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Water release standards in the Alligator Rivers Region

An assessment by the Alligator Rivers Region Research Institute

(Historic document)

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Contents

Background

Water release standards for the Magela and Coopers Creeks, downstream of the Ranger and Nabarlek uranium mines respectively, were set during the 1980s based on the recommendations of the Supervising Scientist. The age of these standards, the acquisition of long-term data sets for the area, improved analytical techniques and changed recommendations/guidelines by peak bodies (ie the World Health Organization and the Australian and New Zealand Environment and Conservation Council) mean that the original standards require reviewing. Therefore, the Supervising Scientist has committed to review the standards applied to waters downstream of the Ranger Uranium Mine[1] prior to the 2003–04 wet season.

To facilitate a review of those standards the original unpublished working document, *Water release standards in the Alligator Rivers Region: An Assessment by the Alligators Rivers Region Research Institute* (circa 1984), containing the rationale and assumptions on which the recommendations were based is reproduced here, along with an extract from the Alligator Rivers Region Research Institute Annual Research Summary for 1984–85 which summarises the original document.

As the original document was a working document only it remains incomplete ie, no figures are included and it contains numerous typographical errors. However, it is a very comprehensive document and is invaluable reference material in any review of the water release standards. It is therefore now being published in its original state to formally record the work done historically and enable ease of access and reference to the original work. The section of the original document that covers radiological standards has been summarised and published (Johnston A (1987)[2] and Johnston et al (1997)[3]), and updated models for setting radiological standards for the Magela Creek have since been produced (Martin P 2000)[4].

Other related works available from the Supervising Scientist Division that would also be valuable for the review of the water release standards are Martin P (1999)[5], Klessa DA (2000)[6] and Klessa D (2001)[7].

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[1] As the Nabarlek mine is no longer operational the standards relating to Coopers Creek does not require reviewing.

[2] Johnston A 1987. *Radiation exposure of members of the public resulting from operations of the Ranger Uranium Mine.* Technical memorandum 20, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

[3] Johnston A, Murray AS & Martin P 1997. Radiological standards for the discharge of water from uranium mines in the Alligator Rivers Region. Internal report 233, Supervising Scientist, Canberra. Unpublished paper.

[4] Martin P 2000. Radiological impact assessment of uranium mining and milling. PhD thesis. Queensland University of Technology, Brisbane.

[5] Martin P 1999. A radiation exposure assessment for the release of water to Swift Creek from the proposed Jabiluka retention pond. June 1999, Internal Report 318, Supervising Scientist, Canberra. Unpublished paper

[6] Klessa DA 2000. *The chemistry of Magela Creek: A baseline for assessing change downstream of Ranger.* Supervising Scientist Report 151, Supervising Scientist, Darwin.

[7] Klessa D 2001. Water quality in Magela Creek upstream and downstream of Ranger: A summary of performance for 2000–2001 and derived triggers and limits for 2001–2002. Internal Report 380, Supervising Scientist, Darwin. Unpublished paper.

PREFACE

Water release standards

(Section 8: Alligator Rivers Region Research Institute Annual Research Summary for 1984–85)

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8. WATER RELEASE STANDARDS

8.1 Receiving water standards for the Alligator Rivers Region

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Background

The original water management plan proposed by Ranger Uranium Mines in its submission to the Ranger Uranium Environmental Inquiry (RUEI) envisaged that controlled releases of water from the mine site would need to be made to Magela Creek throughout the life of the project and that, given non-extreme weather, there was an even chance that water would need to be released by about the third year of operation of the mill. In discussing the water management plan, the Ranger Inquiry emphasised the desirability of continuing to study options for water management with the aim of implementing all practicable modifications that would reduce the quantities of contaminants released.

Following the commencement of mining operations at Ranger, considerable attention was focused on the waste management system to devise management strategies that would lead to the minimisation of the release of contaminants to the environment. Ranger agreed in 1979 to implement a 'zero release' system (beyond the initial 5 year zero release period already agreed to) if it was agreed, on balance, to be environmentally desirable and if the supervising authority required it. The Co-ordinating Committee endorsed the adoption of the 'zero release of contaminants' policy.

The five years or so in which this policy has been in place has allowed Ranger to plan and undertake an evaluation of Best Practicable Technology (BPT) for long-term water management and has enabled the various authorities to address the task of devising suitable release standards should controlled water release be a component of BPT in water management. It is clear that guidelines on water release standards and the conditions of their implementation are important elements in optimisation of water mangement schemes.

A similar 'zero release of contaminants' policy has been in operation at Nabarlek. Queensland Mines Ltd have, however, been addressing the problem of establishing BPT with respect to the decommissioning of the Nabarlek mill in 1988-89. It is clear that one of the options available to the company could involve the release of excess water into Cooper Creek and there is, therefore, a clear need for the establishment of suitable release standards.

Following discussion within the Co-ordinating Committee on the development of water quality standards suitable to assess the acceptability of release of retained water on uranium mine sites, the Supervising Scientist, through the Alligator Rivers Region Research Institute, undertook to investigate the topic as a broadly based research project. The Research Institute reported progress to the Co-ordinating Committee on 9 August 1983 and on 13 December 1983. Members of the Co-ordinating Committee were in agreement with the approach proposed and recommended that the investigation proceed to development of numerical standards.

This report gives a description of the methods used by the Research Institute in the development of its recommendations on receiving water standards for the Alligator Rivers Region. The extensive contributions made by many members of staff from the Research Institute are acknowledged.

ARRRI approach to the development of standards

Several stages occur in the development of suitable standards to be applied to the quality of receiving waters. They are:

- specification of the objectives to be met by the setting of standards;
- specification of a list of chemicals or other constituents for which standards are required;
- development of scientific criteria against which it can be judged whether or not the objectives will be met; and
- use of existing scientific information combined with modelling, where required, in the derivation of numerical standards which comply with the scientific criteria.

Objectives. The objectives which form the basis of the Research Institute approach to the development of standards are:

- Humans should not be harmed as a result of consumption of food or water which might be affected as a result of release of waste water; and
- no change should be experienced by the ecosystem that would be detrimental to its status as part of a national park or a world heritage area.

It was considered appropriate to apply the same ecological objective to both Cooper and Magela systems.

Identification of constituents. Hazardous constituents originate from two principal sources associated with uranium mining and milling. These sources are: (a) constituents of ore and waste rock mobilised as a result of mining, and (b) constituents resulting from introduced substances used in the milling process. The starting point taken was the list of elements and compounds for which the US EPA gives water quality standards or which it recommends for inclusion in the development of water quality standards. Both the orebody and the mill were examined for the presence of these substances.

The chemistry of natural surface waters is principally determined by the interaction of rainwater and the regional soils and rocks. Changes in water quality due to mining are therefore likely to arise primarily from those elements which are enriched in the orebodies compared to the natural regional rocks. Consequently, the elements likely to be significant hazardous constituents can be identified by examining the available data for concentrations of elements in ore and waste rock at the Ranger mine and ore at the Nabarlek mine and comparing these concentrations with those in natural rocks of the Alligator Rivers Region.

The question arises of what enrichment factor can be considered to be significant. The choice was primarily determined by the fact that the mean dilution of released waters by the natural creek waters under conceivably suitable hydrological conditions is expected to be a factor of 100 or more. The use of an ore enrichment factor of greater than 10 should then be a conservative figure. It should be borne in mind that the waterbodies being considered as candidates for release at Ranger are not recipients of water from those circuits of the mill in which chemical processing of the ore takes place, so that additional chemical enrichment does not occur. This comment does not apply with equal validity to Evaporation Pond 2 at Nabarlek, because processed tailings water is present in EP2. Further assessment of metal concentrations is therefore required at Nabarlek.

All known available sources of data in the Ranger and Nabarlek ores were used to determine the enrichment factor of each element in the ore with respect to Alligator Rivers Region rocks. Any element with an enrichment factor of 10 or greater was retained. Further detail on the method used to determine the enrichment factors is given in 'Analytical chemistry: identification of hazardous constituents from uranium mining'.

The mill processes associated with the sub-catchments of RP2 at Ranger and EP2 at Nabarlek were examined to determine those elements and compounds which might be introduced into Restricted Release Zone (RRZ) water. The significance of each introduced constituent was assessed by reference to the US EPA list and by considering properties such as chemical stability and chemical half-life.

On the basis of these examinations of ore and mill processes, a list of chemical constituents of possible significance in the Region was drawn up. To this were added the long-lived radionuclides of the uranium series. The final list of constituents derived by this process is shown in Table 29.

A deficiency in identifying hazardous constituents by the above process is that some important constituents could remain unidentified, e.g. specific hydrocarbons. For this reason, the Research Institute recommends that any release of RRZ waters that is authorised to meet specified receiving water standards, be subject to a comprehensive and simultaneous program of biological monitoring of the discharge waters.

Table 29. Water quality constituents for which standards are required

pH	Barium	Nickel
Turbidity	Cadmium	Vanadium
Dissolved oxygen	Calcium	Zinc
Sulphate	Chromium	Uranium-238
Ammoniacal nitrogen	Copper	Uranium-234
Nitrate and nitrite	Iron	Thorium-230
Phosphate	Lead	Radium-226
Alkalinity	Magnesium	Lead-210
Total organic carbon	Manganese	Polonium-210
Suspended solids		

Criteria

The objectives stated above require criteria to be specified with respect to protection both of humans and of the ecosystem.

Protection of humans. Risk to humans could arise from two factors: radiation exposure and metal intake.

(a) Radiation exposure: in deriving limits for the release of radionuclides the recommendations of the International Committee on Radiation Protection (ICRP) have been followed. Two types of exposure period were considered, long-term (appropriate for Ranger) and short-term (appropriate for Nabarlek). The annual dose limits applied were 1 mSv and 5 mSv for long-term and short-term exposure respectively. The annual limits on intake used take into account the differences between dose limits for radiation workers and for the general public and the presence of children in the critical group. Only stochastic annual limits on intake (ALI_s) were considered as recommended by ICRP 39, leading to a public annual limit on intake (ALI_p) of 0.01 ALI_s for both short-term and long-term exposures. For the uranium isotopes, a gut absorption factor of 0.2 has been used for environmental uranium rather than the value of 0.05 normally used for industrial chemical forms. The six long-lived uranium series radionuclides listed in Table 29 were considered and the criterion adopted was:

$$\sum_{j=1}^{6} (I_j/A_j) < 1$$

where I_j is the intake of the j^{th} nuclide in the year following release and A_j is the public annual limit on intake derived above.

(b) Metal intake: metals can be divided into those not known to be carcinogenic and those specifically identified as having carcinogenic properties. For the non-carcinogenic metals, annual limits on intake were derived from NHMRC recommendations on limiting concentrations in fresh food and dietary details of the critical group. In many cases, daily intake limits are set for metals but the concept of an annual limit is appropriate in the case of metals with a long biological half-life. However, it can also be applied in the case of metals with short biological half-lives when it is defined using the actual diet of the population group at risk combined with the concentration limits applicable to the constituent parts of that diet.

Since the toxicity of heavy metals to an individual organism is generally considered as being non-stochastic (i.e. there is a threshold concentration below which a particular effect does not occur), it is necessary to subtract a normal background intake from the annual limit on intake (ALI_p) before applying this limit to a particular industrial practice. The definition of the public annual limit on intake used here for the chemical toxicity effects of each heavy metal is, therefore,

$$ALI_p = \sum_{i=1}^{n} L_i F_i - \sum_{i=1}^{n} c_i F_i$$

where L_i = NHMRC concentration limit of the metal for food item i;

F_i = annual intake of food item in the diet of this group;

c_i = average normal concentration of the metal in the food item; and

n = number of significant food items in the diet.

