.

Water extraction

Early community stakeholder consultations (see Daly River Community Reference Group Draft Report 2004) identified water extraction as a potential key threat to in-stream and floodplain environmental flows and, hence, the "condition" of associated biotic and riparian habitats. For example, Georges (2002) modelled the negative impact that various dry season flow reductions due to water harvests in the Daly River would have on populations of the iconic pig-nose turtle (*Carettochelys insculpata*) as mediated through changes in ambient water temperatures and, hence, temperature-dependent sex ratios. Although significant dry season water extraction is not considered a highly likely landuse scenario for the Daly River in the near to intermediate future (Jolly pers. Com.), we nevertheless will consider its potential impact on both the magpie geese and barramundi ecological endpoints. The reasons are twofold: if water extraction is not a serious future risk to the Daly River then it must be the exception rather than the rule in Australia, and we would rather hedge our bets than accept an assumption. Given rapidly converging economic and social drivers in the Daly region (eg. increasing pressures from agro forestry & horticulture ventures in nearby catchments, the aspirations of Aboriginal communities in remote northern Australia to make a living independent of welfare, a 10% p.a. increasing Aboriginal population in the NT & other stakeholders wishing to diversify away from rocks, cattle & tourists), future dry season water extractions in the Daly River cannot be absolutely discounted. Accordingly, the above QERA for land clearing is retouched in terms of water harvesting as a key stressor *per se*. The above Bayesian Network and "what if" scenario modelling results that may predict increased flows due to land clearing will be used in combination with additional and linked scenarios that predict reduced flows due to water harvesting. The effects of the two stressors in combination, however, would not necessarily "cancel out" when considering the relative risks of multiple threats at a regional scales because of complex and possibly non-intuitive ecological interactions.

Invasive species (weeds)

In contrast to the overwhelming ecological pressures due to flow extraction, drainage and habitat alteration experienced by wetlands and waterways in south-eastern Australian, wetland weeds have been identified as possibly the key threat to our relatively "pristine" northern aquatic ecosystems (Finlayson et al 1988). Accordingly, two of the most serious tropical wetland weeds were chosen for impacts analysis on the Daly River floodplain and these are the mimosa shrub (*Mimosa pigra*) and para grass (*Urocloa mutica*) (see Walden *et al*. 2004 for mimosa & Walden & Bayliss 2003 for mimosa & para grass). The choice was based on their ability to rapidly colonise most wetland habitats whilst simultaneously forming dense monocultures with maximum impact or effects on native plant biodiversity and associated wildlife habitat. In a QERA of the Magela floodplain, Bayliss et al (2006) showed that para grass is currently the major landscape-scale ecological risk because of its extent (15% cover), effect (a monoculture that displaces native vegetation) and rapid spread rate (14% p.a.). They showed also that the potential spread rate and impacts of mimosa, which is well documented on the adjacent Oenpelli floodplain (Longsdale 1993), is currently controlled on Kakadu National Park through an annual "search and destroy" investment of about $0.5 million. Ferdinands et al (2001) demonstrated also that para grass is a major risk to the biodiversity of the Mary River floodplains.

Summary

One of the objectives of the *Tropical Rivers Inventory and Assessment Project* (TRIAP) is to undertake ecological risk assessments (ERAs) of the key threats to Australia's tropical rivers. This paper outlined the proposed approach to these assessments. Risk assessments will be undertaken at various levels of detail and spatial scale. A hierarchical approach is proposed that is consistent with the concept of tiered ERA and the associated requirements for working across multiple spatial scales. As spatial scale and the number of threats being assessed reduces, the level of quantification of risk and uncertainty will increase. The project will utilise aspects of established risk assessment frameworks and methodologies, and will involve the following key components:

- Semi-quantitative assessment of risks to Australia's tropical rivers;
- Semi-quantitative assessment of risks to three focus catchments; and
- Quantitative assessment of risks of key threats to selected sites within the focus catchments.

