Australian Government

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Supervising Scientist

internal report 474

Progress on the development of a conceptual model of contaminant pathways from Ranger uranium mine

R van Dam, CM Finlayson & P Bayliss

June 2004

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Registry File SG2004/0107

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Contents

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Background

This report combines three recent outputs associated with the following ARRTC (Alligator Rivers Region Technical Committee) Key Knowledge Need (KKN):

Develop a conceptual model of the ARR system (including the uranium mines) and reassess and quantify contaminant movement within the biophysical pathways.

Section 2 represents a Discussion Paper prepared for the 11th Meeting of ARRTC on 17-19 February 2003. This paper discusses the initial efforts to address the above KKN and places the issue of mining in the Alligator Rivers Region (ARR) within a landscape context, highlighting the multiple pressures acting on the region.

Section 3 represents a Discussion Paper prepared for the 13th Meeting of ARRTC on 15-16 March 2004. This paper provides further context and background of the above KKN and represents the progression of the associated tasks/activities introduced in the previous Discussion Paper (Section 2). It also outlines the proposed process to complete the activities associated with addressing the KKN.

Section 4 represents a PowerPoint presentation presented at the joint CSIRO and Land & Water Australia workshop on *Contaminants and Ecological Risk Assessment*, in Adelaide, 5-7 April 2004. The purpose of the presentation was to communicate the importance of conceptual models in risk assessment and to seek feedback and suggestions for improvement on the approach being adopted for the development of the conceptual model for contaminant pathways at Ranger.

When completed, it is envisaged that the conceptual model will provide a useful tool/ mechanism for operational risk management of environmental contaminants, knowledge management, communications, identification of information and research gaps and priority-setting.

Conceptual model of ecosystem processes and pathways for pollutant/propagule transport in the environment of the Alligator Rivers Region

Discussion paper for 11th Meeting of ARRTC, 17–19 February 2003

CM Finlayson & P Bayliss

Background

1. A discussion and diagrammatic, conceptual model showing pathways and ecological linkages between uranium mining activities and the biophysical environment of the Alligator Rivers Region (ARR) is presented. The model is presented as two separate components (figures 1 and 2) with notes on each component. Readily available and discrete sources of information are indicated as examples of the extent of available data. It is noted that much more information is available. It is also evident that each component of the model could be developed further to outline the ecological processes that influence the fate/effect of pollutants/propagules transported through any of the identified pathways.

2. The conceptual model is used as a guide for identifying the major pathways for transfer of pollutants/propagules between the mine-site(s) and surrounding environment in the ARR. The model can initially be used to identify the key components in the system and the linkages between them. It can also be used to identify the environmental pressures with likely ecological consequences and provide a basis for the development of stochastic models or decision trees. In this respect they can become more complex and linked with sophisticated analyses of environmental features and processes, such as landform mapping and landform evolution modelling. Landform mapping and evolution modelling have been done in the ARR (figures 3 and 4) but not explicitly linked with each other or to a broader ecological model.

Mining and the biophysical environment of the ARR

3. The ARR is considered to include the catchments of the West Alligator, South Alligator and East Alligator rivers with parts of the Wildman (in the west), Mary (in the south-west), Katherine (in the south) and the Mann (in the east). The ARR is defined legally according to the map shown in the Fox report (subsequently amended by Gazettal to include Gimbat & Goodparla leases) and includes Kakadu National Park. A recent analysis (unpublished) using 1:250 000 topographical maps has shown that the boundaries of the ARR and KNP shown in the Fox report do not correspond to the river catchments as generally thought; part of the South Alligator catchment is excluded and parts of the Wildman, Mary and Katherine catchments are included as the boundary in the

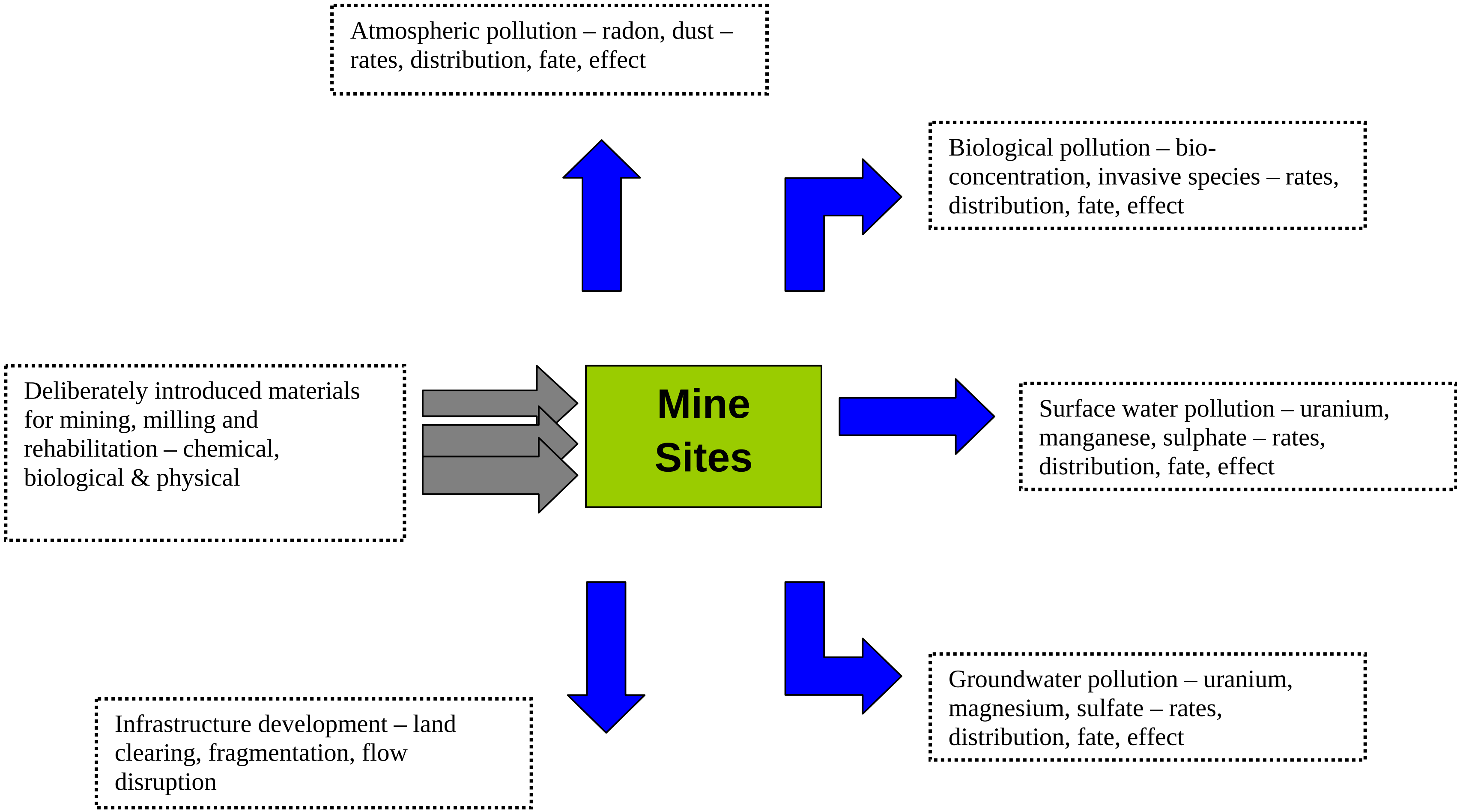

Figure 1 Conceptual model of pathways for pollutant/propagule transport in the environment of the Alligator Rivers Region

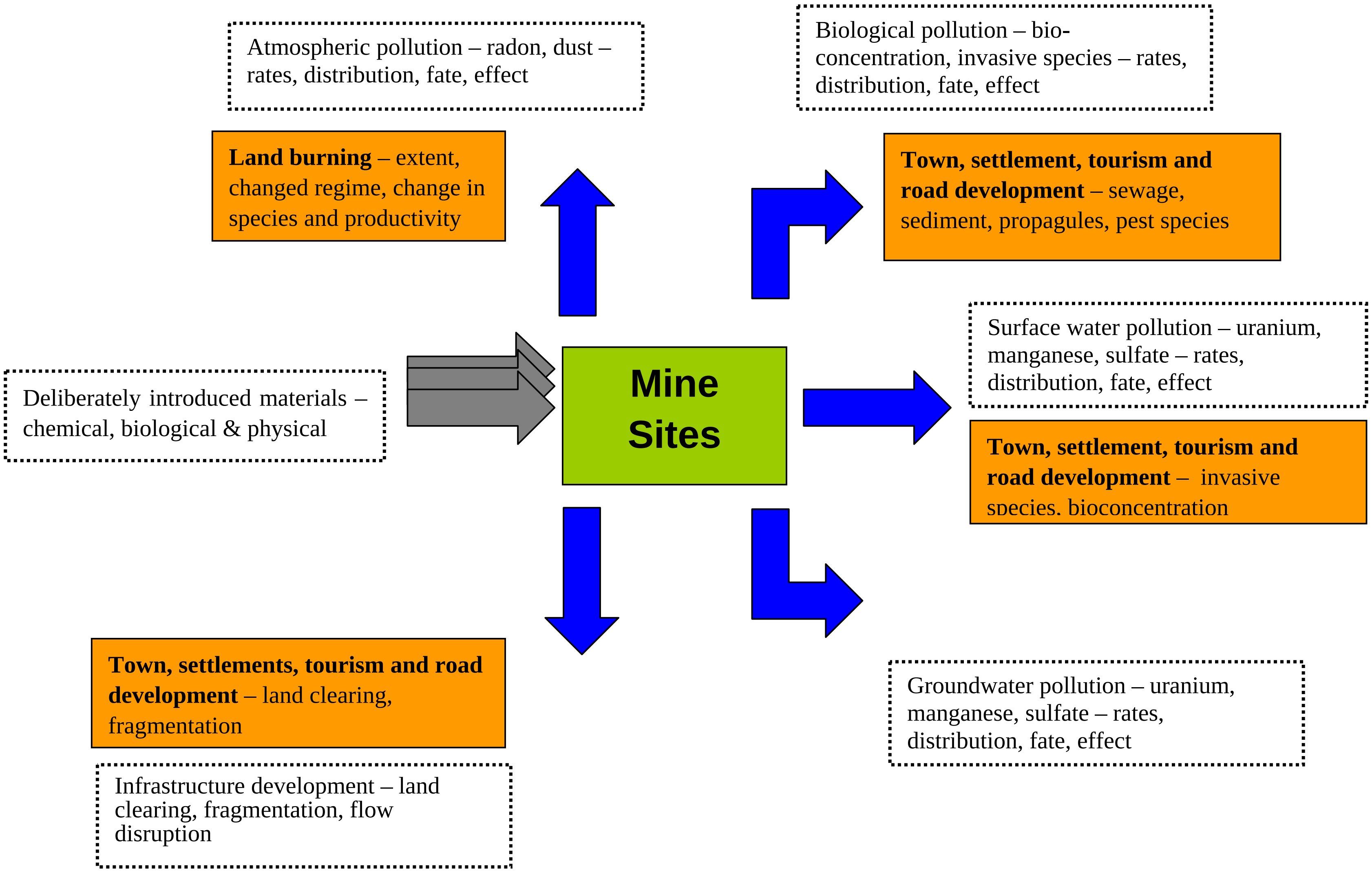

Figure 2 Multiple pressures interacting with transport pathways conceptual model

west-south of the ARR follows former pastoral lease boundaries and not the catchment boundaries; the exclusion of part of the East Alligator catchment and the inclusion of part of the Mann catchment are thought to have occurred as a result of inaccuracies in transcribing the boundary from whatever data source was used. A report is under preparation.