The metals, listed in Table 29, for which recommendations have been made by NHMRC were considered and, in addition, an allowed limit on intake was derived for manganese. Using these limits for each element (A_j) the criterion applied was:

$$(I_j/A_j) < 1$$

where I_j is the intake of the $_j$th metal in the year following release.

The possibility of carcinogenesis by enhanced intake of certain metals was considered by the Research Institute and a literature review was undertaken to establish the current status of carcinogenic risk assessment in other parts of the world. It was found that carcinogenic risks are poorly understood and, for this reason, no limits based on these risks can be included in the recommendations until further information is available.

Protection of the ecosystem. The main difficulty in setting standards for the protection of the ecosystem is the very large and unknown number of species to be protected in an area where there is limited relevant experimental data on the interrelationships between the species present and the water chemistry. In the absence of this information, a three stage process was adopted for the derivation of receiving water quality standards for the two specific locations under consideration in the Alligator Rivers Region.

The first stage was the adoption of a general criterion which is considered conservative by biological scientists and which is based upon the observed natural fluctuations of the concentrations of the chemicals of concern in the natural waters of the two creeks into which waste waters might be discharged. Preliminary receiving water standards were deduced on the basis of this criterion.

The second stage was the application of these preliminary standards to a hypothetical release from particular artificial waterbodies at the two mine sites into the Magela and Cooper creeks. By this process it was possible to identify specific constituents that would limit release volumes of such waters in any Wet season. The problem of making an ecological impact analysis was then reduced to examination of these few limiting constituents.

The development of a criterion based upon natural fluctuations in the environment is bound to be somewhat subjective. Nevertheless, an assessment of the significance of a given increase in the concentration of a contaminant has been made by considering the resulting change in the probability distribution for that contaminant. It was assumed that a change of approximately 10% in the frequency of occurrence of concentrations of any constituent between the 2.5 and 97.5 percentiles of the natural distribution of that contaminant would not lead to unacceptable changes in the environment. By examining the properties of both normal and log-normal distributions and the possible effects of the use of different discharge procedures, the following criterion was adopted:

- during a discharge period, the mean value of the altered distribution of each variable of concern is to be greater than the mean value of the natural distribution for that variable by no more than one standard deviation of the natural distribution, provided that a discharge mechanism is employed which ensures either a constant discharge rate or a proportional discharge rate of effluent to the creek.

The final stage was a toxicological and chemical assessment of the likely impact of increased concentrations of these limiting constituents on the local ecosystem. The philosophy adopted was that the conservative preliminary standards can be discarded in cases where data exist suggesting that certain increases in concentration might be ecologically acceptable. A final set of recommended standards for receiving waters was then proposed on the basis of both the general approach and the particular assessment of the critical chemical constituents.

Derivation of recommended receiving water standards

Protection of humans. The criteria given above for the development of standards for the protection of humans require an estimate to be made of the annual intake of radionuclides and trace metals in the diet of the critical group. Thus a model is required which relates the quantity of an element released into the creek to the intake of that element by people. Such a model has been developed which includes dispersion of radionuclides and metals in the Magela and Cooper creek systems, bioaccumulation in aquatic and terrestrial animals and plants, and a diet for the critical group.

The various stages considered in the dispersion model were:

- initial dilution with creek water;
- transport in the creek region including deposition and absorption;
- dilution on the flood plain; and
- the annual cycle on the flood plain, including deposition and absorption, drainage to the sea during the Wet season, evapoconcentration during the Dry season, and possible resuspension during the early part of the subsequent Wet season.

The available data on natural transport processes were used, where possible, to determine the parameters of the model. Wherever such information was not available conservative assumptions were made.

Transfer factors relating concentrations in the water column or soil to those in aquatic or terrestrial animals and plants were used to represent bioaccumulation processes. Initially, these were derived from the literature and previous work in the Region but, for the most significant food items, further experimental work has led to locally derived transfer factors. Whilst this program of work is still proceeding, the values now being used for freshwater mussels (the most important dietary item from this point of view) and other important items (such as fish and water lilies) are locally derived.

The critical group for the Magela system was identified as that group of people who live near Mudginberri Billabong and whose diet contains 70% bush food. Quantitatively detailed documentation of the diet of local Aboriginal people is unavailable, but there is sufficient information from a number of sources, particularly studies by Ranger personnel, to make possible the construction of a 'typical' annual bush diet. No serious error is believed to exist in the most significant items in this diet, but a research project has been commissioned by the Office of the Supervising Scientist to study and quantify the diet of local people (see 'External research projects, Quantification of Aboriginal consumption of bush foods').

On the basis of this model, limits have been deduced for the maximum annual load of radionuclides and trace metals that can be added to creek waters without violating the criteria given earlier for the protection of humans.

Protection of the ecosystem. Preliminary receiving water standards which are considered suitable for protecting the ecosystems of Magela and Cooper creeks were derived by examination of the historical water quality data for both creeks obtained by the Water Resources Divison of the NT Department of Mines and Energy. The data sets from gauging stations GS821009 and GS821028 were used to specify the water quality distributions for Magela Creek and those from stations GS821024A, GS821024, GS821001 and GS821038 were used for Cooper Creek distributions. Mean concentrations and the standard deviation of the distributions were derived for each variable in Table 29 for which historical data are available (no such data are available for barium, vanadium and nickel). Recommendations on the maximum value of the mean for each variable during a discharge period were then deduced using the criterion described above for protection of the ecosystem.

Limiting constituents were identified by considering the hypothetical release of waters from RP2 at Ranger and EP2 at Nabarlek into Magela and Cooper creeks respectively under suitable hydrological conditions. The principal hydrological condition was that of creek flow rate: specified as a minimum of 20 m^3/s in Magela Creek and 5 m^3/s in Cooper Creek. Any constituent which gave rise to a mean concentration in excess of the preliminary standards was defined as limiting. These were:

- Ranger - sulphate and uranium, with magnesium and manganese imposing moderate limitation; and
- Nabarlek - calcium, magnesium, sulphate, ammonia, nitrate, manganese and uranium.

An ecological and toxicological assessment was carried out using these seven limiting constituents. While the biological impact of chemicals can never be confidently predicted (except at acutely lethal concentrations), it was considered that, for calcium, magnesium, sulphate, nitrate and manganese, sufficient information exists in the scientific literature to indicate a possible change of the conservative preliminary standards to values recommended by other environmental protection agencies. An interim recommendation on ammonia, based on the extensive research on the toxicity of ammonia conducted elsewhere in the world and summarised in the recommendations of the US EPA, has also been made. The toxicity of uranium to local animal species was assessed in a series of experiments conducted by staff of the Research Institute (see 'Effects of stream discharge: laboratory studies').

Table 30. Recommended interim receiving water standards

The allowable additional radionuclide loads are subject to the summation of the fractions (i.e. load over limit) for each radionuclide present, with the sum of all fractions to be less than one.

Constituent		Magela Creek mean or (limit)	Cooper Creek mean or (limit)	Basis of assessment
pH		5.5-6.5	5.4-6.8	Statistical
<u>Concentrations</u>				
Turbidity	NTU	33	33	Statistical
Dissolved oxygen	mg/L	> 6.0	> 6.0	Ecological
Calcium	mg/L	(20)	(20)	Ecological
Magnesium	mg/L	(20)	(20)	Ecological
Sulphate	mg/L	(200)	(200)	Drinking water
Fluoride	mg/L	0.02	0.02	Statistical
Molecular NH_3 (as -N)	mg/L	(0.020)	(0.020)	Toxicological
Nitrate/nitrite (as -N)	mg/L	(10)	(10)	Drinking water
Phosphate (as $-PO_4$)	mg/L	0.01	0.036	Statistical
Suspended solids	mg/L	20	31	Statistical
Alkalinity	mg/L	20	10	Statistical
Total organic carbon	mg/L	6	7	Statistical
Iron, total	mg/L	1.2	1.8	Statistical
Copper, total	μg/L	2.4	1.4	Statistical
Lead, total	μg/L	1.2	1.3	Statistical
Zinc, total	μg/L	17	14	Statistical
Manganese, total	μg/L	(50)	(50)	Human health
Uranium, total	μg/L	(10)	(10)	Toxicological
Cadmium, total	μg/L	0.15	0.1	Statistical
Chromium, total	μg/L	1.5	0.8	Statistical
Radionuclides, total α	Bq/L	(0.1)	(0.1)	Drinking water
<u>Additional Load</u>				
Uranium-(238+234)	GBq/yr	88	110	Human health
Thorium-230	GBq/yr	170	170	Human health
Radium-226	GBq/yr	13	15	Human health
Lead-210	GBq/yr	8	10	Human health
Polonium-210	GBq/yr	7	9	Human health
Cadmium	tonne/yr	1.3	1	Human health
Copper	tonne/yr	90	36	Human health
Lead	tonne/yr	8	3.3	Human health
Manganese	tonne/yr	6	2.5	Human health
Zinc	tonne/yr	200	90	Human health
Phosphate (as -P)	tonne/yr	2.8	0.7	Ecological
Nitrate (as -N)	tonne/yr	4.4	1.1	Ecological

In addition to these considerations of concentrations in the water column, an assessment was carried out on the effects of increased loads of sulphate, nitrate and phosphate on the ecosystem.

On the basis of this work a set of recommendations on interim receiving water quality standards was derived. These recommendations are given in Table 30.

Current Status

A report which presents a full description of this work is currently in preparation and will be published in the Research Report series of the Supervising Scientist. Discussions have taken place between officers from the OSS and from the responsible supervising authorities of the Northern Territory Government. As a result of these discussions, a list of preliminary discharge standards have been given to Ranger, by the NT Minister for Mines and Energy, for guidance in Ranger's current assessment of Best Practicable Technology as applied to their water management system.

The assessment of acceptable receiving water standards is a continuing process. As discussed in an earlier section of this report (see 'Effects of stream discharge: field studies'), Ranger was given an authorisation for the discharge of water from RP4, which is not within the Restricted Release Zone, during March 1985. A research program was carried out to observe any environmental effects produced by this discharge. Specific effects were observed within the mixing zone on the reproductive activity of freshwater mussels, *Velesunio angasi*.

Although detailed chemical analyses were not carried out at each of the sites where such effects were observed, a full study was conducted on the nature and extent of the mixing zone. In addition, full chemical analyses of the discharge waters were provided by Ranger. From these data it has been possible to determine the concentrations of constituents at each of the mussel study sites. This analysis has shown that the concentrations of all constituents considered in the setting of water release standards were below the recommendations listed in Table 30. On the other hand, the concentrations of sulphate, magnesium and uranium were in excess of the preliminary standards based solely on the natural fluctuations criterion.

Laboratory investigation of the observed effects is currently in progress but the above findings illustrate the advisability of incorporating biological testing in any release program to take into account possible synergistic effects, chemical speciation and the effects of any unidentified constituents in the discharge water.

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Water release standards
in the Alligator Rivers Region:
An assessment by ARRRI

(Historic document)

Water Release Standards in the Alligator Rivers Region:

An Assessment by ARRRI

1. Introduction

This report addresses the question of standards to be applied to waters released by mining companies into the environment of the Alligator Rivers Region. The answer cannot be provided in purely scientific terms since it is implicit in the question that man, the ecosystem, or both must be protected to some degree by the application of standards. It will, therefore, be necessary to consider precisely what we are attempting to protect, to what extent protection is requred, and how that degree of protection can be provided by the application of suitable standards.

The general question of the objectives of a scheme of water release standards is addressed in chapter 2. Whenever release of radionuclides or heavy metals is being considered the protection of man is clearly a prerequisite and the degree of protection has been considered at length by such authorities as the International Commission on Radiation Protection and the National Health and Medical Research Council. Defining objectives in this case is, therefore, relatively straightforward. Such a definition is, however, not so easy when protection of the environment is considered. Value judgements are required on what constitutes the environment, how important different aspects of the ecosystem are, and what level of protection is required. These judgements are not for the Institute to exercise and we must seek guidance in the form of national and local government directives for the management of the Region. The fact that the Magela Creek, into which any effluent from the Ranger Mine would discharge, runs through the projected Stage 2 development of Kakadu National Park will clearly have a very significant impact on discharge control.