The process of problem formulation/hazard identification will rely heavily on existing reports/data and stakeholder consultation, and will result in the construction of conceptual models of region/catchment aquatic ecosystem *assets* and *threats* and their inter-relationships. The conceptual models will be used to guide the semi-quantitative and quantitative analyses. Semi-quantitative risk analyses for the tropical rivers study area and focus catchments will rely on spatial risk modelling using a GIS-based approach known as the Relative Risk Model. Uncertainty analyses, using Monte Carlo and other methods, will be incorporated into the model. Quantitative risk analyses at the focus catchment (or selected sub-catchment) scale will be undertaken for selected threats and assets, depending on the results of the semi-quantitative analyses and stakeholder views. Most likely, Bayesian Networks (BNs) will be developed that explicitly identify links between hypothesised causes and effects, and highlight the complexities and uncertainties in the system. Again, uncertainty will be incorporated into the assessments using Monte Carlo simulation and other techniques such as sensitivity analysis.

Overall, it is envisaged that the ecological risk assessment sub-project of the TRIAP will illustrate (i) the need for, (ii) the various approaches to, and (iii) the benefits that can arise from the use of, ecological risk assessment for managing and protecting Australia's tropical rivers.

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Attachment A National Rivers Consortium (Tropical Rivers): Australia's tropical rivers – an integrated data assessment and analysis. Detailed Work Plan for Sub-Project 2: Assessment of the major pressures on aquatic ecosystems

Duration

2 person equivalents at each of ***eriss*** and ACTFR for 16.5 months each (Years 1 and 2)

Description

The tropical rivers of northern Australia are under increasing pressure due to environmental threats and human activities. The objective of this sub-project is to develop a risk assessment framework applicable to the key focus catchments and significant locations that meet stakeholder needs, within the region of the Tropical Rivers Project. In developing the risk assessment framework, semi-quantitative and quantitative risk analysis will be undertaken where possible, for selected threats. The key focus catchments that will be assessed are: the Daly River Catchment (Northern Territory); Flinders (Queensland); and Fitzroy River Catchment (Western Australia). Throughout this sub-project stakeholders will provide input and feedback.

There a number of key elements in developing the risk assessment framework that will be addressed. Firstly, identification of assets and threats within the focus catchments will be undertaken through a combination of consultations with stakeholders and a review of existing reports and management plans. Both spatial and non-spatial data related to assets and threats will also be collated. Spatial data will then be compiled in a GIS. Secondly, conceptual models for each of the focus catchments will be developed, focussing on the links between key assets and threats. Finally, both semi-quantitative and quantitative risk analysis will be conducted on selected threats.

Responsibilities

Database development and quantitative ecological risk assessments will be led by ERISS. Collation of information on pressures will be led by ACTFR with assistance from ERISS.

Outputs

Within selected major catchments and at important sites: specific analyses of major pressures (eg. weeds, feral animals, infrastructure, water pollution); recommendations for risk reduction/ management steps and monitoring; and a database of available information.

Work Plan & Schedule

The project tasks and associated task leads and timeframes are detailed below.

1. Develop risk assessment framework and describe methodology

1.1 Prepare internal paper describing the risk assessment framework and proposed methodology, including clarification of terminology (eg. threat v. stressor v. hazard).

2. Problem definition/hazard identification

2.1 Agree on risk assessment focus catchments (most likely Fitzroy – WA, Daly – NT, Flinders – Qld) and, in liaison with State/Territory Govts, NRM bodies and TRP Steering Committee, determine need for stakeholder workshops.

2.2 Identify key stakeholders (eg. Commonwealth/State/Territory/Local Govts, NRM bodies, industry groups, community groups, environment groups) for each catchment.

2.3 Liaise with key stakeholders to identify key catchment assets and threats (may involve workshops).

NB – perceptions of assets and threats will depend on stakeholders' interests. This issue will be clearly articulated, with a possibility of defining assets and threats based on 2–3 generic stakeholder types (eg. biodiversity conservation, agricultural development).