4. The major landforms of the ARR have been mapped at a scale of 1:250 000 and presented by Lowry & Knox 2002. A poster has been published and presented to ARRTC and other interested parties. More detailed mapping at 1:50 000 scale within a GIS platform is planned for the Magela floodplain and the creeks that pass the Ranger and Jabiluka mine-sites. This was supported at ARRTC10 as part of the Landscape Analyses. The physical landscape of the ARR has been described by a number of authors. East (1996) has provided a summary of this information.

5. Mining-related activities have occurred at a number of sites in the ARR. Those of most interest in the context of this conceptual modeling exercise are Ranger and Jabiluka. Others include Nabarlek where rehabiltation has occurred and is currently being assessed; Koongarra where mining has not yet occurred; and the South Alligator valley where rehabilitation is again being conducted and monitored. Baseline environmental analyses have not generally included Koongarra since initial descriptions were undertaken in the early-1980s, although some more recent information has been collected through the use of ‘extra-catchment’ controls for stream biological monitoring. Radiation anomalies in the Magela catchment are being mapped and assessed as part of the Landscape Analyses.

6. The main components of the conceptual model for mining-sites include: input of chemical, biological and physical materials, taking into account past and current site and landscape practice; output of chemical, biological or physical materials through atmospheric (radon, dust, propagules), surface water (uranium, magnesium, sulfate, sediment, biota and propagules) and ground water (uranium, manganese, sulfate) pathways. In some instances the concentrations, loads, deposition/transport features of these materials have been or are being investigated (eg radionuclide transport, pollutants borne by surface-water); the effect of some pollutants on the biota has been or is being tested (see also separate paper submitted to ARRTC11 on eco-toxicological testing); the establishment of invasive biota on the mine-sites or spread from the mine-sites to the surrounding environment (or vice versa) has received little attention; and the effect of infrastructure development and fragmentation of habitats has not been addressed.

7. The role of mining-related activities and structures in the spread of invasive species has not been widely investigated, nor has the effect of habitat fragmentation. Invasive species and habitat fragmentation are now recognized as major disturbance factors in many landscapes/ecosystems and could have a longer adverse environmental legacy than the physico-chemical parameters that have been more intensively investigated and regulated.

8. Each component of the conceptual model could be further developed with the addition of information on the factors that influence the transport and fate of pollutants, whether chemical or physical substances, and species propagules. This could entail more detailed pathway analyses with spatial and temporal considerations of the ecological processes that influence both the fate of the particular substance and its effect on the biota. Biological invasion is included within the conceptual model given the greater recognition that development activities within the ARR have provided highly attractive habitats for invasive species and provide sources of propagules for direct or indirect further distribution. A conceptual model based on life-history features of plant species has

previously been used for assessing possible invasion of rehabilitated structures (Cowie & Finlayson 1987) and wetlands in the ARR (Finlayson 1993).

Cumulative and synergistic effects on the environment of the ARR

9. The environment of the ARR is under pressure from a number of separate and inter-related pressures in addition to mining-related activities, including invasive plants and animals, infrastructure development, including settlements and tourism facilities, deterioration of infrastructure, fire and changed fire regimes, waste products, saline intrusion, and climate change. ARRTC10 supported proposals to investigate these pressures in as far as they contributed to further assessment of the effect of mining-related activities on the environment (see separate paper submitted to ARRTC11 reporting on progress of Landscape Analyses).

10. These pressures add a further layer of complexity to the conceptual model, as shown in figure 2. On the whole the extent of cumulative or synergistic effects from multiple pressures has not been investigated. Nor has the relative importance of individual or cumulative pressures on the ARR environment been quantified. Note that the Landscape Analyses are planned to only assess the inter-relationship between mining and other pressures. ERA is understood to have undertaken some comparative analyses of different pressures in the ARR during the 1990s.

11. The pressures shown in figure 2 will to some extent be considered within the Landscape Analyses. These analyses will also include an assessment of the effect of climate change and sea level rise on the environment of the ARR, building on past investigations (Bayliss et al 1997; Eliot et al 1999) and supplemented with more recent analyses of mangrove change (Lucas et al 2002). In assessing these analyses it is noted that environmental management is increasingly being undertaken within a ‘whole ecosystem’ framework. This is exemplified by the guidelines adopted by the Convention on Biological Diversity and supported through a formal Joint Workplan with the Ramsar Wetland Convention. The whole ecosystem concepts have been incorporated into the Landscape Analyses that also make use of the integrated wetland inventory, assessment and monitoring system promoted by the Ramsar Convention. Further, maintenance of the ecological character of internationally important wetlands requires maintenance of the biological, chemical and physical components of the wetland (generally considered as comprising the biodiversity) as well as the ecological processes that support these components and provide a basis for ecosystem services derived from the wetland. The latter have not been assessed within the ARR.

12. A key component of these concepts is the inclusion of people – that is social and cultural issues are not treated as an add-on to the ecological issues. The Ramsar Convention went one step further in 2002 and openly stated that ‘ecology’ would be considered to include ‘human ecology’ and hence the cultural and socio-economic interactions with the biophysical components of the environment. The World Heritage Convention separates natural and cultural heritage while encouraging listing of cultural landscapes. In this respect issues of human health and wellbeing are considered alongside ecological investigations and maintenance of the biological diversity (genetic, species and ecosystem components) of any particular ecosystem.

13. Within the ARR environmental programs have considered human health with a focus on protecting people from radionuclides transported by atmospheric and water pathways. Such investigations and analyses have not on the whole been integrated with ecosystem analyses, although initial steps have been taken to change this situation (van Dam et al 2002). Social impact monitoring is being addressed through different processes.

14. Maintenance of the natural World Heritage values, as they pertain to pressure from mining-related activities, underpins the Landscape Analyses being undertaken by ***eriss***. It is noted that on occasions it has been expressed that the formally recorded World Heritage values may not reflect the natural values afforded to KNP by indigenous landowners. Maintenance of the Ramsar Wetland values that are generally expressed in a more quantitative manner is similarly addressed.

Information sources and further tasks

15. Information on the fate of pollutants has been reported in many separate reports and the like. The ARR information catalogue being developed by SSD should list all such published material. This material can be supplied as required. It is anticipated that ARRTC will provide guidance on priority emphases within the conceptual model(s) and hence provide a basis for assessing the adequacy or otherwise of the available information. Several published papers on water borne materials (Hart et al 1987, Johnston et al 1997, Martin 1999, 2000, Finlayson 1991, 1994) are listed as examples of the type of analyses hitherto undertaken, and also illustrate the difficulties in making assessments due to natural variability and sampling error/bias. The latter are key factors that need to be considered when making decisions on the value/extent of all data sources – what data will suffice for the purpose noting the risk (extent and effect) of environmental degradation and the costs of obtaining data in relation to other needs.

16. It is perhaps unnecessary to emphasise that most information exists for that component of the Magela creek and floodplain in the vicinity of the Ranger mine-site. Little information is available, even as a baseline, for the Koongarra site. Various risk assessments already proposed for the Magela will identify relative and cumulative effects from other pressures and also assess the extent and usefulness of existing data sources.

17. Analysis of and further development of the conceptual model will also require information and knowledge collected by different organizations and individuals over the past 3 decades approx. This can include incorporation of digital elevation models, such as that for the Magela floodplain, as well as 3-d landform modeling such as that undertaken for rehabilitation planning at the Ranger mine site (Figs 3 & 4). To ensure that a whole ecosystem approach is implemented knowledge from traditional owners and long-term residents of the region will be required. Obtaining the latter has proved contentious in many instances elsewhere (eg Carbonnel et al 2001) but could be addressed with input from the most relevant organizations and individuals, noting recent guidelines on science and traditional knowledge (ICSU 2002) and involving local communities and indigenous people in wetland management (Ramsar Convention), and building on past experience within ***eriss*** (Finlayson & Eliot 2001).

18. On the whole the above concepts provide a static picture of the environmental issues within the ARR and in particular those most relevant to mining-related activities. It is proposed that in developing the conceptual approach that consideration is given to dividing the analysis of key issues into three sections, namely, condition and trend, scenarios, and responses. This would include information on past environmental decisions and outcomes, current operations and rehabilitation, possibly within agreed time-lines and bounds.