Once objectives are determined it becomes necessary to translate them into scientific statements or criteria by which any proposed standards can be judged to assess whether compliance with the objectives is achieved. These criteria are proposed and discussed in Chapter 3.

Chapter 4 is devoted to a discussion of the data and models required in the development of standards. Assessment of the impact of a particular water release on man's health requires models to be proposed of the dispersion of contaminants through the ecosystem, the absorption and concentration of these contaminants in the food chain, and man's dietary intake. These topics are dealt with in sections 4.1 and 4.2. The effect of water discharge on the natural distribution of contaminants in the waters of the region and the toxic effects of such contaminants on local species are considered in section 4.3 and 4.4.

On the basis of the information gathered in Chapter 4 and by consideration of the criteria developed in Chapter 2, standards for water release are proposed in Chapter 5. Application of these standards to the release of waters from two artificial water bodies at Ranger and Nabarlek is then considered and preliminary conclusions are drawn.

A summary of our findings and some recommendations for future action are given in Chapter 6.

2. Objectives and Requirements

2.1 Objectives

Basically the standards required here are those which will ensure with a high degree of probability that pollution will not occur; that is, that there will be no change in water quality which is of such magnitude that present, or foreseeable, "uses" of the surface waters, or of their associated ecosystems, will be impaired. (It is assumed that within the Kakadu National Park 'damage' as such would not be acceptable). Such "uses" can range from the preservation of the present biota, to preservation of particular parts of it; from preservation of the waters as a wholesome supply for man to preservation of its quality for wildlife watering and so on. In order to determine the adequacy of any standards it is therefore essential that the responsible authorities define as soon as possible the entire range of uses foreseen at the present time. It may be, that in due course, management plans for animals (eg. crocodiles) may have more effect on the fauna than would any waste discharged under appropriately controlled conditions from mining.

2.2 General Considerations

Some of the difficulties and uncertainties involved in the setting of environmental standards are discussed below. An appreciation of these is essential if problems over the acceptability of standards are to be minimised.

2.2.1 In the present context the requirements (2.1) for environmental protection do not imply that changes must not occur. By their very nature the systems involved are already subject naturally to both short-term and long-term changes and the organisms present in waters of the Region tolerate at present considerable variation in water quality. This must be recognised in the determining of any standards that might be set. Equally, however, it must also be recognised that the rate of ecological change occurring naturally, and its direction, and any "immediate" end-point, are not known and are not necessarily the same as those which might be brought about by changes caused by man's activities, so differences in "changes" must be recognised.

Fundamentally what is required in the present instance is that any changes brought about by the release of mine wastes should not significantly alter such things as the composition and diversity of the fauna and flora, or of the nature, degree, periodicity or rates of faunal and floral changes occurring naturally (excluding extreme or catastrophic events). Ideally they should also not alter the "direction" of those changes. As discussed below therefore, while the release of any waste inevitably brings about some change, "change" in itself is not an abnormal phenomenon in the ecosystem and should not automatically be equated with "harm".

2.2.2 A further point, and indeed a major consideration that must be borne in mind when setting standards, is that absolute safety does not exist and, cannot, therefore, sensibly be sought. Risk is attendant on all activities, so that once it has been agreed that some particular activity, such as mining, will take place, then it has also implicitly (at least) been accepted that some degree of risk, however low, will be present. But under proper management such risk should be trivial. However, there is no standard value against which risk * from a particular hazard ** can be assessed as being acceptable or not. "Acceptability" of a particular degree of risk varies from hazard to hazard, situation to situation, depending on the level of benefit perceived as being present in the particular activity involved. And while description and quantification of the nature, degree, rate of occurrence, and so on, of adverse effects from any particular hazard can be defined by scientific processes all decisions regarding the particular degree of risk

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* Risk: The probability of exposure to (and danger from) a particular hazard.

** Hazard: The nature of any danger.

which is acceptable are, in the final analysis, subjective. Some compromise has therefore always to be reached and the attainment of such compromise is a measure of the success of decision making, not its failure. But the greatest problem in reaching agreement about a particular standard arises in this particular area. To put matters into a wider context, it might be useful to point out that even in the use of "beneficial" drugs on man it is accepted that perhaps one person in 100,000 (or even in 10,000) may respond adversely and be severely harmed - even to the extent of being maimed or killed in some circumstances. So what is being done here in attempting to set environmental standards in the presence of extensive uncertainties is not something "different" or "wrong" but is simply in line with the way similar types of problems have to be resolved elsewhere once it has been agreed that a particular action will take place. Nevertheless, there is one important exception here from the examples given above, and to which some weight must be given and that is that in the release of wastes no beneficial element to the ecosystem is foreseen. Nevertheless there are associated benefits in terms of the knowledge of the ecosystems which is incidentally acquired and which flow from the proposals to discharge wastes, making the systems involved, particularly the Magela system, the best studied and described in Kakadu Park.

Ideally, in order to set standards all of the hazards inherent in some situation should be known. In the case of the release of chemicals basically this means (a) identification of the physico-chemical properties of the substances involved, (b) determination of the toxicological properties of those chemicals, and (c) identification of the organisms/systems with which reaction will take place. In the case of man in the work place this is a relatively simple thing to do but in the environment at large, it is never possible to have an equivalent amount of information or to forecast where the major initial impact, if there is to be one, will be, or what the subsequent reactions of any particular ecosystem will be. Often, indeed, the only things that can be defined with any confidence are the physico-chemical properties of the substances involved. It is, therefore, imperative that any standards that are set are "cautious and conservative" ones.

2.3 **Basic Concepts of Environmental Toxicology**

2.3.1 In discussing this topic a large number of generalisations have, of necessity, had to be made in order to allow a very complex subject to be reduced to a statement of acceptable lengths. Important terms, for example, have not been given the degree of definition which they require if they are to receive unequivocal interpretation. Nevertheless, it is believed that when read <u>in the context of this particular discussion</u> this account should not give rise to problems. (The main message of this section is the high degree of uncertainty that exists.)

2.3.2 **Reactions Between Organisms and Chemicals**

Toxicology is concerned with describing and quantifying <u>all</u> of the adverse effects which a substance can have on living organisms as a direct consequence of its specific chemical properties. While a large number of factors, both biological and chemical, affect the outcome of exposure to any specific chemical basically this depends on (a) the dose involved and (b) the duration of exposure to that dose. In the case of aquatic organisms "concentration" of a chemical in water is commonly used in place of "dose" and is of direct practical value in the derivation and application of data. (The term "exposure", where not otherwise qualified, incorporates both concentration and time.)

The response of an organism to a chemical is, however, not simply a one-way reaction. Because organisms are exposed to many natural "undesirable" compounds (some self-produced eg.hydrogen cyanide in the gut) it is normal for them to be constantly involved in lowering the body concentrations of such substances (by metabolism, complexation, detoxification, excretion) in order to maintain their physiological and biochemical integrity. And these same processes are called into play whenever possibly adverse levels of man-produced wastes are encountered.

For most substances there are levels of exposure at and below which any particular individual is effectively unharmed. At the opposite extreme the exposure can be such that the protective systems available to the organism are totally overwhelmed and the individual dies within a short time. This latter area, that of acutely lethal concentrations, is not one from which information on suitable standards can be derived in the present context. Attention must be drawn here, however, to those substances which, because of their chemical properties, are carcinogenic, i.e. produce malignant neoplasms and to which the above considerations do not apply. This again is a subject too complex to examine in detail here, but simply, with such substances it is believed that even a single molecule can (but not necessarily will) initiate a carcinoma. Consequently this type of substance raises an entirely different set of problems. Release of such chemicals should be avoided where possible. Where particular chemical carcinogens or mutagens are present naturally in the environment then increase in these should be kept as low as operational requirements and technology of any relevant activity will permit. (It should also be recognised that there are other substances, which, although non-carcinogenic (eg. beryllium), give rise to problems with regard to determination of "safe" levels, because the onset of the diseases they produce, is considerably delayed (years).)

The particular responses that will be provoked by a substance depend upon its specific chemical properties, although the types and ranges of responses which organisms can make are limited. Commonly, for example, many chemicals will finish up by causing, amongst other things, liver damage. But different exposures will induce in animals, for example, responses varying from reversible eye, or skin irritation, through mild to severe structural and functional changes (including abnormal behaviours), to cancer, genetic changes, reproductive pathologies and ultimately premature death. Various combinations of adverse effects can occur unexpectedly and ideally it is therefore important to ensure before any discharge takes place that (a) the waste to be discharged is itself tested, (because it may contain unknown substances, or mixtures which produce unexpected responses), and (b) the test exposure (conditions, duration) reflects that likely to occur in the environment, in order to ensure that there is opportunity for full expression of pathological changes. This will also ensure that any unknown or unexpected constituents in the waste will not be overlooked when standards for that waste are finally set. The specific nature, time of onset, or rates of development of pathological changes cannot be predicted, particularly in the presence of combined "insults", nor can the changes which will lead to irreversible damage or death.

But abnormal exposures to chemicals are not always, or necessarily, harmful. Many reactions to chemicals at increased (but still toxicologically "low") concentrations are readily reversible following removal of those chemicals, and under conditions of such types of exposures, these chemicals can be repeatedly tolerated. This gives some flexibility to levels that can be present in the environment. This situation applies to many of the heavy metals, substances of major concern here, but is not true for all. Those for example which, because of their properties and physico-chemical states in the body, become incorporated into compartments in which they have a slow turnover (i.e. have a long biological half-life) can accumulate even as a result of discontinuous exposures to levels at which they become harmful. Such substances must receive special consideration.

Much of the toxicity information in the literature is derived from experiments involving single substances at constant concentrations. Such data are extremely difficult to apply to the problem in hand here where simultaneous exposure to a number of substances at enhanced levels and at fluctuating concentrations is involved. In such situations recovery can take place at times of low concentration from responses induced when concentrations were high (within limits). In addition, it is not possible to know in advance what the particular responses to mixtures of substances at apparently potentially harmful levels will be. In some cases for example, the presence of increased levels of one substance may well offset the otherwise harmful effects of some second substance (eg. selenium and mercury; zinc and cadmium), while in other cases one substance may greatly increase the toxicity of a second substance. Such effects are largely unpredictable and because of this, and other reasons discussed below, it is desirable that exposures are kept well below levels at which harm might be expected to occur.

2.3.3 Variation in Susceptibility

2.3.3.1 Individual Variability

The degree of risk following exposure to a particular chemical is not uniform for all organisms. Even within a single species population each individual differs from all others in its susceptibility to poisoning. Typically the frequency distribution for the individual thresholds * in each population is a positively-skewed lognormal one. This means that within any single species population there is a small proportion of (relatively) highly resistant individuals. These do not reflect the response of the greater part of that population and decisions made on the basis of the presence, or the survival, of these particular individuals in a particular

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* The minimum concentration producing a response

ecosystem would be very misleading. For this reason, (as well as that of maximising precision) certain types of toxicity measurements are presented in terms of the concentrations at which a substance has a particular adverse effect upon 50% of a tested population (eg. the median lethal concentration (LC50), the median concentration for some other (defined) effect (EC50)). It should be stressed that these values may be very poor estimates of what the true LC50 (EC50) might be for the population from which the test sample was drawn.