2.4 Acquisition of relevant spatial and non-spatial data/information on assets and threats.

- most of the 'assets' data will already have been collected as part of sub-projects 1 and 3. Most of the 'threats' data will need to be collected as part of this sub-project.
- A second search/request for new data will be made during the last half of the project.

2.5 Compile new GIS data layers based on spatial assets and threats data additional to those acquired in sub-project 1 (and ensure consistency/compatibility with existing GIS datasets).

2.6 Recording/creation and updating of metadata and evaluation of data/information quality.

∗∗ Most of Task 2 will be undertaken in parallel for each focus catchment ∗∗

3. Development of conceptual models

3.1 Describe the key ecological assets (ecological values) and threats, and their inter-relationships (focus is on conceptualising which assets are potentially at risk from which threats).

3.2 Use the above information to develop conceptual models of the interactions between key assets and threats for each focus catchment (the final form of the models is yet to be determined, but for practical reasons, may involve disaggregation of the complex systems into a series of simpler, more useable sub-models).

3.3 Seek feedback and confirmation on the models from key stakeholders, and iterate/finalise models as required (may involve workshops).

3.4 Agree on scope of semi-quantitative and quantitative risk analyses with respect to the threats and assets being assessed (agreement to be reached internally and with key stakeholders).

∗∗ *Focus catchments will be assessed sequentially, thereby focusing resources on one catchment at a time* ∗∗

4. Semi-quantitative risk analysis

4.1 *Effects/consequence analysis* – collate data/information on documented effects of key threats to key assets (possibly apply a semi-quantitative 'consequences' ranking scheme), and document the associated level of confidence in the data/information.

4.2 *Exposure/likelihood analysis* – integrate relevant GIS layers to determine extent or likelihood of exposure of key assets to key threats, and document the associated level of confidence in the data.

4.3 *Risk Characterisation*– integrate outcomes of effects and exposure analyses to estimate risks of threats to assets. Outputs include: identification of relative risks (and, therefore, highest risk threats); assets least/most under risk; initial indication of cumulative risks; and articulation of uncertainty.

4.4 Describe applications of semi-quantitative risk outputs to catchment management and NRM – ie. how do they inform risk management/risk reduction?.

∗∗ *Focus catchments will be assessed sequentially, thereby focusing resources on one catchment at a time* ∗∗

5. Quantitative risk analysis

5.1 Based on outcomes of semi-quantitative risk analyses and stakeholder views, select one threat/issue for quantitative risk analysis, and reaffirm/revise the conceptual model for this threat/issue.

5.2 **Land clearing**

- Review and, if necessary, modify the Daly River "Land clearing" impacts conceptual model presented in the CRG Report (2004). Undertake the review in consultation with NTG senior water policy advisors and technical experts in the field.

- Confirm with NTG senior water policy advisors and technical experts in the field the magpie geese and barramundi ecological and measurement endpoints identified *a priori* and, link them via "cause-effect" mechanisms to measurement endpoints.

Barramundi & in-stream impacts:

- Obtain NTG Fisheries time series catch data on the "Barramundi Classic Tournament" series (1981-2006) for the Daly River. Analyse catch-effort and length frequency data for trends in relation to effort (harvesting impact *per se*) and long-term flow patterns (as potentially affecting fecundity, survival & dispersal processes via habitat change).

- Simultaneously assess the relative importance of changes in water quality, flow and fishing effort on the "barramundi" ecological endpoint and rank effects.

- Attempt to link the results of this single-species analysis with work recently commenced by CDU on fish biodiversity in the Daly River.

- Construct a Bayesian Network using empirical data and expert opinion to examine potential causal links between changes in river flow (here predicted increases & possibly quality) to changes in barramundi population measurement endpoints and, ultimately, to recreational catch after variations in effort and management regimes are factored out.

Magpie geese & floodplain impacts

- Use time series and CUSUM analyses to match decadal trends in river flow at the nearest long-term stream gauging station to major magpie geese nesting colonies, and assess its influence on spatial and temporal trends in nesting success and population size.