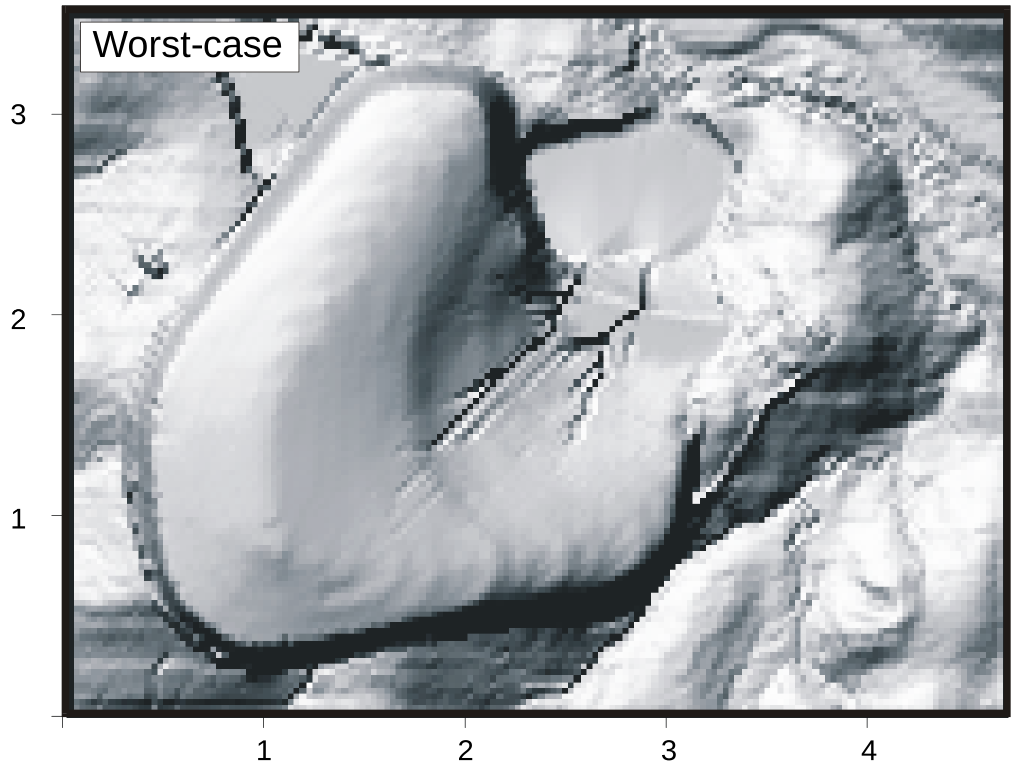

Figure 3 An example of a landscape evolution model of a hypothetical post-rehabilitation landform in the ARR

19. It is also proposed that a more ambitious outcome is built into such analyses. Namely, the development of a GIS-based relational database that can be used to store and present information from nominated sampling points (localities), and provide a platform for the development of relevant ecological models based on the risk assessments underway and proposed. Thus, steps to develop the conceptual model should not be taken independently of developments with GIS and database technology and the eventual production of quantitative risk assessments of major pressures associated with mining-related activities in the ARR. Note that separate papers on the development of risk assessments and GIS/remote sensing technology within ***eriss*** have been submitted to ARRTC11.

20. In considering the abovementioned conceptual model and extensions into more quantitative formats it is essential that previously conducted analyses of 'pathways' are reassessed (and where necessary published) and further information needs identified. This will require access to vast amounts of information; the information sources can be catalogued in the ARR library database being compiled under the Landscape Analyses. It will also require further collaboration between organizations within the region and assistance with sampling and access to sampling sites etc. Importantly, if the conceptual model and associated analyses are to be conducted within a whole ecosystem scenario relevant information from traditional land owners and other residents in the ARR is required, noting that much of this may not be readily accessible or recorded in written formats. Providing a cultural layer to the analyses may require expertise beyond that currently available within ***eriss***.

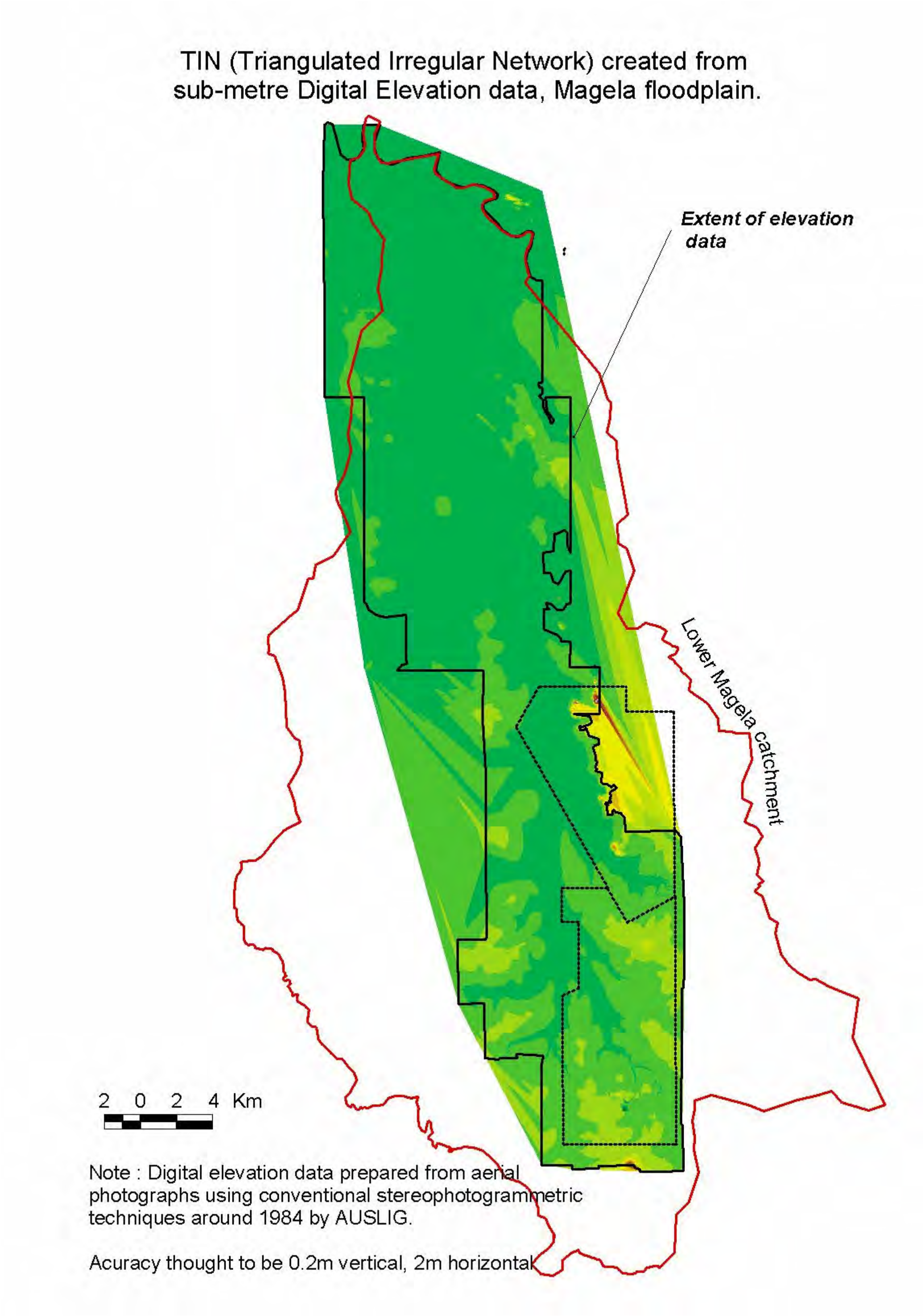

Figure 4 Digital elevation model for the Magela floodplain prepared from remotely sensed data around 1984. See also Bayliss et al 1887

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Progress report on the development of a conceptual model of contaminant pathways for uranium mining activities in the ARR

Discussion paper for 13th Meeting of ARRTC, 15–16 March 2004

R van Dam

Outcome of 10th Meeting of ARRTC (9–10 September 2002):

ARRTC would like to see a conceptual model of the system developed, with transport pathways clearly shown and best estimates of the loads/fluxes of contaminants shown.

ARRTC Key Knowledge Need:

Develop a conceptual model of the ARR system (including the uranium mines) and reassess and quantify contaminant movement within the biophysical pathways

Background

1. In response to an outcome of the 10th meeting of ARRTC and one of the Key Knowledge Needs identified by the seven independent science members of ARRTC (see above), ***eriss*** prepared a Discussion Paper for the 11th meeting, titled *Conceptual model of ecosystem processes and pathways for pollutant/propagule transport in the environment of the Alligator Rivers Region* (Finlayson & Bayliss 2003). The paper introduced a draft conceptual model that identified the major chemical, biological and physical inputs and outputs and broadly identified the major pathways (figure 1). It also acknowledged the potential risks to the ARR from mining in the context of the numerous non-mining related pressures (eg. invasive species, climate change, tourism, fire and altered fire regimes, etc.), thus, identifying the need to place uranium mining and milling operations in the ARR in a landscape scale context.

2. This Discussion Paper presents some additional background to the development and use of contaminant pathway conceptual models for uranium mining activities in the ARR and the progress on the further development and refinement of the mining-related component of the draft conceptual model of Finlayson & Bayliss (2003). In particular, it focuses on the elaboration and population of the model sub-components. This paper is closely linked to, but does not detail the parallel development of the conceptual model of the ARR system (see Landscape projects Discussion Paper).

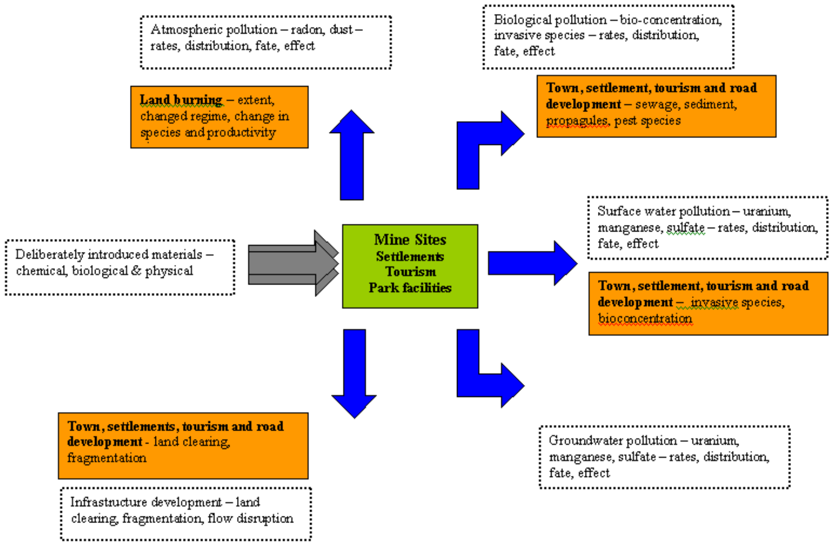

Figure 1 The draft conceptual model of Finlayson & Bayliss (2003) incorporating mining and non-mining activities in the ARR

Historical conceptual modelling of contaminant pathways for uranium mining and milling in the ARR

3. One of the early tasks of the Supervising Scientist was to assemble a group of relevant experts/scientists to consider and agree upon key mining-related issues in the Alligator Rivers Region (ARR) and to use this information to advise on research priorities and programs that should be initiated. Workshops were held in 1978 and 1980 to address these tasks, and covered varied fields of study including aquatic biology/limnology, water quality, groundwater/hydrogeochemistry, surface hydrology, aquatic toxicology, soils and metals (erosion and metal transport), terrestrial biology, radiation protection and monitoring, radiochemical analysis and air quality monitoring/airborne contamination/atmospheric dispersion (Supervising Scientist 1982).