The concentration defining the mid-point (eg the EC50) of the individual susceptibilities is, however, only one characteristic of that population. The other major characteristic which defines the population is the range of threshold values within that population, (i.e. the overall tolerance of the population). This is not the same for all substances. With some chemicals the difference between the concentration causing effectively no response * and that producing effectively 100% response may be quite small; in other cases it will be quite large. Chemicals having a narrow range are, for any given EC50, much more hazardous than those with a wide range, because even small increases in exposure above the E50 can effect the whole population. Because of that, when the intent of any exercise is the setting of standards which should allow the maintenance of well-being of this greater part of a species population, it is important to take into account the slope of the concentration response curve (with an awareness that considerable error can be attached to this). It is not appropriate, nor scientifically sensible, to attempt to derive acceptable concentrations from the use of some arbitrary "application factor" with the acute median lethal concentration (acute LC50) as

* The observed degree of response depends upon sample size. A concentration observed as producing no response in a sample of 10 animals could give at the 99% probability level), response of up to

recommended in the Fox report.

Finally, within any one species both the EC50 and the slope of the concentration-response curve for any chemical differ with differences in age, developmental state, nutritional state, metabolic state, state of sexual maturation, presence of disease, as well as with certain major environmental factors eg. levels of dissolved oxygen, temperature and so on. In general organisms are most sensitive early and late in life. But because of these many compounding factors no single concentration is "safe" to all members of a population at all stages of its life, unless this concentration happens to be that applicable to the most sensitive member at its most sensitive stage, under the most otherwise stressful environmental conditions (were it possible to define all of these). But standards based on such concerns may be unrealistic and industrially costly particularly should they not be relevant to the time and place at which discharges are to be made.

2.3.3.2 Species Variability

Before considering different species it should be pointed out that even a single species is not necessarily constant throughout its range. Several distinct "populations" , each with its own sensitivites, may exist at different sites, and the implications of this should not be overlooked. Such differences are, however, usually small compared with those that occur between different species. The concentrations at which substances have some particular adverse effect on different species can range, for an individual substance (and including heavy metals), over four or five orders of magnitude. In order to establish the concentration at which a substance or mixed waste may be acceptable in the environment it is therefore essential that information is available from more than one species. And if possible these species should cover a range of physiological "types" eg. from those having a high dissolved oxygen respiratory demand to those tolerant of low dissolved oxygen concentrations etc. The species used should also be the same as those occurring within ecosystems to which any waste is to be discharged.

Problems arise in defining or extrapolating effects because all organisms (and referring here particularly to animals) do not possess the same detoxifying mechanisms, or metabolic and excretory pathways. (Even when they do the rate processes involved may differ so much between species that the outcome of any particular concentration of waste is quite different). Consequently not only can the degree of reaction to a single chemical differ but so can the nature of that reaction, and often quite unpredictably so. In the case of drugs for example, (which happen to be particularly well documented) the therapeutic dose (mg/kg body weight) of morphine that sedates man or dog, drives a cat wild because in this latter case the drug is metabolized to a highly toxic compound; and repeated doses of a widely-available analgesic, at a rate equivalent to that therapeutic in man, will kill a cat because it is unable to excrete the compound.

Obviously, in environmental protection it is impossible to have information on all of the species in the ecosystem. Instead information derived from a few conveniently available test species is therefore obtained and this is considered to apply to at least all species belonging to the same taxonomic group as the test species. The potential dangers in this procedure, where extrapolation is made without there being evidence of common biochemical/physiological characteristics cannot be stressed enough.

2.3.4. **Ecological Aspects**

All of the issues discussed above have been concerned with the adverse effect of chemicals on individuals and on single populations. However, effects within ecosystems are much more complex than this. They involve not only the direct effects of chemicals on organisms but also an understanding of the indirect damage than can occur. Such indirect effects can be as damaging as any direct effects. Thus for example, where a close interdependence exists between two species (eg. predator/prey; parasite/host) then even though the prey species (or some particular single class of organism) is the only one of the pair to be affected by the concentration at which some chemical is present, should that species be lost (eg. by being killed or repelled) from the ecosystem then the predator will die of starvation, just as surely as if it had been poisoned. Even if the relationship is not an obligative one, species availability as food might be a particular seasonal matter and suitable alternative food supplies may not be available at the time when the normal food-species is wiped out. And although a chemical may have immediate adverse effect on organisms in a system, if it has long chemical and biological half-lives (so that it can be accumulated by organisms to high levels) it can give rise to adverse effects on consumers high up the food web.

Major ecological aspects of concern involve such things as how a chemical directly or indirectly affects all population characterisics - size, dynamics, age-structure, and so on, how it affects relationships between populations, how it affects community structure, diversity and functioning; how it affects material and energy flows in ecosystems and so on. There seems to be no way of predicting what these interactions will be and little real progress has been made in this field anywhere in the world. Generally it is not even known what relationships are involved and certainly most of them are unquantified. Monitoring serves to demonstrate what the effects of exposure have been, but this can only be quantified if sufficient environmental information is available before wastes are released.

One major ecological characteristic which should be taken into account however, in setting standards is that of the type of "strategy" by which a particular species maintains its population. Essentially, there are those species which are short-lived, but which have a high rate of increase and are successful in colonizing and exploiting to their advantage competitively the resources of ephemeral habitats. Organisms with this type of strategy ("r-selection") succeed better in fluctuating "stressful"situations than do species with low rates of increase, which are long-lived, and generally have populations typically at or near saturation level in any particular habitat ("K-selection"). It is species with this latter type of strategy and which tend to require relatively stable environments which are particularly vulnerable and to which greater attention ought to be paid when determining environmental standards.

Concept of Radiotoxicology

Radionuclides have the capacity to damage living tissues not only by their chemical properties but also by a physical property, namely that of the radiations which they emit. It is the latter aspect which is looked at here for the purpose of putting this form of hazard into overall context of environmental problems. Because it is generally believed that no threshold exists for the induction of carcinogenesis (the main hazard from ionizing radiation in the present context) this property of such radiation is usually of greater concern than are any of the chemical properties of the substances involved. But there are exceptions. In the case of uranium, for example, chemical toxicity is considered as being more important than radiotoxicity in man (under "typical" conditions of exposure) and in other organisms in the environment at large.

Like other heavy metals metallic radionuclides tend to accumulate within the bodies of organisms, and thereby subject internal organs to relatively high levels of radiation, often over prolonged periods of time. (Such high internal contamination, the radiation from which an organism cannot excape, represents a greater hazard then does the presence of the radionuclides involved at lower concentrations in the environment at large.)

The harmful effects of radionuclides arise not from the specific properties of their radiation but from the highly reactive substances (electrically-charged radicals) and molecular fragments which they produce in living tissue. These chemicals react abnormally within cells, disturbing metabolic pathways and producing abnormal substances, some of the reaction products or structural changes being eventually harmful. In contrast to chemical poisoning, however, in which every substance has its own specific reactions, the property of causing ionization is common to all radionuclides irrespective of their chemical character, and the overall result of iradiation from any mixture of radionuclides can therefore be summed (in terms of a common effect). This is something which is absolutely impossible to do in the case of chemical poisoning (except when this involves acutely lethal conditions). This is a fundamental difference to be recognized between chemical toxicity and radiotoxicity. However, common to both types of poisoning is the need to determine dose-response relationships.

Two final points might be made here with regard to the effects of ionizing radiation in the environment at large. The first is that it is, in general, the more highly "evolved" organism (i.e. those highest up the phylogenetic tree) which are the most sensitive to such radiation; and, the second, that for any particular organism the most vulnerable states, for any given dose of ionizing radiation, are the early developmental stages, the "single-cell" stage (including the gametes) being the most sensitive.

Hazard Assessment

Hazard assessment is a complex subject which can only be touched on briefly here, to bring out some of the salient features with regard to the setting of water quality standards for the purpose of environmental protection.

As was indicated earlier, because of the innate problems of toxicology, and the great variability of the reacting organism and of the interrelationships involved, assessment of risk to any ecosystem from a particular chemical or waste cannot be made with accuracy, precision, or even necessarily correctness. Because of the almost inevitable absence of information on the identity and ecology of the particular species most at risk, of of probable levels of exposure and so on environmental standards have commonly been based elsewhere on simple characteristics such as EC50, LC50 values (often for short exposures), with or without extrapolation involving the use of concentration-response curves. This is an incorrect approach to environmental protection. It has become recognised more and more in recent years that basically what is required in all cases is information on the maximum "no-observed-adverse-effect-level" (NOAEL) of some waste or chemical for various highly sensitive responses (eg. reproduction, survival of early-life stages,, larval and juvenile growth, effects on respiration etc) over exposure periods reflecting those likely to be encountered within the environment.

But even when such information is available, the interpretation of risk is not a simple one. As indicated earlier the maximum level at which a "no-effect" level is detected depends on sample size. Thus, for example, the maximum concentration at which some waste or chemical was found not to produce any adverse effect on a test involving 100 animals (a sample size much greater than that typically used in such studies) could, at the 99% probability level still have a true risk of 4.5%. Such a degree of risk addition to that already existing naturally for a species would seem to be quite unacceptable for the protection of their populations and on the basis of this factor alone the "no-effect" concentrations would have to be "appropriately" reduced. In the case of environmental protection therefore, the problem to be resolved is whether such levels of risk could be regarded as constituting "change" rather than "damage" to an ecosystem. As indicated earlier, species having a short generation time, large populations, able rapidly to exploit a particular habitat/food resource and so on, tend to be less vulnerable to adverse conditions than are species not possessing these characteristics. With the former type of species it is possible to contemplate the destruction of a large part of its population as not constituting "harm" - simply because the population can readily recover. For such types of organism then, "acceptable change" might even include what might be considered as being short-term "damage" without this necessarily being harmful to the species or the ecosystem in the long term. Such would not be the case, however, for a species taking a long time to mature, slow to reproduce, having few offspring and so on where damage to even a relatively small part of the population of which could seriously affect its survival.

In seeking a rational basis for the determination of standards to apply in the case of discharges to sample waters effectively untouched by man, and whose ecology is largly unknown, great problems arise. These are not helped by the toxicological uncertainties involved (as discussed earlier) or uncertainties about the qualities of waters which it is _________ to release. However as the waste substances of concern are virtually all ones occurring naturally in the area then evidence is available now (as it would not be for "exotic" compounds) of concentrations which are presently acceptable. This contributes therefore a sensible starting point from which to attempt to derive standards. Even the highest concentrations at which heavy metals occur are self-evidently tolerable and these concentrations must therefore be substantially below their maximum "no-effect-level" (although, unfortunately, how far below is not yet known). With the exception of ammonia the substances involved (i.e. heavy metals) are harmless or slow-acting at the sorts of levels being considered here. Consequently, on the basis of the large body of evidence available from the field of human industrial health management it is indicated that for short periods of time levels of individual heavy metals could go up by possibly a factor of two or three (at least) from their present levels without causing irreverisble damage. (The accepted "wisdom" in industrial health management is that "momentary" peaks of slow-acting substances are of "no toxicological concern provided that they are not astronomic").

Ammonia, a substance of particular concern here, is not, however, something which can be dealt with in this way. Ammonia is quick-acting as a poison and therefore any "excursion" in concentration from some defined mean level can only be very small and of brief duration. The approach adopted in this paper is, however, much more conservative than that accepted in industrial mealth management. This is justifiable (and necessary) because, among other things, in nature a knowledge of the exact exposures involved in generally not available, as it is in the factory environment and control of exposures is difficult or impossible to ________. Furthermore, should some high sensitive organism be suffering an unacceptable degree of exposure this will not readily be detected <u>at an early stage</u>, (as it might be with man), nor can the organism necessarily "escape" (as can man) to some "safe" place for recuperation. Additionally, however because the area involved is one of great conservation value as a national park t=and the water source is an important source of food and water for local people a greater degree of caution must be shown than might be necessary in other areas. Initial (provisional) standards must err (if they are to err at all) on the side of diminishing any risk, not increasing it. This does not mean that if in due course, evidence becomes available to demonstrate the inappropriation of any standard that this cannot be amended (either up or down) as deemed appropriate.