- Construct a Bayesian Network using empirical data and expert opinion to examine potential causal links between changes (here increases) in flow to changes in magpie geese population measurement endpoints.

5.3 Water extraction

- Review and if necessary revise previous conceptual models on risks to in-stream and floodplain environments associated with dry season water extractions. Undertake the review in consultation with NTG senior water policy advisors and technical experts in the field.

- Confirm with NTG senior water policy advisors and technical experts in the field the magpie geese and barramundi ecological and measurement endpoints identified *a priori* and, link them via "cause-effect" mechanisms to measurement endpoints (eg. reduced flood extent & altered timing).

- Repeat above quantitative ecological assessments for reduced flow rather than increased flow, and its effect on the ecological and measurement endpoints for magpie geese and barramundi.

- Develop a Bayesian Network that predicts reduced flows due to water harvesting and combine with the above Bayesian Network predicting increased flows due to land clearing. Re-examine the above "what-if" management scenarios.

5.4 **Invasive species (weeds)**

- Review and, if necessary, revise previous conceptual models on conceptual model for ecological risks associated with the colonisation of mimosa and para grass weeds on the Daly River floodplain. Undertake the review in consultation with NTG senior water policy advisors and technical experts in the field.

- Confirm with other stakeholders and technical experts in the field the magpie geese and ecological and endpoints identified *a priori* and, link them via "cause-effect" mechanisms to measurement endpoints (eg. extent of floodplain vegetation communities, extent of nesting & rearing floodplain habitats, nest and geese numbers & densities).

- Profile ecological risks to Daly River floodplain assets in greater detail, specifically risks to native wetland vegetation *per se* and magpie geese breeding habitat. Examine possible links to the condition of sustainable barramundi populations (eg. if floodplain act as major nursery habitats).

- Develop Bayesian habitat suitability models for both weeds and combine with existing spread rate models to spatially predict exposure and effects within identified time frames. Use the spatial model to highlight ecological risks to floodplain vegetation and wildlife habitat by encompassing current distribution, habitat preferences of both weeds, distance to source and potential invasion pathways.

- Develop a Bayesian Network using empirical data and expert opinion to assess different control scenarios via “what if” simulations. Use existing bioeconomic sub-models (control-cost functions) in the BN to asses the benefits and costs of different weed control scenarios.

6. Communication and consultation

6.1 Establish contact with agencies, boards and representative panels in WA, Qld & NT to notify of the commencement of the project, reiterate its objectives and links to the other two sub-projects, and seek collaboration and support and access to information.

6.2 Establish schedule and purpose for continued consultation, including ongoing exchange of information, collaboration and reporting and demonstrating initial analyses and outcomes.

NB – consultation tasks are embedded in all the tasks described for this sub-project

7. Reporting

7.1 Coordinated final draft risk assessment report.

Timeline for tasks

Task	04-05			05-06												06-07		
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1.1 Risk assessment framework	■	■	■															
2.1 Select focus catchments	■																	
2.2 Identify key stakeholders		■	■															
2.3 Identify key assets & threats			■	■														
2.4 Data acquisition		■	■	■	■	■						■						
2.5 Compile new GIS layers/datasets			■	■	■	■	■											
2.6 Metadata & data quality			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3.1 Describe assets & threats			■	■	■	■	■											
3.2 Develop conceptual models			■	■	■	■	■											
3.3 Incorporate stakeholder feedback						■	■											
3.4 Agree on scope of risk analyses							■											
4.1 Semi-quant. effects analysis							■	■	■	■	■							
4.2 Semi-quant. exposure analysis							■	■	■	■	■							
4.3 Semi-quant. risk characterisation								■	■	■	■	■						
4.4 Describe application of outputs											■	■						
5.1 Select threat & reaffirm conceptual model												■						
Quantitative risk analyses													■	■	■	■	■	■
6.1 Initial consultation		■	■															
6.2 Ongoing communication and consultation				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
7.1 Reporting (interim and final milestones)			■							■								■
Risk assessment workshops	To be advised																	