4. Even in these early days, the general approach of ensuring acceptable environmental impact from uranium mining was framed within a risk analysis context, specifically, the following four components:

    - risk/hazard identification;
    - risk estimation;
    - risk evaluation; and
    - risk control.

    Some of the key activities associated with the first component of this process included:

    - separation of mining and non-mining factors;
    - identification of sources and sub-sources of contaminants;
    - characterisation of contaminant material;
    - identification of transport pathways for contaminants into the environment; and
    - identification of susceptible populations.

5. Through this process, several conceptual models of possible pathways of contaminants and radionuclides from a mining/milling operation for the ARR were developed (see Supervising Scientist 1982, Johnston & Murray 1983). One of these is shown in figure 2, and, although having an ultimate focus on humans as the receptor, still has relevance to the non-human biotic components of the ecosystem. The model compartmentalises the mining/milling process into four components (mine water, mill water tailings, retention ponds, tailings dam) and from these depicts connective pathways and interactions that must be considered to establish the rate at which exposure might occur as a result of mining (Supervising Scientist 1982).

6. As another example, a simplified conceptual model of the primary pathways for radionuclide exposure to humans from uranium mining and milling operations was developed more recently by Martin (2000) (figure 3).

7. The key message here, is that the conceptual model currently being developed is by no means the first, and, at the broad planning level, the development and review of the research program of the Supervising Scientist has always been underpinned by a good conceptual understanding of the various contaminant pathways.

8. Nevertheless, with the emergence of new issues, the development of new and/or improved approaches/technologies for assessing existing issues and the recognised need to periodically 'validate' research priorities and programs, there exists great value in the undertaking of periodical, iterative conceptual modelling processes.

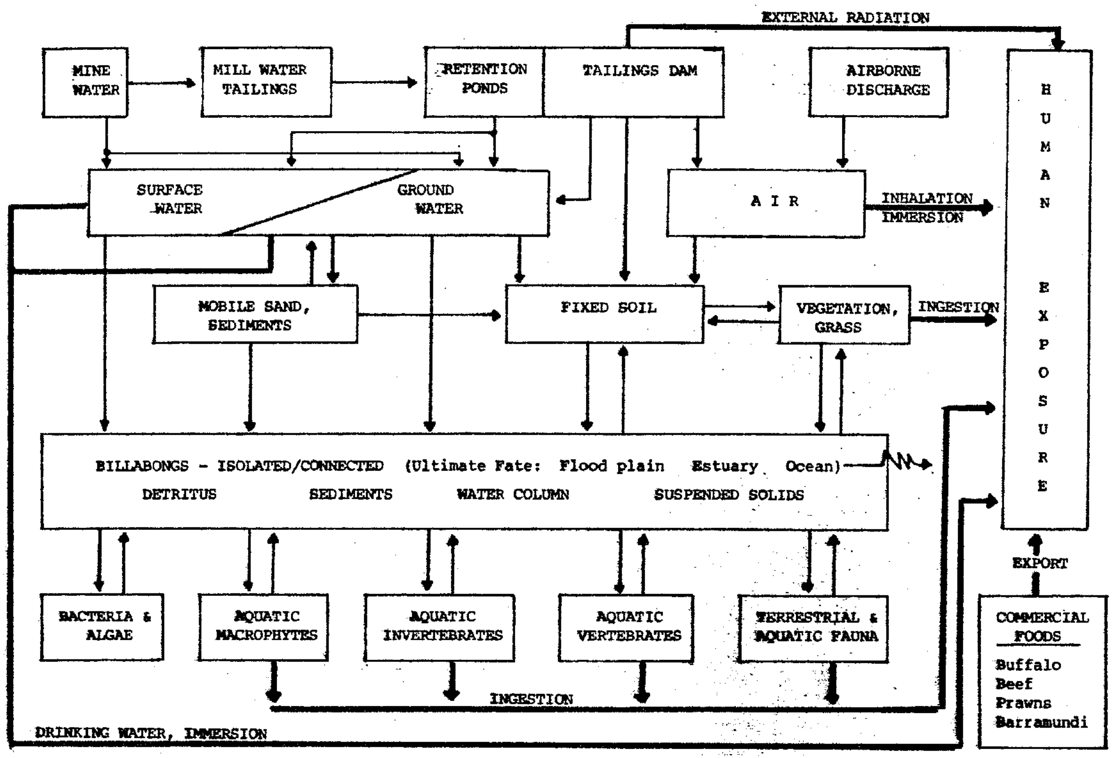

Figure 2 1982 conceptual model of pathways of waterborne contaminants from a mining and milling operation in the ARR (Supervising Scientist 1982)

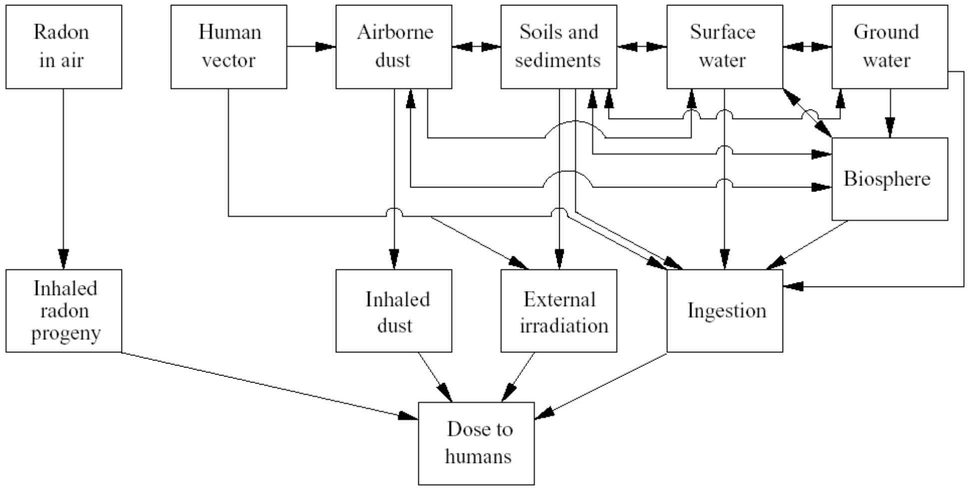

Figure 3 2000 conceptual model of the primary pathways leading to radionuclide dose to humans from a uranium mining and milling operation in the ARR (Martin 2000)

Progress on the development of a new contaminant pathways conceptual model

9. Following discussion and agreement among ***eriss*** senior scientists, the scope of the conceptual model was agreed as follows:

    - Focus on contaminant pathways specifically from Ranger; and
    - Focus on the operational phase of mining with development of a model for the closure/post-rehabilitation phase to follow.

    As stated above, the development of the conceptual model of the ARR is a linked but separate task that is also underway (see Landscape projects Discussion Paper).

10. Rather than simply revising or updating the early conceptual models, it was considered more appropriate to construct a new model in its entirety (using the draft model of Finlayson & Bayliss (2003) as a base), then cross-check it with historical versions for final refinement.

11. The initial information gathering exercise involved the identification by ***eriss*** senior scientists of the relevant details within the following model elements:

    - *stressors (chemical, physico-chemical, radiological, biological)*;

    and then for each stressor, its:

    - *sources*;
    - *transport/exposure pathways off-site*;
    - *exposure media/affected environmental compartments*;
    - *receptors*;
    - *routes of exposure*;
    - *types of effect*; and
    - *measures of effect*.

The resultant information is shown in table 1.

Table 1 Detailed information for development of a conceptual model of contaminant release during operational phase of Ranger Uranium Mine (RUM)

Stressor [1]	Uranium	Magnesium sulfate	Manganese
Sources of stressors	All on-site water bodies at RUM: process water (tailings dam, Pit #1and tailings corridor), pond water (RP2, Pit #3 and RP1 wetland filter), sediment control water (RP1, Corridor Creek constructed wetlands, Djalkmara Billabong and the RP1 constructed wetland), spray irrigation water (treated pond water)		
Transport/exposure pathways off site	Controlled release of sediment control water from Djalkmara B'bong, and semi-controlled release of sediment control water from RP1 and Corridor Creek constructed wetlands to Magela Ck (or associated back-flow billabongs) surface water Spray irrigation to land and ultimately groundwater of treated RP2 water following passage through wetland filters and untreated RP2 water Water seepage from on-site waterbodies (eg. tailings dam, Pit #3) into groundwater and potential expression in surface waters (ie. of Magela and Gulungul Creeks) Trophic transfer to mobile species (eg. birds, reptiles) visiting on-site water bodies		
Exposure media/compartments	Soil, water, sediment, terrestrial plants, aquatic biota (animals and plants)		
Receptors	Aquatic biota (bacteria, algae, macrophytes, invertebrates, vertebrates), terrestrial biota (fauna and flora), humans		
Route of exposure	Ingestion, respiratory uptake, adsorption, absoprtion		
Potential ecological effects	Changes to aquatic biota community structure and function Changes to vegetation cover and community structure in spray irrigation area Impaired human health	Changes to aquatic biota community structure and function Changes to vegetation cover and community structure in spray irrigation area	Changes to aquatic biota community structure and function Changes to vegetation cover and community structure in spray irrigation area Impaired human health
Measures of effects	Lab and field aquatic toxicity testing (+ modelling based on species sensitivity distributions where possible) Field monitoring of surrogates of aquatic ecosystem health – ie. macroinvertebrates, fish Assessment of bioaccumulation in mussels and fish	Lab and field aquatic toxicity testing (+ modelling based on species sensitivity distributions where possible) Field monitoring of surrogates of aquatic ecosystem health – ie. macroinvertebrates, fish Assessment of bioaccumulation in mussels and fish	Lab and field aquatic toxicity testing (+ modelling based on species sensitivity distributions where possible) Field monitoring of surrogates of aquatic ecosystem health – ie. macroinvertebrates, fish Assessment of bioaccumulation in mussels and fish

Table 1 (cont.)