Nevertheless, it should be recognised that the approach adopted here does rely on the validity of a number of assumptions. These are:

(a) that the higher concentrations at which particular substances are present are randomly distributed in time (risk of harm being a function of both concentration and time),

(b) that changes in the ratios at which particular chemicals are present (and this would include such things as calcium and magnesium) do not effect toxicity.

(c) that unknown substances of high toxicity are not present in thie waste, and

(d) that chemical speciation (and biological availability) do not differ from those occuring naturally.

The result of these assumptions requires investigation The only time assessment of how loxic any waste is can only be obtained by appropriate toxicity testing which replicates in time and concentration the likely nature of the exposures involved. It cannot be determined, for example, by "on-going" monitoring while a waste is being released. Systemic adverse responses may (and almost certainly will, at low exposures) take some considerable time to be revealed. Consequently it is essential that at an early date as possible waters to be released are identified and tested. Such tests may well reveal that levels __________ than those proposed here are acceptable. However, it is considered that in the absence of such test data the present approach is a basis for the setting of initial provisional standards.

3. Identification of Hazardous Constituents

The list of water quality variables which are currently measured in the monitoring programmes of the Northern Territory Supervising Authorities and of the mining companies for both the natural and impounded waters of the Alligator Rivers Region is extensive. It was drawn up on the basis of the recommendations of the Fox Inquiry and on the basis of previous experience in uranium mining, notably at Rum Jungle. Since the initiation of these monitoring programmes much new information has been obtained and it is appropriate, before recommending receiving water standards for the ARR, to review the list of variables in the light of information now available.

Hazardous constituents are defined, for the purposes of this document, to be those substances which may be present in the impounded waters ar the uranium mines in concentrations at which they could, if released to the environmental waters, give rise to detrimental effects on the aquatic ecosystem or present a hazard to manthrough ingestion. Such constituents may already be presentinthe natural waters but at concentrations at which thay have no deleterious effects on the ecosystem. They may also be substances no found in the environment.

The hazardous constituents will consistofboth radi~~i~~oactive and non-radioactive substances. The former are easily identified by the nature of the ore, but the identification of the latterrequires the adoption of a logical procedure which will reduce the potentially infinite list of contaminants to a finite list of significant constituents.

In the present review, the list of hazardous constituents has been obtained by examination of the enrichment of elements in the ore bodies, by determination of those substances introduced in the milling process, and by limitation of the list to those substances which, in the opinion of the U.S. Environmental Protection Agency (USEPA), should be included in the development of water quality standards.

3.1 Hazardous Non-Radioactive Constituents

Hazardous constituents may be derived from two sources associated with uranium mining and milling. These are: (a) constituents of ore and waste rock which may be mobilised as a result of mining, and (b) constituents which arise from substances used in uranium milling and which may be foreign to the natural environment.

3.1.1 Constituents Derived from Ore

A basis for considering which elements from ore are likely to be significant hazardous constituents was made by examining the available data for concentrations of elements in ores and waste rock at the Ranger mine and ores at the Nabarlek mine and comparing these concentrations with those in natural rocks of the Alligator Rivers Region. The reason for doing so is that the natural creek water chemistry is determined by rainwater-rock interactions while water passes over and through the regional soils and rocks. Changes in water quality due to mining of the ore are therefore likely to arise primarily for those elements which are enriched in the ore bodies compared to the natural regional rocks.

Concentrations of elements in Ranger ore and waste rock and in Nabarlek ore were compared with average ARR rocks. Information was available on concentrations of a considerable number of elements in Alligator Rivers Region rocks but data for both ores and waste rocks was more limited. A summary of the data is given in Appendix A. Elemental data for rocks and ores was compared with average ARR rock abundance by the calculation of their enrichment factor, defined as follows:

$$\text{Enrichment factor } EFx = \frac{(\frac{Cx}{Cs})\text{ sample}}{(\frac{Cx}{Cs})\text{ crust}} \qquad \frac{(Cx/Cs)\text{ sample}}{(Cx/Cs)\text{ ARR}}$$

where Cx is the concentration of the element and Cs = Concentration of Rubidium. Rubidium was chosen as the element against which to normalise data because accurate data exist for this element in Alligator Rivers Region rocks and ores. The concentration of rubidium does not vary markedly between rocks and ores in the A.R.R.

The question arises of what value of enrichment is considered to be significant. The choice was primarily determined by the fact that the mean dilution of released waters by the natural creek waters under conceivably suitable hydrological conditions is expected to be a factor of 100 or more. The use of an enrichment factor of greater than 10 should then provide a safety factor of 10. It should be borne in mind that the water bodies being considered as candidates for release at Ranger are not recipients of water from those circuits of the mill in which chemical processing of the ore takes place, so that additional chemical enrichment does not occur. This comment does not apply with equal validity to Evaporation Pond 2 at Nabarlek because processed tailings water is present in EP2. Further assessment of metal concentrations is therefore required at Nabarlek. Although the choice of a minimum enrichment factor is somewhat subjective, it does receive retrospective justification in the analysis of Chapter 6, where both copper and lead, elements considered only because of their enrichment in ore, are found to produce concentration increases in creek water which are well contained within the observed natural fluctuations.

The number of elements to be considered here as being possibly high risk constituents was reduced by including only those for which water quality criteria are given by the USEPA, or are deemed by USEPA to warrant consideration in the development of water quality standards. These elements were as follows:

a. Elements (or their more toxic compound forms) for which water quality criteria are given by the USEPA.

Arsenic
Barium
Beryllium
Boron
Cadmium
Calcium
Chromium
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Phosphorous
Selenium
Silver
Zinc

b. Elements for which the USEPA gives no water quality criteria but states that they should be included in the development of water quality criteria.

Aluminium
Antimony
Bromine
Cobalt
Fluoride
Lithium
Molybdenum
Thallium
Uranium
Vanadium

In addition pH, bicarbonate, sulphate, ammonia, nitrate/nitrite together with total and dissolved organic carbon and suspended solids are not listed here but will be included and discussed later. These variables are included in the USEPA list for water quality criteria.

The following summarises the conclusions from the study of enrichment factors and includes only those elements by the USEPA (pararagraphs 'a' and 'b' above):

(1) Elements showing enrichment relative to ARR rocks (i.e. with enrichment factors greater than 10) are as follows:

Ranger Ore	**Nabarlek Ore**
Copper	Copper
Cadmium	Lead
Lead	Uranium
Uranium	

(2) Elements for which no data are available.

Ranger Ore	**Nabarlek Ore**
Selenium	Lithium
	Boron
	Fluorine
	Selenium
	Bromine
	Thallium
	Mercury

The data set for waste rocks is not as extensive as that for ore (see appendix A). Nevertheless, it is noted that, for all elements which have enrichment factors greater than unity in ore, enrichment in waste rock is less than in ore. The final list is of hazardous constituents has, therefore, been assessed on the basis of enrichment in ore only.

3.1.2 Constituents Derived from Milling Processes

Several compounds are used in uranium milling to assist with the extraction of uranium from ore and in conjunction with various activities associated with uranium milling. Knowledge of all of the substances under this sub-heading is not extensive. However, the number of substances arising from milling processes will be far less extensive for EP2 at Nabarlek than for RP2 at Ranger. This is because RP2 has received unrestricted run-off whereas EP2 has received "treated" waters.

Constituents which might constitute a risk, and their sources at the Ranger site were as follows:

Pyrolusite (Manganese)	Extraction Process
Lime (Calcium, Magnesium, Cadmium,Phosphate)	Tailings Treatment
Sulphur	Sulphuric Acid Production
Sulphuric Acid	Extraction Process
Iron	Mill Grinder
Vanadium	Catalyst in Sulphuric Acid Production
Ammonia	Extraction of Uranium
Groundwater (Bicarbonate, Calcium, Magnesium)	Make up Water
Nitrate/Nitrite	Sewage and Soluble Explosive Residue
Alamine 336	Solvent Extraction
Kerosene	Solvent Extraction
Dodecano	Added to Solvent Extraction
Detergent Additives	General Use in Mill
Distillate	Power Station
Oils and Greases	Power Station and Mill
Chromate Inhibitor	Small Quantities
Pesticides and Herbicides	Limited use on Mill site
Zinc and Cadmium	Galvanised Iron Roofs
Nickel and Chromium	Stainless Steel ware
Polychlorinated Biphenyls (PCB)	Transformer Oil

Phenols may be present as impurities in fuels including distillate and may find their way to RP2 via rainfall run off. Kerosene and distillate have a half life of less than 100 hours before evaporation. However, the evaporation rate depends upon the exposure area and the quantity of material which is free floating. The high intensity of ultra-violet radiation at Jabiru would assist in the photo-degradation of hydrocarbons.

Emulsified oils and greases have been commonly observed in RP2 water and in association with sediments at the bottom of RP2. Thus biological oxygen demand (BOD) and dissolved oxygen level could constitute significant criteria in determining the suitability of water for biota, if waters are to be released from RP2.

Currently run off to RP2 from various stock piles and mill areas is unrestricted. These include run off from the following areas:

- the elemental sulphur pile
- the pyrolusite pile
- adjacent mill plants including the power station, acid plant, solvent extraction plant and other buildings
- the crushing area and lime stockpile

In general RP2 is the recipient of unrestricted run off. Impurities in the various materials used in the mill processes are not known and may include chemicals constituting significant risk.

Sources of hazardous constituents identified at the Nabarlek site were as follows:

Pyrolusite (Manganese)	Extraction process (prior to use of Caro's acid - hydrogen peroxide)
Hydrogen Peroxide	Extraction process (Caro's acid, other impurities unknown)
Barium	Tailings Treatment
Lime (Calcium, Magnesium, Cadmium, Phosphate)	Tailings Treatment
Soda Ash (Sodium Carbonate)	Occasional neutralization of acid in EP2
Sulphuric Acid	Extraction Process
Iron chloride	Extraction Process
Kerosene	Solvent Extraction
Alamine 336	Solvent Extraction
Ammonia	Solvent Extraction
iso - Dodecanol	Added to Solvent Extraction

Floc agents (Floc 351, Floc 156 unknown composition)	Added to Tailings
Sodium Hydroxide	Neutralisation of acid
Zinc and Cadmium	Galvanised Iron Roofs
Shellsol (Organic solvent), other oils and greases	Minor Plant Use
Detergents and Sewage	Laundry, shower, soap wastes all transferred to EP2.
Pesticides and Herbicides	Limited use on Mill site

The power station at Nabarlek is located away from the mill site and it is highly unlikely that distillate would find its way into EP2. Many of the other chemicals found in RP2 do not occur in EP2 because unrestricted run off to EP2 from other mill activities does not generally occur.

It should be noted that hydrogen peroxide rapidly degrades in solution in the presence of sunlight. Minute amounts, less than 1ppm may cause manganese in solution to be oxidised, i.e. be converted to $Mn\ O_2$. Particulate manganese can concentrate heavy metal ions in solution by anion-exchange process. Other metals are not present at sufficiently high concentrations to cause any changes to their chemical speciation. However, the presence of hydrogen peroxide in EP2 would assist the oxidation of organic compounds.

An increase of sodium in EP2 water is not likely to have any deleterious environmental effect and will not be further considered. The co-anion of sodium is ultimately sulphate. Silica is ubiquitous and its presence in waters is reflected by the level of suspended particulates. Soluble silica is not considered to be an environmental threat. A problem arises with the exotic organic compounds Alamine 336, dodecanol and detergents. Both Alamine 336 and dodecanol are used in solvent extraction of uranium and may therefore find their way into RP2 and EP2. Various detergents of unspecified chemical composition are used in both Ranger and Nabarlek mills. There are no available toxic limits for these substances and they will not be further considered in a specific way in this document. It is therefore important that, while the standards developed here should be used to establish the suitability of a particular water body for release under specified discharge conditions, any release should be subject to the presence of a suitably designed on-line biological testing station.