Stressor	**Ammonia** **(a future stressor)**	**Radionuclides** ***(Uranium-238, 234, 230; Thorium-230; Radium-226; Lead-210; Polonium-210)***	**Radon-222** ***(and its progeny)***
Sources of stressors	Pond and process water passed treated by the proposed water treatment plant (lime softening and reverse osmosis)	All on-site water bodies at RUM: process water (tailings dam, Pit #1and tailings corridor), pond water (RP2, Pit #3 and RP1 wetland filter), sediment control water (RP1, Corridor Creek constructed wetlands, Djalkmara Billabong and the RP1 constructed wetland), spray irrigation water (treated pond water), eroded materials (waste rock, etc.)	Ore stockpiles, waste rock, tailings, spray irrigation application areas, mill
Transport/exposure pathways off site	Through constructed Corridor Creek wetland filter into Magela Creek via Georgetown Billabong Through constructed RP1 wetland filter into Magela Creek via Coonjimba Billabong	Controlled release of sediment control water from Djalkmara B'bong, and semi-controlled release of sediment control water from RP1 and Corridor Creek constructed wetlands to Magela Ck (or associated back-flow billabongs) surface water Spray irrigation to land and ultimately groundwater of treated RP2 water following passage through wetland filters and untreated RP2 water Water seepage from on-site waterbodies (eg. tailings dam, Pit #3) into groundwater and potential expression in surface waters (ie. of Magela and Gulungul Creeks) Trophic transfer to mobile species (eg. birds, reptiles) visiting on-site water bodies Airborne dust from mine site	Exhalation from the ground and transport in the atmosphere
Exposure media/compartments	Water	Soil, water, sediment, terrestrial plants, aquatic biota (animals and plants)	Atmosphere
Receptors	Aquatic biota (bacteria, algae, macrophytes, invertebrates, vertebrates)	Humans, aquatic and terrestrial fauna	Humans
Route of exposure	respiratory uptake, absoprtion	Ingestion, inhalation, respiratory uptake	Inhalation of the progeny
Potential ecological effects	Changes to aquatic biota community structure and function	Radiological dose (increased risk of cancer)	Radiological dose (increased risk of cancer)
Measures of effects	Lab and field aquatic toxicity testing (+ modelling based on species sensitivity distributions where possible) Field monitoring of surrogates of aquatic ecosystem health – ie. macroinvertebrates, fish	Modelling based on measurements in the environment Modelling based on knowledge of exist fluxes	Modelling based on measurements in the environment Modelling based on knowledge of exist fluxes

Table 1 (cont.)

Stressor	Gamma dose	Suspended sediment *(silt + clay; <63 μm - >45 μm diameter)*	Weed propagules
Sources of stressors	Ore stockpiles, waste rock, tailings, spray irrigation application areas, mill	Disturbed and/or unvegetated areas of mine site/mine lease (eg. Fire impacted, infrastructure scars)	Whole of mine site/mine lease, but more likely along flow channels, pipelines and other infrastructure, including fence lines and roadways
Transport/exposure pathways off site	None	Controlled release of sediment control water from Djalkmara B'bong, and semi-controlled release of sediment control water from RP1 and Corridor Creek constructed wetlands to Magela Ck (or associated back-flow billabongs) surface water Stormwater run-off from mine lease into Gulungal Ck, Corridor Ck and Magela Ck surface waters	Surface water, air/wind, human (establishment off-site facilitated by disturbance to habitat, including from fire, erosion, feral animals, clearing etc.
Exposure media/compartments	Ground surface at the mine site	Water, sediment (in depositional areas – eg. floodplain)	Soil, sediment, water
Receptors	Humans	Aquatic biota (bacteria, algae, macrophytes, invertebrates, vertebrates)	Aquatic and terrestrial habitats
Route of exposure	Direct gamma radiation (external irradiation)	Direct contact with external biological surfaces (causing smothering, clogging etc.)	Direct invasion and replacement
Potential ecological effects	Radiological dose (increased risk of cancer)	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Measures of effects	Measurements of gamma dose rate and modelling based on occupancy	Laboratory effects studies Field monitoring of surrogates of aquatic ecosystem health – ie. macroinvertebrates, fish	Distribution mapping (spatial/temporal extent) Monitoring/survey of aquatic and/or terrestrial fauna and fauna community structure and function

[1] Additional stressors that have been identified and that are in the process of being added to the model include sewage and various chemicals used in the milling of uranium or elsewhere on-site (eg. sulphur, sulfuric acid, diesel, ammonium sulfate, herbicides).

12. In order to construct a model that is most useful and practical from both an environment protection and a mining environmental management perspective, the details in table 1 were re-ordered and in some cases modified or merged such that the contaminant sources and associated transport pathways off-site represented the top level of the model. The result is shown in table 2 and represents the progress to date of this project.

13. Thus, building on the draft conceptual model of Finlayson & Bayliss (2003), nine key transport pathways and at least 10 chemical, physico-chemical or biological key stressors or stressor groups (eg. weed propagules; chemicals transported onto site/produced on-site/used in milling process) have been identified. Within each transport pathway, the model has been further progressed through the identification of relevant exposure media/environmental compartments, routes of exposure and receptors for each stressor. In addition, we have outlined the potential ecological effects associated with each pathway/stressor combination, and provided an indication of how these responses are or could be measured/monitored.

Process from here

14. The model is still in draft form and requires further discussion, clarification and verification from SSD senior staff and external parties including ARRTC before being finalised. The final conceptual model will be presented in both graphic (ie. flow chart) and narrative form.

15. The relative status of research and associated information addressing the stressors and their behaviour and effects within the various transport pathways will be determined. This will include the review of bioaccumulation and trophic transfer information for aquatic and terrestrial pathways from the mine sites requested by ARRTC.

16. Where possible, the risks associated with each pathway/stressor will be quantified and compared. In undertaking such analyses of risks, information on the factors that influence the transport and fate of contaminants, whether chemical, physico-chemical or biological, will need to be incorporated. Analysis of the various sub-models should also enable an estimate of cumulative risk to the environment of uranium mining and milling operations, noting the potential additive, synergistic and antagonistic interactions.

17. Additionally, the conceptual model and associated analyses will serve to identify the information/research gaps and, as noted by ARRTC, priorities for future program planning.

18. The development of the conceptual model and its associated benefits in relation to understanding relative and cumulative risks to the environment from Ranger, identifying information gaps and assisting SSD's research program planning processes, is to be presented at an upcoming CSIRO/Land & Water Australia workshop on *Contaminants and Ecological Risk Assessment*, on 5-7 April. The Abstract for this presentation is provided at Appendix A. Feedback from this forum will also be used to refine the model.

19. Eventually, the Ranger contaminant pathways conceptual model will be incorporated as a sub-model into the landscape scale conceptual model of pressures to the ARR, which will enable an assessment of relative and cumulative risks of the various pressures to the ARR, or more specifically, the Magela Creek catchment.

20. As a last point, the completion of this conceptual model for the operational phase of Ranger will prompt the commencement of the development of a similar model that encompasses mine closure, rehabilitation and post-rehabilitation.

Table 2 Tabulated conceptual model of contaminant pathways for Ranger

Source & transport pathway [1]	Stressor	Exposure media/compartments	Routes of exposure	Receptors	Potential ecological effects
Controlled release of sediment control water from Djalkmara B'bong, and semi-controlled release of sediment control water from RP1 and Corridor Creek constructed wetlands to Magela Ck (or associated back-flow billabongs) surface water	U, $MgSO_4$, Mn, NH_3	Water, sediment, aquatic biota [2]	Ingestion, respiratory uptake, adsorption, absorption	Aquatic biota, humans	Changes to aquatic biota community structure and function Impaired human health
	radionuclides	Water, sediment, aquatic biota	Ingestion, inhalation, respiratory uptake	Aquatic biota, humans	Radiological dose (increased risk of cancer)
	Suspended sediment	Water	Direct contact with external biological surfaces (causing smothering, clogging etc.)	Aquatic biota	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
	Weed propagules	Water, sediment	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Water seepage from on-site waterbodies (eg. tailings dam, Pit #3) into groundwater and potential expression in surface waters (eg of Magela and Gulungul Creeks)	U, $MgSO_4$, Mn	Water, sediment, aquatic biota, soil	Ingestion, respiratory uptake, adsorption, absorption	Aquatic and terrestrial biota [3], humans	Changes to aquatic biota community structure and function Changes to vegetation cover and community structure Impaired human health
	radionuclides	Water, sediment, aquatic biota, soil	Ingestion, inhalation, respiratory uptake	Aquatic and terrestrial biota, humans	Radiological dose (increased risk of cancer)
Spray irrigation to land and ultimately groundwater of treated RP2 water following passage through wetland filters and untreated RP2 water	U, $MgSO_4$, Mn	Soil, water, sediment, aquatic and terrestrial biota	Ingestion, respiratory uptake, adsorption, absorption	Aquatic and terrestrial biota, humans	Changes to aquatic biota community structure and function Changes to vegetation cover and community structure in spray irrigation area Impaired human health
	radionuclides	Soil, water, sediment, aquatic and terrestrial biota	Ingestion, inhalation, respiratory uptake	Aquatic and terrestrial biota, humans	Radiological dose (increased risk of cancer)
	Weed propagules	Soil	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Trophic transfer to mobile species (eg. birds, reptiles, frogs, aquatic insects) visiting on-site water bodies	U, Mn	Aquatic/semi-aquatic/terrestrial fauna	Ingestion	Higher order terrestrial and aquatic biota, humans	Effects on individuals of higher order terrestrial and aquatic biota possibly leading to population level effects, impaired human health
	radionuclides	Aquatic/semi-aquatic/terrestrial fauna	Ingestion	Higher order terrestrial and aquatic biota, humans	Radiological dose (increased risk of cancer)
Atmospheric dispersion	radionuclides	Atmosphere, soil	Ingestion, inhalation	Humans, terrestrial biota	Radiological dose (increased risk of cancer)
	Weed propagules	Soil, sediment, water	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
	Chemicals transported onto site/produced on-site/used in milling process	Atmosphere, soil, water, sediment, terrestrial and aquatic biota	Ingestion, respiratory uptake, adsorption, absorption, inhalation	Terrestrial and aquatic biota, humans	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Exhalation from mine site ground (and transport in the atmosphere)	Radon-222 (and its progeny)	Atmosphere	inhalation	Humans	Radiological dose (increased risk of cancer)
Stormwater runoff from non-mine site areas of mine lease	Suspended sediment	Water, sediment (in depositional zones)	Direct contact with external biological surfaces (causing smothering, clogging etc.)	Aquatic biota	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Human carriage	radionuclides	humans	Ingestion, inhalation	Humans	Radiological dose (increased risk of cancer)
	Weed propagules	Soil, sediment, water	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Spillage/Leakage into surface waters	Chemicals transported onto site/produced on-site/used in milling process	Water, sediment, aquatic biota	Ingestion, respiratory uptake, adsorption, absorption	Aquatic biota, humans	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)

1 Gamma dose has not been included, because there is no pathway off-site. 2 Aquatic biota broadly represent aquatic bacteria, algae, macrophytes, inverebrates, vertebrates 3 Same as above for terrestrial biota

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Appendix A Abstract of presentation for Workshop on *Contaminants and Ecological Risk Assessment*, Adelaide, 5–7 April, 2004

The multiple benefits of conceptual models: Ranger uranium mine as an example

R van Dam, M Finlayson, P Bayliss, C Humphrey, P Martin & K Evans

This paper considers the importance of conceptual models for ecological risk assessment in the context of contaminant emissions from the Ranger Uranium Mine in the Alligator Rivers Region (ARR), northern Australia, a Ramsar and World Heritage listed area where the mining and milling of uranium has occurred for over 20 years.