3.2 Hazardous Radioactive Constituents

Both uranium and thorium are enriched in the ore bodies of the ARR so that enhanced concentrations of all radionuclides in the two natural series occur in the impounded water bodies at Ranger and Nabarlek. Thorium concentrations are, nevertheless, lower than uranium by approximately a factor of 100 so that the radiation hazard is dominated by the uranium series radionuclides. Only the latter are considered in this document.

The time scale for surface water transport of contaminants is measured in days rather than hours. This is followed by bioaccumulation, harvesting of food, and ingestion by man. Thus only the long-lived radionuclides need be considered directly, although the hazard associated with the short-lived daughters which they support is taken into account indirectly by the use of appropriate annual limits on intake. The long-lived radionuclides of the uranium series are ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, and ^{210}Po. These are the hazardous radioactive constituents for which standards must be determined.

3.3 Summary of Hazardous Constituents

The hazardous constituents and other water quality variables which must be considered and for which receiving water standards should be derived , have been determined on the basis of the considerations outlined in sections 3.1 and 3.2. The list is presented in table 3.1. (A more extensive table which summarises the origin of each of the constituents is presented in appendix A.)

Those elements for which no information is available on ore concentrations at Ranger and Nabarlek have not been included, but it is recommended that the companies be required to provide the necessary information which will allow an assessment of their potential significance to be made. The elements are selenium for Ranger, and lithium, boron, fluorine, selenium, bromine, thalium and mercury for Q.M.L.

Some substances indentified as arising from mill operations have been excluded either because they have been replaced by suitable general chemical parameters (e.g. dissolved oxygen) or because reasons for their exclusion have been given previously. In addition, other general physico-chemical variables (pH, alkalinity, turbidity and suspended solids) have been included because they reflect requirements of biota in the ecosystem.

Although the list of constituents has been compiled as a result of examination of the individual mining operations of two separate companies, it is presented as a list of water quality variables requiring assessment in the ARR. This is not inconsistent since the choice of variables which will be specified as requiring measurement in an authorisation for release will be necessarily more restrictive than shown in table 3.1 and will reflect not only the differences between the individual operations identified previously but also the assessment of the known water quality history of the particular water body under consideration.

A summary is presented in table 3.2 of the environmental significance of the hazardous constituents and other water quality variables. The radionuclides, with the exception of uranium, are excluded from this table since they are only considered to present a risk to Man. Included, however, is a description of the significance of those elements on which no information is available on ore body concentrations.

Table 3.1

Chemical Constituents of Environmental Significance

pH

Turbidity

Dissolved Oxygen

Sulphate

Ammoniacal Nitrogen

Nitrate and Nitrite

Phosphate

Total Phosphorus

Alkalinity

Total Organic Carbon

Dissolved Organic Carbon

Suspended Solids

Barium

Cadmium

Calcium

Chromium

Copper

Iron

Lead

Magnesium

Manganese

Nickel

Vanadium

Zinc

^{238}U, ^{234}U

^{230}Th

^{226}Ra

^{210}Pb

^{210}Po

Table 3.2

Environmental Significance of Chemical Constituents

Description

Variable	Environmental Significance
Sulphate	Plant macro-nutrient. May be reduced to sulphide under reducing conditions with reversal of reaction under oxidising conditions. With high levels of calcium will precipitate as calcium sulphate.
Ammoniacal nitrogen (NH_3-N)	Plant macro-nutrient. Free ammonia is toxic form to animals and increases in concentration in water pH (particularly above pH7). Under oxidising conditions ammonia converts to nitrate.
Nitrate and nitrite nitrogen (NO_3/NO_2-N)	Plant macro-nutrient. In chemical equilibrium with ammonia. Biota take up nitrate and release ammonia. Nitrate can be toxic in drinking water.
Total phosphorus phosphate	Macro-nutrient. Cycled but not destroyed chemically. Phosphate taken up by biota is in ortho-phosphate form. Inactive form is insoluble inorganic phosphate.
Suspended Solids	An indicator of the concentration of particulate matter in water. Influences light transmission and if high my eventually be deposited at site of slack water.
pH	Indicates the concentration of hydrogen ion present in solution. Controls chemical behaviour of most chemical species.
Alkalinity	Arises from the bicarbonate/carbonate ions in solution. Indicates the ability of a solution to neutralise the effect of adding hydrogen ion (buffering capacity). The absence of buffering capacity may result in a decrease in pH if acid is added to the water.
Turbidity	Indicates light scattering properties of particles in the water.
Total Organic Carbon	Indicates the amount of organic matter present in the

Table 3.2 Cont'd

Variable	**Environmental Significance**
Dissolved Organic Carbon	water. When high, bacterial activity can reduce dissolved oxygen concentrations in water.
Calcium and Magnesium	Macro-nutrients. Ratio of both ions is important to aquatic biota. Both ions remain in solution at pH<6.0. In the presence of high sulphate ion concentrations calcium precipitates as calcium sulphate as neutral pH. At higher pH(>8) hydroxides of both cations form. High doses of magnesium cause diarrhoea, ataxia, and death; excess magnesium denatures serum proteins; required for enzyme transport functions.
Manganese	Present as particulate or colloidal MnO_2 at neutral pH and under oxidising conditions. MnO_2 is a very strong ion exchanger for heavy metals in solution and can act as a carrier for these metals leading to deposition following coagulation. Under reducing and acidic conditions MnO_2 and any adorbed metal ions go into solution. Manganese undergoes Redox behaviour. Affects central nervous system causing cramps, tremors, hallucinations; causes manganic pnumonia and renal degenration.
Iron	Exists in solution at low pH. Above pH7 iron exists in particulate form under oxidising conditions as hydrated ferric oxide. This precipitate behaves as an ion exchanger in natural waters. Exists in natural waters as particles coated with humic material which enhance the ability to adsorb free metal ions in solution. Essential; required for hemoglobin requirements dependent on age and sex; FEII not excreted; supposedly causes benign pneumoconiosis; has synergistic effects with SO_2 and carcinogens; inhibits gluose-6-phosphates, succinic acid dehydrogenase, and other oxidative enzymes.
Copper	Free ion is toxic to biota but availability of the free ion is reduced by the presence of humic materials in natural waters which complex the free copper ion. Above pH 6.5 the free ion also undergoes reactions to form insoluble inorganic particulate and colloidal species (hydroxy and carbonate forms). Free ion is concentrated by algae. Essential in trace amounts; found in hepatocuprein, cytochrome C oxidase, and ceruloplasmin; involved in a number of enzymes, e.g., phenol oxidasis and cytochrome oxidases; hemolysis from high concentrations.

Table 3.2 continued

Variables	**Environmental Significance**
Lead	Free ion is the toxic form to biota, and can accumulate in high levels. Is complexed by humic materials. The most dominant forms of lead is natural waters in inorganic (lead hydroxy carbonate) and is insoluble. Metabolism similar to Ca; accumulates in bones and soft tissues, particularly in the brain, resulting in reduced functioning; complexes with S-H groups, inhibits biosynthesis of heme, particulaly in conversion of J amino levulinic acids to prophobilinogen, inhibits formation of heme from iron and protoporphyrin, decreases formation of δ-amino levulinic acid, decreases conversion of protoporphyrin IX; causes loss of amino acids, glucose, and phosphate in urine by structural damage to mitochondria of kidneys; has been linked to increased dental caries and is poorly excreted.
Cadmium and Zinc	Free ions are the toxic forms to biota; both exhibit similar chemical behaviour and tend to be adsorbed on particulate matter in natural waters. Above pH 6.5 they are completely precipitated as carbonate and hydroxy species. Zinc is contained in a number of metalloproteins and enzymes; large amounts cause malaise, dizziness, vomiting, diarrhoea; required for skin repair. Cadmium depresses growth and reduces protein and fat digestion; causes hypertension and cardiovascular problems; accumulates in kidney, liver, and reproductive organs; replaces Zn and binds irreversibly; causes proteinuria, glycosuria, carcinomas, edematons, and proliferative and fibrogenic effects on lungs.
Barium	Forms an insoluble carbonate, sulphate and fluoride. These insoluble barium compounds are rapidly removed from solution by adsorption and sedimentation. No known requirement; used as marker in digestive tract; similar to Ca in its properties; highly toxic when ingested; causes vomiting, diarrhoea, affects central nervous system; causes convulsions; causes stomach, intestines, and kidneys to hemorrhage; causes pneumoconiosis; stimulates all muscles.

Table 3.2 Cont'd

Variable	**Environmental Significance**
Chromium	Toxic to biota in hexavalent form (dichromate, Cr VI) but essential in trivalent form (Cr^{3+}). Redox conditions determine which form of chromium is in solution. CrVI more toxic than CRIII; combines with β-globulins; essential for normal metabolism of glucose; causes perforation of nasal septum, congestion, hyperemia, emphysema, tracheitis, bronchitis, pharyngitis, bronchopneumonia, cancer of respiratory tract, and dermatitis.
Vanadium	Essential for some biota eg. algae, at low concentrations. Exists in variable oxidation states (2-5) but pentavalent compounds are most stable (vanadyl ion VO^{2-}). Anionic forms are more toxic than cationic forms and pentavalent compounds are more toxic than lower valence states. Mobilizes Fe to liver and Ca to bones; inhibits synthesis of cholesterol, phospholipids, and other lipids and amino acids (theoretic acid, uric acid); inhibits activities of following enzymes: tyrosinase, nathine reductase, zanthine, cystine, and nitriate reductase; has adverse bio-effects on tissue oxidation; inhibits sulfydral activity, reduces blood lecithin content and precipitates serum proteins; inhibits excretion of corticosteroids, acetylcholine metabolism, liver acetylation process, activities of coenzymes A,Q, and I, adenosine triphosphatases.
Uranium	Non-essential. Generally exists as uranyl ion in the aquatic environment.
Nickel	Essemtial. Has similar chemical behaviour to both iron and cobalt. Involved in enzyme activity, hormonal action, structural stability of biological macromolecules, and general metabolism; causes dermatitis, respiratory disorders, and cancer of respiratory system; reduces activities of cytochrome oxidase, isocitrate dehydrogenase of liver, maleic dehydrogenase of kidney.
Lithium	Forms insoluble carbonate and hydroxide but has a soluble bicarbonate. Other chemical forms are generally water soluble. No known requirement; reversible kidney damage from Li accumulation of high Li doeses or low Na doses.
Boron	An essential element for plant growth but no evidence that it is required by animals.

Table 3.2 continued

Variable	**Environmental Significance**
Fluoride	Exists in solution as a co-anion. Forms insoluble salts with Ca, Mg, Sr and Ba. Precipitation occurs only when solubility product is exceeded.
Selenium	Essential element. Elemental selenium must be oxidised to the selenite or selenate forms before it has apreciable solubility in water. Complexes with plasma proteins and is distributed to all tissues; replaces S in cystine, methionine; connected with increase in dental caries in children; irritates eyes, nose, throat, and respiratory tract; causes cancer of liver, pneumonia, degeneration of liver and kidney, and gastrointestinal disturbances; blocks some enzyme systems; found in mammary gland secretion.
Bromide	Has chemical similarity to chloride. Little information available.

Table 3.2 continued

Variable	**Environmental Significance**
Thallium	Not an essential element. Forms soluble mono- and trivalent ions (Tl^+ is more stable than Tl^{3+}). Tends to exist as Tl^+ in nature and this ion resembles and behaves like potassium. Accumulates in erythrocytes, agglutinates, and lyses erythrocytes; accumulates in kidney, bone, and soft tissue.
Mercury	Inorganic mercury can be readily converted to methylmercury under reducing conditions by bacterial activity. $Hg+$ salts oxidised by tissues and erythrocytes to highly toxic Hg^2+; Hg retained by liver, kidney, brain, heart, lung, and muscle tissues; complexes with - SH groups; inhibits S-amino-leulinic acid dehyratase and chlorinesterase activity; Hg protoplasmic poison, damages central nervous system.