Identifying the environmental priorities associated with uranium mining at Ranger commenced some 30 years ago. In the late 1970s and early 1980s a process of expert and stakeholder discussions and workshops led to further clarification of the environmental concerns. As early as 1982, the approach to the problem of ensuring acceptable environmental impact from uranium mining was framed within a risk analysis context. This included the development of conceptual models describing various contaminant-related processes including loss points, pathways and ecological interactions. This collective knowledge was used to determine research and monitoring priorities, the majority of which focused correctly on the aquatic environment.

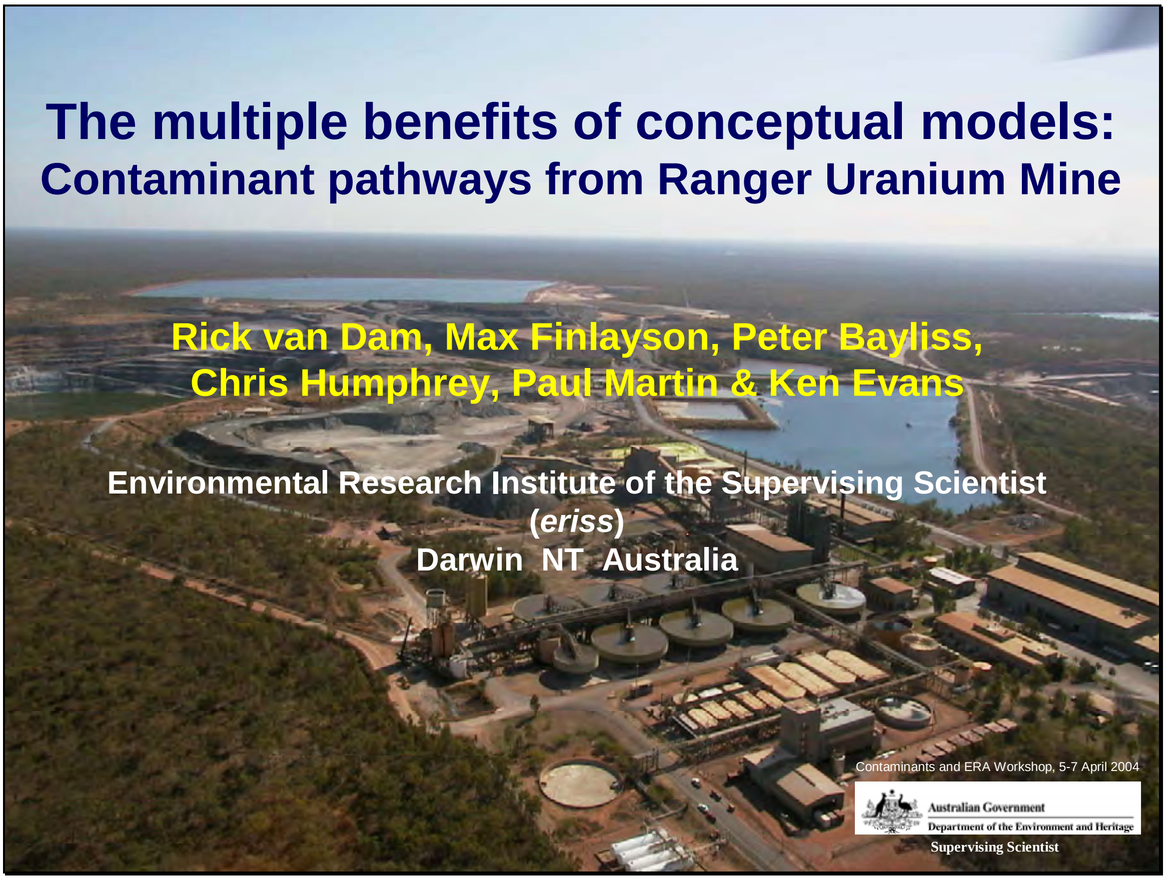
More recently, and following intense scientific scrutiny of the measures in place to protect the ARR from the potential adverse effects of uranium mining, it was recommended by two independent scientific panels that a conceptual model and associated sub-models of contaminant emissions from Ranger be re-articulated, primarily to incorporate new issues and data and to provide assurance that the major issues had been, or were being, addressed. Further, it was imperative that the Ranger model be placed in the context of a landscape-wide conceptual model of existing and future threats to the ARR.

Rather than revising the early conceptual models, a new model was constructed in its entirety, then cross-checked with existing versions for final refinement. Specific components were identified for the following model elements: *source*, *stressor (chemical, physico-chemical, radiological, biological)*, *transport/exposure pathway*, *affected environmental compartment*, *receptor*, *route of exposure*, *type of effect* and *measure of effect*. Links and inter-relationships between the elements and their components were then defined and articulated. The final model was peer-reviewed.

The development of a new conceptual model has enabled the iteration and integration of previous models through the incorporation of new knowledge and understanding of the relevant processes and issues. This, in turn, has provided the ability to look back, identify gaps, compare risks already quantified, begin to quantify cumulative risks, determine priorities and look ahead, all within a risk management framework that accounts for uncertainty in the data and knowledge, and links clearly to the ongoing management of mining operations.

Keywords: Alligator Rivers Region, Ranger Uranium Mine, contaminants, ecological risk assessment, conceptual model

Presentation at CSIRO Contaminants and Ecological Risk Assessment Workshop, 5–7 April 2004



Preface

Northern Territory News, 25 March 2004

Uranium found in drinking water

Twelve workers fall ill

By EDITH BEVIN

Twelve workers complained of nausea and headaches yesterday after drinking water contaminated with uranium and acid.

The workers were sent home after reporting for the morning shift at Ranger mine, 220km east of Darwin.

The mine was evacuated and could stay closed until the end of this week.

It is not known how long the contaminated water had been leaking into the drinking water supply. The water is used by the mine, airport and businesses in the nearby town of Jabiru.

The town water supply was not affected.

"We still haven't been officially told what's happened," one worker said yesterday afternoon.

Continued: Page 2

Northern Territory News, 27 March 2004

Uranium alert in wetlands

Fear Kakadu water tainted

By REBECCA HEWETT

Scientists fear water contaminated with uranium will get into Kakadu's wetlands after an accident at a mine.

About 100 cubic litres of processing water — carrying four times the acceptable level of uranium — has spilled from a holding tank near the airport at Jabiru, 220km east of Darwin.

The Office of the Supervising Scientist — the federal agency

Overview

- Background
  - Risk assessment & conceptual models
  - Ranger Uranium Mine
- History of problem definition for Ranger
- A new conceptual model
- Risk analysis
- A landscape perspective

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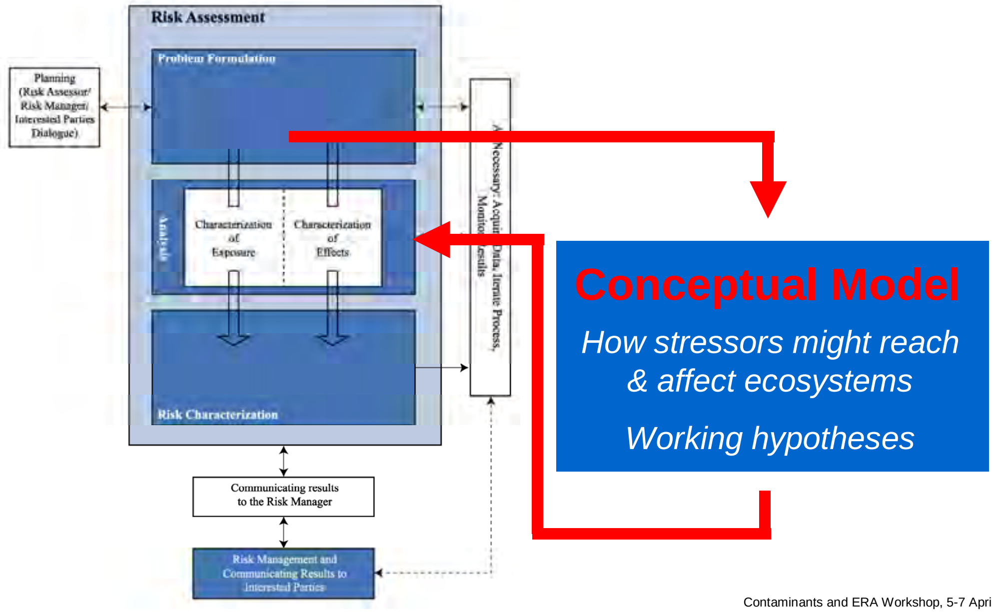
Risk assessment & conceptual models



modified from US EPA (1998)

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Risk assessment & conceptual models

“Everything is contingent on the premise that risk assessment has been guided at the outset by good conceptual models”

Burgman (in press)

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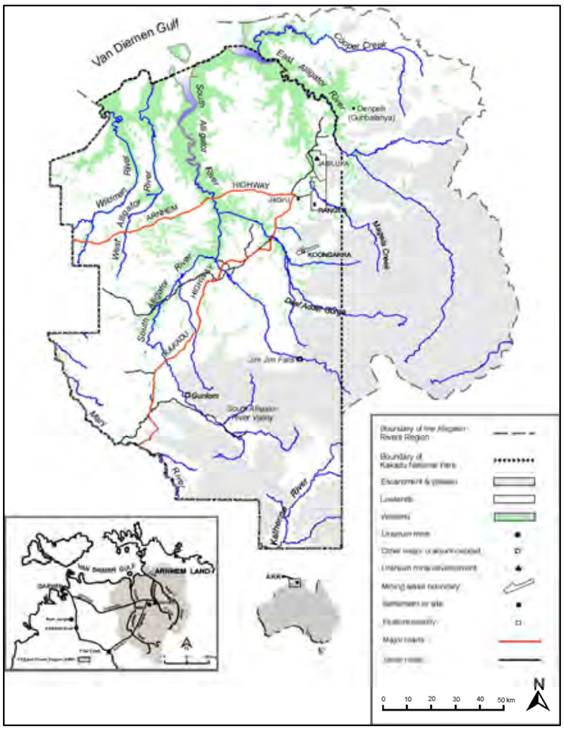
Ranger Uranium Mine

- Wet-dry tropical climate
  → *~1500 mm/yr; Nov-Mar*
- Surrounded by Kakadu National Park
  → *World Heritage & Ramsar listed*

- Mining commenced 1981 and is scheduled for closure/rehab 2011

- Office of the Supervising Scientist (OSS) est. 1977-78 to ensure protection of the off-site environment



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History of problem definition

1982 – A risk analysis context

- Risk/hazard identification
- Risk estimation
- Risk evaluation
- Risk control

→ Separation of mining and non-mining factors

→ Identification of sources and sub-sources of contaminants

→ Characterisation of contaminant material

→ Identification of transport pathways for contaminants into the environment

→ Identification of susceptible populations

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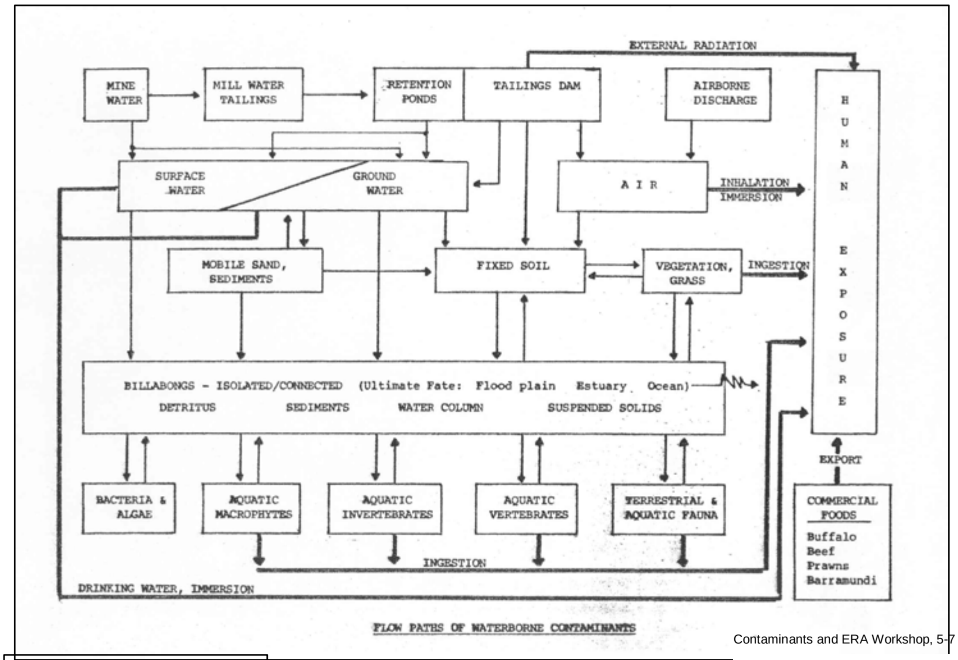
History of problem definition

Pathways of contaminants from mining and milling in the ARR - 1982



Supervising Scientist (1982)

History of problem definition

Key message

Development of Supervising Scientist research and monitoring programs underpinned by sound conceptual understanding of the issue(s)

A new conceptual model

Drivers

- WHC Independent Science Panel – 1998
- Alligator Rivers Region Technical Committee (ARRTC) – 2002

Value

- Identification/incorporation of new/emerging issues
- Validation of research priorities and programs
- Identification of information/research gaps
- Communication and knowledge management tool

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A new conceptual model

Scope

- Contaminant pathways from Ranger
- Operational phase only (closure/rehab model will follow)
- Off-site impacts

Model development

- Panel of experts (internal)
- Collated & agreed on information for:

Stressors	*Receptors*
Sources	*Routes of exposure*
Transport pathways	*Potential ecological effects*
Exposure media	*Measures of effects*

- Stakeholder consultation and external review (current and planned)

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Source & transport pathway	Stressor	Exposure media	Routes of exposure	Receptors	Potential ecological effects
Controlled release of sediment control water from Djalkmara B'bong, and semi-controlled release of sediment control water from RP1 and Corridor Creek constructed wetlands to Magela Ck (or associated back-flow billabongs) surface water	U, $MgSO_4$, Mn, NH_3	Water, sediment, aquatic biota	Ingestion, respiratory uptake, adsorption, absorption	Aquatic biota, humans	Changes to aquatic biota community structure and function Impaired human health
	radionuclides	Water, sediment, aquatic biota	Ingestion, inhalation, respiratory uptake	Aquatic biota, humans	Radiological dose (increased risk of cancer)
	Suspended sediment	Water	Direct contact with external biological surfaces (causing smothering, clogging etc.)	Aquatic biota	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
	Weed propagules	Water, sediment	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Water seepage from on-site waterbodies (eg. Pit #1, #3) into g'water and potential expression in s' waters (eg. of Magela and Gulungul Cks)	U, $MgSO_4$, Mn	Water, sediment, aquatic biota, soil	Ingestion, respiratory uptake, adsorption, absorption	Aquatic and terrestrial biota, humans	Changes to aquatic biota community structure and function Changes to vegetation cover and community structure Impaired human health
	radionuclides	Water, sediment, aquatic biota, soil	Ingestion, inhalation, respiratory uptake	Aquatic and terrestrial biota, humans	Radiological dose (increased risk of cancer)
Spray irrigation to land and ultimately groundwater of treated RP2 water following passage through wetland filters and untreated RP2 water	U, $MgSO_4$, Mn	Soil, water, sediment, aquatic and terrestrial biota	Ingestion, respiratory uptake, adsorption, absorption	Aquatic and terrestrial biota, humans	Changes to aquatic biota community structure and function Changes to vegetation cover and community structure in spray irrigation area Impaired human health
	radionuclides	Soil, water, sediment, aquatic and terrestrial biota	Ingestion, inhalation, respiratory uptake	Aquatic and terrestrial biota, humans	Radiological dose (increased risk of cancer)
	Weed propagules	Soil	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Trophic transfer to mobile species (eg. birds, reptiles, frogs, aquatic insects) visiting on-site water bodies	U, Mn	Aquatic/semi-aquatic/terrestrial fauna	Ingestion	Higher order terrestrial and aquatic biota, humans	Effects on individuals of higher order terrestrial and aquatic biota possibly leading to population level effects, impaired human health
	radionuclides	Aquatic/semi-aquatic/terrestrial fauna	Ingestion	Higher order terrestrial and aquatic biota, humans	Radiological dose (increased risk of cancer)
Atmospheric dispersion	radionuclides	Atmosphere, soil	Ingestion, inhalation	Humans, terrestrial biota	Radiological dose (increased risk of cancer)
	Weed propagules	Soil, sediment, water	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
	Chemicals transported onto site/produced on-site/used in milling process	Atmosphere, soil, water, sediment, terrestrial and aquatic biota	Ingestion, respiratory uptake, adsorption, absorption, inhalation	Terrestrial and aquatic biota, humans	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Exhalation from mine site ground	Radon-222 (and its progeny)	Atmosphere	inhalation	Humans	Radiological dose (increased risk of cancer)
Stormwater runoff from non-mine site areas of mine lease	Suspended sediment	Water, sediment (in depositional zones)	Direct contact with external biological surfaces (causing smothering, clogging etc.)	Aquatic biota	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Human carriage	radionuclides	humans	Ingestion, inhalation	Humans	Radiological dose (increased risk of cancer)
	Weed propagules	Soil, sediment, water	Direct invasion and replacement	Aquatic and terrestrial habitats	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)
Spillage/Leakage into surface waters	Chemicals transported onto site/produced on-site/used in milling process	Water, sediment, aquatic biota	Ingestion, respiratory uptake, adsorption, absorption	Aquatic biota, humans	Changes to aquatic and/or terrestrial fauna and flora community structure and function (and ecological processes)

A new conceptual model

Key stressors

Uranium

Magnesium sulfate *(emerging)*

Manganese *(emerging)*

Ammonia *(future)*

Suspended sediment

Radionuclides *(emerging for aquatic biota)*

Radon-222 (and progeny)

Gamma dose

Weed propagules *(emerging)*

Key pathways

- Controlled and semi-controlled release of contaminated water to Magela Creek surface water at 3 locations
- Water seepage from on-site waterbodies into g'water → s'water
- Spray and flood irrigation to land of contaminated water
- Trophic transfer to mobile species visiting on-site waterbodies
- Atmospheric dispersion
- Human carriage

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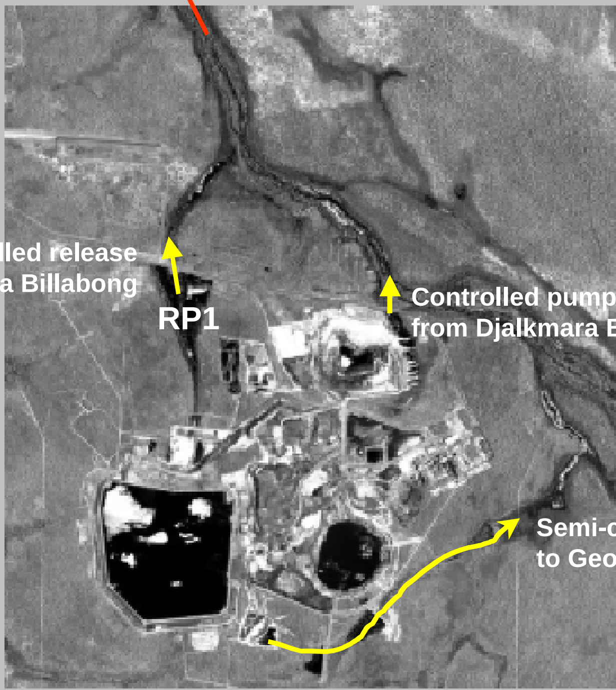
A new conceptual model

Surface water pathways



Ranger Mine, Feb 2003

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Risk Analysis

Example Issue

- Uranium in surface water downstream of mine site, derived from direct mine water releases

Approach

- Probablistic – comparison of cumulative probability distributions of effects and exposure
- Local species chronic toxicity data
- Long-term monitoring data
  chemical → exposure
  biological → integration/verification