Appendix A.

Concentrations of Elements in Rocks and Ores from the Alligator Rivers Region

Data for the concentrations of elements in rocks and ores from the Alligator Rivers Region was obtained from various published and unpublished references. These references are listed at the end of this appendix. Mean elemental data for rocks and ores are listed in Table 1.

Elemental data was used to calculate the "Enrichment Factor" relative to "Average World Crustal Abundance" and "Alligator Rivers Region Rocks".

The Enrichment Factor was calculated using the following equation:

$$EF_x = \frac{(\frac{Cx}{Cs})\ \text{Sample}}{(\frac{Cx}{Cs})\ \text{Crust}} \qquad \text{where } Cx = \text{Element},\ Cs = \text{Rubidium}$$

Rubidium was used as the element against which to normalise elemental data, as described in section 3.1.1.

A summary of all data is given in Table 1.

Listed below are the references from which the data was obtained.

1. Elemental Average Crustal abundance

   (Crust and Granite) Table 5.1, "Trace Element Analysis of Geological Materials", R.D. Reeves & R.R. Brooks, John Wiley and Sons Inc, New York, 1978.

2. Alligator River Region Rocks.

   * Private communication from Ranger Uranium Mines.

   * Various papers in IAEA - Uranium in the Pine Creek Geosyncline - Proceedings of the International uranium symposium on the Pine Creek Geosyncline, Sydney 4 - 8 June, 1979, Vienna, 1980.

The BMR Geology and Geophysics Record 1982/7 G.R. Ewers, "Chemical Analysis of Early Proterozoic Meta-Sedimentary Rocks from the Pine Creek Geosyncline."

3. Ranger Ore and Ranger Waste Rocks.

* Private communication from Ranger Uranium Mines.

* IAEA "Uranium in the Pine Creek Geosyncline". 1980

* R.J. Ring, Proceedings Australas. Inst. Mine Metall. 242 Dec. 1979.

4. Nabarlek Ore.

* Queensland Mines Ltd. Final Environmental Impact Statement, Nabarlek Uranium Project, Table 2.5. "Ore Analysis".

* IAEA "Uranium in the Pine Creek Geosyncline".

* G. R. Ewers, Bureau of Mineral Resources Canberra data used in G. R. Ewers, John Ferguson and T. H. Donnelly "the Nabarlek Uranium Deposit, Northern Territory, Australia: Some Petrologic and Geochemical Constraints on Genesis" Economic Geology 75, 823-837 (1983).

Table A.2

Chemical Constituents of Environmental Significance

Source of Constituent and Relevance to Ranger and/or Nabarlek

Variable	**Monitored**	**Source at Ranger**		**Source at Nabarlek**	
		Mine	Mill	Mine	Mill
Sulphate	*		*		*
Ammoniacal nitrogen (NH_3-N)	*		*		*
Nitrate and Nitrite nitrogen (NO_3/NO_2-N)	*	*	*	*	*
Total Phosphorus	*		*		*
Phosphate	*		*		*
Suspended Solids	*	*	*	*	*
pH	*		*		*
Alkalinity	*		*		*
Turbidity	*	*	*	*	*
Total Organic Carbon	Some Data		*		*
Dissolved Organic Carbon	"		*		*
Calcium	*		*		*
Magnesium	*		*		*
Manganese	*		*		*
Iron	*		*		*
Copper	*	*		*	*
Lead	*	*		*	
Cadmium	*	*	*		*
Zinc	*		*	–	*
Barium					*
Chromium	Some data		*		*
Vanadium			*		
Uranium	*	*		*	

4. Criteria for Assessing Acceptable Risk

The development of criteria by which we can judge whether or not the objectives of a water release standards scheme will be met requires clarification of what is meant by an "acceptable risk", and an evaluation of how the achievement of this acceptable risk may be established. Below we discuss these topics under two headings: Risk to Man, and Risk to the Ecosystem.

4.1 Risk to Man

Assessment of the risk to Man is conveniently divided into risk due to exposure to ionising radiation as a result of the introduction of radionuclides into the food chain, and the risk due to metal toxicity by similar processes.

4.1.1. Radiation Exposure

Two practical radiation exposure problems are assessed in this document. The exposure resulting from the release of waters from the QML Mill at Nabarlek into Cooper Creek will be short term, i.e. lasting for a few years, since release is being considered only on a few occasions during the decommissioning stage of the mill. At Ranger, however, release of waters into Magela Creek is being considered as part of the long term water management strategy. Such releases will, if approved, take place over many years and will lead to long term exposure.

In the case of risk to Man from ionising radiation both the definition of acceptable risk and its evaluation have been well delineated by the International Committee on Radiation Protection (ICRP 26 and 30) and by the International Atomic Energy Agency (IAEA Safety Series No. 9). Recommendations are given on the stochastic and non-stochastic dose limits which should apply both for radiation workers and for members of the general public. In addition, secondary limits on the annual intake of particular radionuclides (ALI) are derived for radiation workers. No firm recommendations have been given, however, by ICRP on annual limits on intake for the general public.

Annual limits on intake for the general public (ALI_p) have been used in the present assessment of the radiation risk to man resulting from the release of contaminated waters into surface waters of the ARR. Details of the derivation of these limits are given. The paragraph references given for ICRP and IAEA refer to ICRP publication 26 and IAEA Safety Series 9 respectively.

Limits on Dose-Equivalent

The stochastic limit on the annual effective dose equivalent recommended by ICRP(119) and IAEA (418) for the general public is 5 mSv. However both ICRP (122) and more explicitly IAEA (419) recommend that, in cases where the same individual member of the public could be exposed at or near the 5 mSv limit for prolonged periods (many years), it would be prudent to restrict the annual limit to 1 mSv. In considering the two types of exposure mentioned above we have, therefore, used the following stochastic limits; 5 mSv dose-equivalent per annum for short term exposures, 1 mSv dose equivalent per annum for long term exposures.

The non-stochastic limit on the annual effective dose equivalent for the general public is given in ICRP (126) and IAEA (418). It is 50 mSv for each tissue or organ.

Secondary Limits for Critical Group Consisting of Adults Only

For occupational internal exposure the appropriate secondary limit for each long lived radionuclide is the Annual Limit on Intake (ALI). This limit is defined by IAEA (903) to be the lower of the intake per annum by reference man which would result in:

(a) a committed effective dose equivalent of 50 mSv - ALI_s.

(b) a committed dose equivalent in the lens of the eye of 150 mSv or 500 mSv to any other tissue or organ - ALI_n.

Thus the limit may arise from either stochastic or non-stochastic effects.

If the critical group being considered in cases of exposure of the general public consists of adults whose age and sex frequency distribution is similar to that of workers, then a suitable public annual limit on intake (ALI_p) may be defined in terms of the worker ALI by comparing the public and worker dose-equivalent limits. However, ICRP 39 shows that the application of the stochastic limit on committed effective dose equivalent for members of the public is in itself ~~in~~adequate in the prevention of non-stochastic effects. X For this reason only the stochastic limits, ALI_s, are considered in the determination of ALI_p. Thus the public limits become:

- Short term exposure; $ALI_p = 0.10 \times ALI_s$
- Long term exposure; $ALI_p = 0.02 \times ALI_s$

Critical Group Containing Infants or Children

Dose Equivalent

ICRP (127) makes it quite clear that "in the calculation of dose-equivalent ..... account must be taken of differences in organ size or metabolic characteristics of children." IAEA (A.IV.500) gives guidance on how to take these differences into account in the two cases of short and long term exposures and when using the secondary limits on annual limits on intake for the public. The suggestions are:

- Short Term; the ALI_p should be reduced by 1/10 to take into account the smaller mass of organs of the critical infant or child
- Long Term; the ALI_p should be reduced by 1/2 to take account

of the mass of organs averaged over a lifetime, as the organ masses increase as individuals become adult.

Using the correction factors given above, the appropriate annual limits on intake for the general public for a critical group containing infants or children become:

- Short Term exposures; $ALI_p = 0.01 X ALI_s$
- Long Term exposures; $ALI_p = 0.01 x ALI_s$

Effect of Use of an Adult Diet

The above considerations of annual limits on intake for a critical group containing adults and children clearly assume that the limits apply to best estimates of actual intake using a realistic diet for adults and children. The diet used in the water release study is that for an adult and suitable adjustment must be made for the actual intake by children.

The simplest method of adjusting the diet is to assume that the composition of the child's diet is similar to that of the adult but that intake is reduced by the ratio of adult to infant intake given in ICRP 23, namely a factor of 3. Thus when the full correction of 1/10 has been applied to take into account the smaller size of an infant's organs the appropriate ALI_p should be readjusted upwards by a factor of 3. Where only the average correction of 1/2 has been used the average child's diet rather than the infant's diet is appropriate. Since the diet averaged over a lifetime is not significantly different from that of an adult, no upward adjustment of the ALI_p is made in this case.

In cases, therefore, where the critical group contains infants and children but where only the adult diet can be estimated the appropriate annual limits for members of the public would appear to be:

- Short Term exposure; $ALI_p = 0.03 X ALI$
- Long Term exposure; $ALI_p = 0.01 X ALI_s$

Use of Summation Formula

The use of ALI (or ALI_p) do not apply directly when a person is exposed to a mixture of radionuclides (IAEA A.III.6). In such cases IAEA recommend (par 421) the use of a summation formula which is (omitting external exposure)

$$\sum_j \frac{I_j}{A_j} \leqslant 1$$

where I_j is the intake of the jth nuclide and A_j is the corresponding ALI (or ALI_p).

The long lived isotopes to be considered in the case of uranium mining are: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po. Since the total dose must be kept below the appropriate limit the criterion for defining acceptable rist to man becomes;

$$\sum_{j=1}^{6} (I_j / ALI_{p,j}) \leqslant 1$$

where I_j is the annual intake of the j^{th} isotope and $ALI_{p,j}$ is the appropriate public limit of intake for that isotope. The annual intake I_j can be determined from source measurements and modelling of the transport processes and uptake in the food chain.

ALI for Uranium Isotopes

For the uranium isotopes an additional modification has been applied. It is stated in ICRP 30 (part 1, page 102) that the f factor used (i.e. the fraction of the total ingested which is absorbed in the gut rather than being directly excreted) is 0.05. This value is that which is appropriate to the activity levels and chemical forms of this element which are most commonly found in industry. Evidence is presented, however, that for environmental uranium a more appropriate value for the f factor is 0.2. Thus the ALIp for ^{238}U and ^{234}U have been further reduced by a factor of 4.

Public Annual Limits on Intake for Uranium Series

The stochastic annual limits on intake for the uranium series radionuclides are shown in table 4.1 (from ICRP 30). The values for the public annual limit on intake for each nuclide are also given using the prescription outlined above. These have been used in the development of water release standards for the ARR by applying the short term limits to Nabarlek and the long term limits to Ranger.

1.2. Metal Toxicity

(a) Non-Carcinogenic Effects

Unlike the situation for radionuclides, where a common property (ionisation) is responsible for all adverse effects, the nature of chemical poisoning is unique for each metal involved. It can also differ from one occasion to another depending on the nature of the source material, on the constituents of the diet and so on.

The non-carcinogenic risks associated with the chemical toxicity of metals are normally expressed in terms of maximum permissible concentrations in foodstuffs. In recommending such limits, the National Health and Medical Research Council (NHMRC) distinguishes between fresh and preserved foods because some methods of preservation unavoidably affect the composition of foods. Fresh food limits have been used in the present analysis, these being the form of concern here.

The concept of an annual limit on intake of metals is applicable in the case of metals with a long biological half-life. It can, however, also be applied in the case of other metals when it is defined using the actual diet of the population group at risk combined with the concentration limits applicable to the constituent parts of that diet. Whilst this approach gives rise to ALI which are diet dependent, it is nevertheless an advantage in cases where the concentrations which give rise to contamination (for example, sediment concentrations resulting from surface water contamination) can only be calculated with any confidence on the basis of an annual average. Such is the case in the present assessment.