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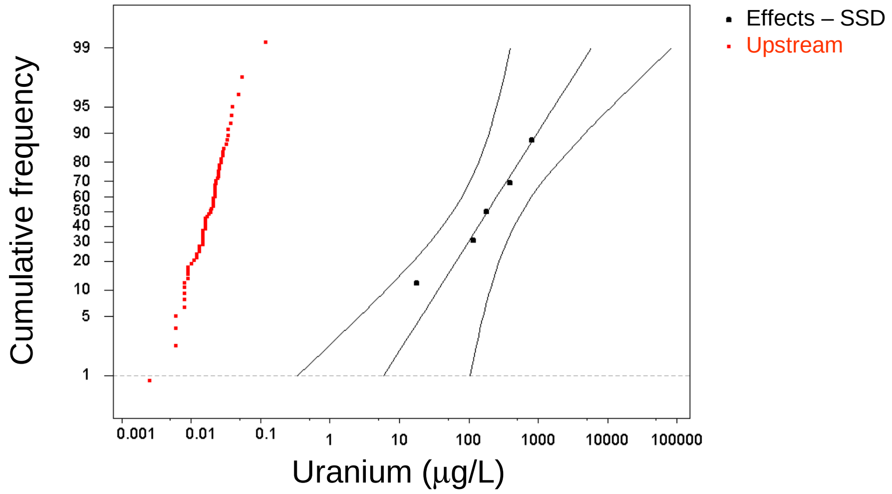
Risk analysis

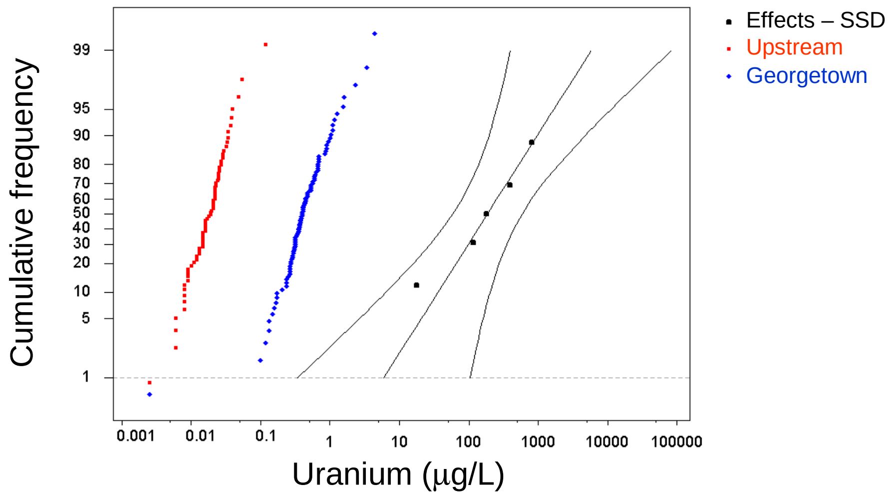
Uranium



Bayliss & van Dam (in prep)

Risk analysis

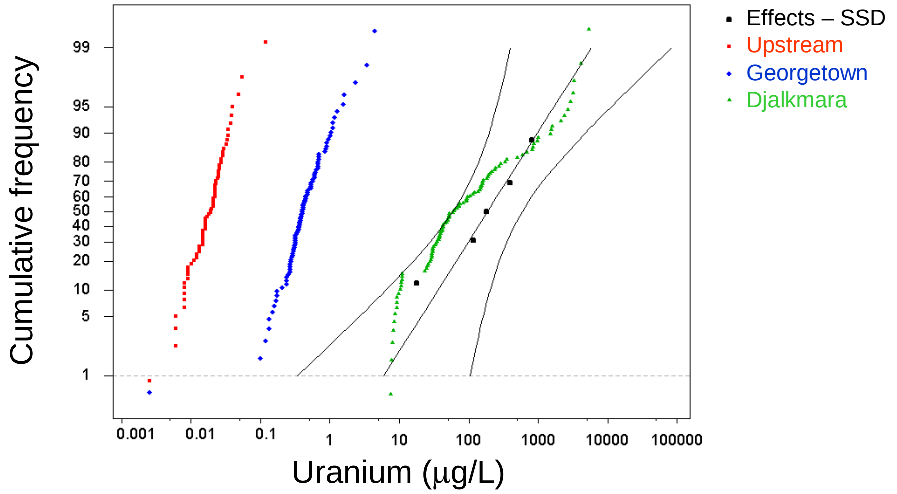
Uranium



Bayliss & van Dam (in prep)

Risk analysis

Uranium



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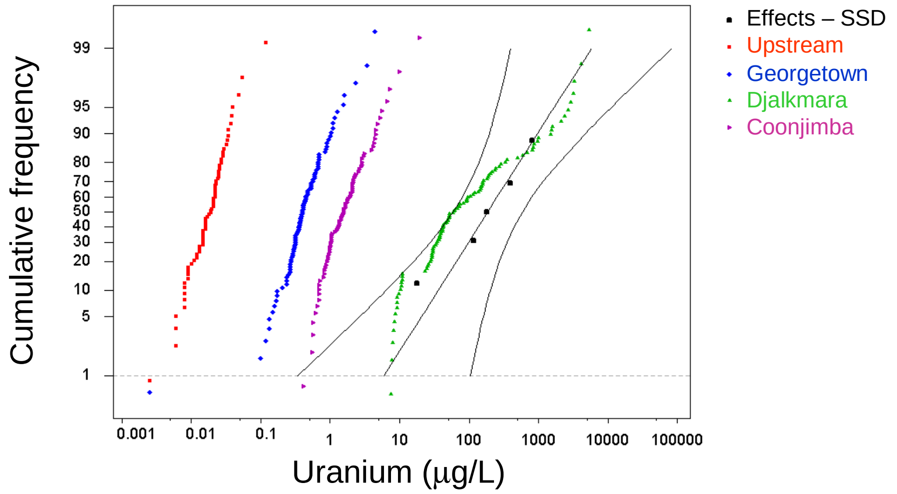
Risk analysis

Uranium



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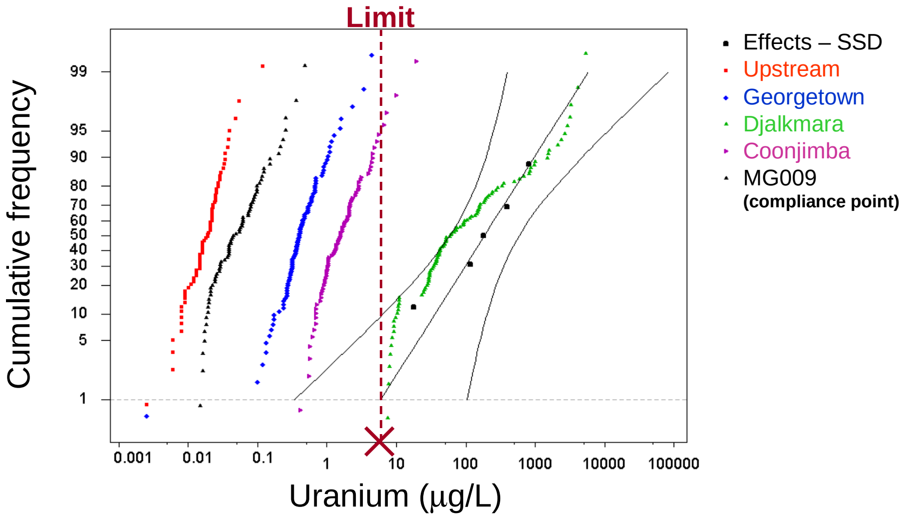
Risk analysis

Uranium



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A new conceptual model

Process from here

- Ensure stressor-pathway inter-linkages are identified
- Consult stakeholders – agree on final form
- Populate each stressor-pathway sub-model with data/information
- Identify knowledge/research gaps (eg. risks of radiological dose to aquatic fauna)
- Where possible, quantify risks and uncertainty
- Determine relative & cumulative risks of pathways and stressors (Bayesian networks?)

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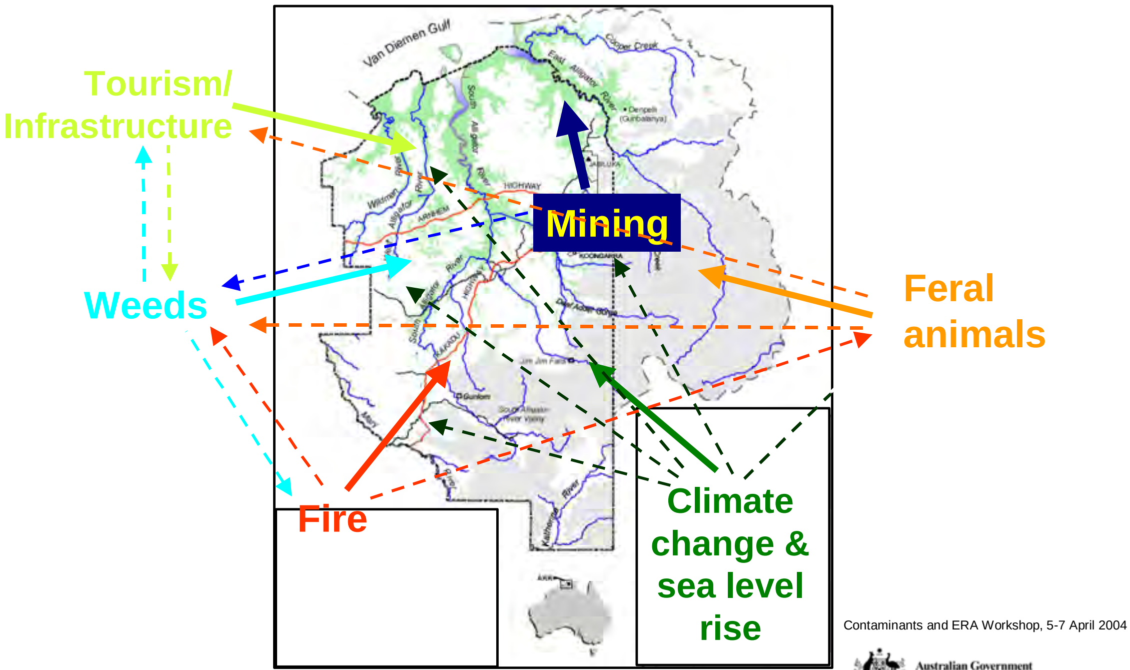
A Landscape Perspective



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