Since the biological effects of heavy metals on individual organisms are generally considered as being non stochastic, i.e., the dose-effect relationships exhibit threshold concentrations below which a particular effect does not occur, it is necessary to subtract a normal background intake from the annual limit on intake before applying this limit to a particular industrial practice. The definition of the public annual limit of intake used here for the chemical toxicity effects of each heavy metal is, therefore,

$$ALI_p = \sum_i L_i F_i - \sum_i c_i F_i$$

where L_i = NHMRC concentration limit of the metal for food item i,

F_i = annual intake of food item in the diet of the group

c_i = average normal concentration of the metal in the food item. This limit applies to industrial practices.

The full details of the derivation of the annual limits on intake for metals, based on non-stochastic effects, are given in appendix D. Of the metals for which an assessment is required, as deduced in Chapter 3, ALI_p may be derived from NHMRC recommendations for copper, lead, zinc and cadmium. Radiotoxilogical effects for uranium are of greater importance than effects due to non-stochastic chemical poisoning; thus, a separate non-stochastic ALI_p is not necessary. Manganese is the principal metal (in terms of its presence in the mine/mill water circuits relative to natural waters) for which no NHMRC recommendation is available. For this reason an ALI_p for manganese has been derived (appendix D) and has been incorporated in this analysis. The deduced values of the annual limits on intake for metals are given in table 4.2.

Using the above definition of ALI_p for heavy metals the criterion for acceptable risk resulting from water release becomes

$$I_j \leq ALI_{p,j}$$

where I_j is the annual intake of metal j derived from source measurements, a model of contaminant transport, and transfer in the food chain.

(b) Carcinogenic Effects

Certain heavy metals are known to be carcinogenic and the United Stated Environmental Protection Agency has, in the documents of the Carcinogenic Assessment Group and the Water Quality Criteria Documents, made estimates of the carcinogenic risks resulting from their ingestion in foods.

Cohen (Risk Analysis 1, (1981), 267-275)considers the risks quoted in these sources and extends the risk estimates to produce a carcinogenic risk per unit mass ingested, R, for the metals Be, Cr, Ni, As and Cd. An acceptable level of risk for these metals , r, per annum, may be deduced from the ICRP dose limits and the conversion factor from dose to risk, namely 10^{-2} Sv^{-1}. Then the public limit of intake for each carcinogen becomes

$$ALI_p = r/R$$

where $r = 5 \times 10^{-5}$ for a short term exposure and 1.10^{-5} for long term exposure. Limits deduced in this way are derived and listed in appendix D.

Limitations on intake based on carcinogenic effects are not as firmly based as the corresponding limitations arising from considerations of radiological effects, of indeed from the effects of chemical toxicity. Considerable uncertainties still exist in the risk assessment. Carcinogenic limitations have, therefore, been included here for completeness but have not been used in determining the final recommendations on receiving water standards presented in Chapter 6.

Table 4.1.

Public Annual Limits on Intake for Uranium Series Radionuclides

Radionuclide	ALI_s (Bq/a)	ALI_p (Short Term) (Bq/a)	ALI_p (Long Term) (Bq/a)
^{238}U	8×10^5 ✓	6×10^3 ✓	2×10^3 ✓
^{234}U	7×10^5 ✓	5.2 5×10^3 ✓	1.75 2×10^3 ✓
^{230}Th	4×10^5 ✓	12×10^3	4~~3~~ $\times 10^3$
^{226}Ra	2×10^5 ✓	6×10^3 ✓	2×10^3 ✓
^{210}Pb	4×10^4 ✓	12×10^2 ✓	4×10^2 ✓
^{210}Po	1×10^5 ✓	3×10^3 ✓	1×10^3 ✓

Table 4.2

Public Annual Limits on Intake for Metals

Metal	ALI_p(mg a^{-1})
Cadmium	20
Copper	6900
Lead	90
Manganese	1900
Zinc	67000

Note: These limits apply only to persons ingesting the background totals given in table D.3 via the diet of appendix B.

4.2 Risk to the Ecosystem

The difficulties associated with the setting of standards for protection of the ecosystem have been discussed at length in Chapter 2 of this report. In summary, the problem is that a very large number of species must be protected and that there exists a paucity of relevant experimental data on the interrelationships between these diverse species and the potential chemical contaminants. Given these difficulties, a three stage process has been adopted for the determination of standards for the two specific sites under consideration in the Alligator Rivers Region.

The first stage consists of the adoption of a general conservative criterion based upon the observed natural fluctuations of the concentrations of the chemicals of concern in the natural waters of the two creeks into which contaminated waters might be discharged. Preliminary receiving water standards are deduced on the basis of this criterion.

The second stage consists of the application of these preliminary standards to the problem of release of waters from particular artificial water bodies at the two mining sites into the Magela and Cooper creeks. By this process the critical or limiting constituents are identified, and the problem of making an ecological impact analysis is reduced to these few critical constituents.

The final stage consists of a toxicological and chemical assessment of the likely impact of increased concentrations of these critical constituents on the local exosystem. The philosophy adopted is that the conservative preliminary standards may be relaxed in cases where data do exist to enable a reliable ecological assessment to be made. A final set of recommended standards for receiving waters is then proposed on the basis of both the general approach and the particular assessment of the critical chemical constituents.

The remainder of this section is devoted to the development of a general conservative criterion based on the natural fluctuations of the concentrations of chemicals of concern in the surface waters of the Region.

The development of a criterion based upon natural fluctuations in the environment is bound to be somewhat subjective. Nevertheless, an assessment of the significance of a given increase in the concentration of a contaminant has been made by considering the resulting change in the probability distribution for that contaminant.

For some of the water quality variables considered in chapter 4 the probability distribution is approximately normal whilst for others a log-normal distribution is more appropriate. Both distributions are considered here.

Consider first a normal distribution for any contaminant with mean M and standard deviation σ. Release of contaminated waters is assumed to increase the mean by a displacement D to M^1 leaving the standard deviation unchanged as indicated in figure 4.1. If the natural and altered probability distributions are $f_N(x)$ and $f_A(x)$ respectively the change in the distribution may be assessed by defining a retention factor in the following way.

The retention factor, $r(D,L_1,L_2)$ is the ratio of the percentage of the *altered* distribution within limits L_1 and L_2 of the *natural* distribution to the percentage of the *natural* distribution within the same limits. Thus, with respect to the variables indicated in figure 4.1.,

$$r(D,L_1,L_2) = \int_{L_1}^{L_2} f_A(x)\,dx \Big/ \int_{L_1}^{L_2} f_N(x)\,dx$$

The values of $r(D,L_1, L_2)$ are plotted in figure 4.2 for displacements D (expressed in units of the standard deviation) varying between 0 and 3.5 and for limits L_1 and L_2 corresponding to 68% and 95% of the natural distribution.

From these data it can be seen that, for the 95 percentile limits of the natural distribution, a displacement of the mean by one standard deviation achieves a retention factor of 0.88 but that this drops rapidly to 0.53 if the mean is displaced by two standard deviations. We would argue that a reduction of 10% in the retention factor is unlikely to cause severe environmental detriment but that a reduction of 50% conceivably could. For the 68 percentile limits of the natural distribution the corresponding figures for displacements by σ and 2σ are 0.70 and 0.23 respectively. Thus if the 68% limits provide a better description of the biologically significant portion of the distribution a two standard deviation displacement will result in only 23% retention.

The above figures show that if the criterion used to define standards for contaminant release is that the mean of the natural distribution of each variable of concern is permitted to increase by no more than one standard deviation, then the water quality and, presumably, the ecosystem will be retained in a state close to that of the system before release occurred. The assumption that this will be the case if the mean is allowed to increase by two standard deviations cannot so readily be sustained. For this reason an increment of one standard deviation as the criterion for defining standards for protection of the ecosystem is used in the derivation of preliminary standards.

As indicated above, some of the water quality variables are better represented by a log-normal distribution than by a gaussian. The positive skewness of the log-normal distribution implies that a larger displacement can be tolerated in order to obtain a given retention factor. The extent of this increase in displacement is determined by the asymmetry, A, of the distribution which may be conveniently defined as

$$A = (M - m) / \Sigma$$

where M, m, and Σ are the mean, median, and standard deviation of the untransformed natural distribution.

A detailed discussion of the log-normal distribution is presented in

Appendix A and in particular the displacement, D, is derived which gives rise to a retention factor of 0.88 for 95 percentile limits of the natural distribution, i.e. the same conditions considered above as suitable for a normal distribution. The results of this analysis are shown in figure 4.3. where the normalised displacement, D/Σ, is plotted against the asymmetry parameter A. It can be seen from these data that under conditions of extreme asymmetry, namely $A \sim 0.3$, the allowable displacement approaches two standard deviations, rather than one in the case of a gaussian distribution.

The above discussion implies that a suitable criterion for protection of the ecosystem could be defined in terms of the displacement of the distribution in order to obtain a given retention factor, e.g. 0.88 for 95 percentile limits of the natural distribution. In practice, however, the application of such a criterion would require accurate data on three parameters of the distribution for all contaminants, i.e. the distribution itself would need to be well determined rather than simply the standard deviation. In many cases the contaminant distributions are not sufficiently well determined to make this approach feasible. A general criterion based simply on the standard deviation of the contaminant distribution has been adopted but with the reservation that, in a practical application of the standards, if a particular contaminant concentration is within a factor of two of the derived limit, the distribution of that contaminant should be examined to determine whether or not the standard should be adjusted.

In summary, the criterion adopted for the derivation of preliminary water quality standards for contaminant release which will adequately protect the ecosystem is that the mean of the natural contaminant distribution should be permitted to increase by no more than one standard deviation of the natural distribution. Preliminary standards are derived on the basis of this criterion and the critical contaminants determined. An assessment of information available both on the details of the natural distribution of the critical contaminants and on the known toxicological and chemical effects of the contaminant is then made before a final set of standards is recommended.

Figure 4.1

Figure 4.2

Figure 4.3

5. LIMITS ON HAZARDOUS CONSTITUENTS

5.1 Limits for Risk to Man

5.1.1 Model for Contaminant Dispersion

The criteria developed in Chapter 4 for the development of standards with respect to the protection of Man require an estimate to be made of the annual intake of radionuclides and heavy metals in the diet of the critical group. Since the diet contains both terrestrial and aquatic foods, both of which could be contaminated by discharge waters, a model is required which relates the annual average concentrations of contaminants in both the waters and the soils of the region to the quantity of contaminants released during discharge. A simple physical model of dispersion is developed in this section which allows such estimates to be made. The results of this model will be compared later to estimates made on the basis of concentrations at the discharge point only.

The two principal sources of water release being considered, Ranger and Nabarlek, are associated with two quite different water systems. The main characteristics of the systems, however, are an initial discharge into a well defined creek which eventually flows into a broad floodplain before discharging into the sea via the tidal stretches of a major river. For these reasons a general model is developed first and it is applied in later sections to the individual creek systems.

The main characteristcs which must be included in the model are shown in block diagram form in figure 5.1. We consider a mass, m, of contaminant contained in volume, v, of water to a discharged per unit time. The rate of discharge is assumed to be constant and to last for time T. Thus the total mass, total volume and concentration of the contaminant (prior to discharge) are

$$M = mT$$

$$V = vT$$

$$C = m/v$$

The discharge takes place into a creek whose flow rate at the time of release is v_1 per unit time. An evaluation must be made of the four stages of initial dilution, creek flow, flood plain dilution and floodplain annual cycle. To be incorporated at each stage are deposition and absorption processes and subsequent resuspension where appropriate.

Initial dilution

Assuming rapid dilution at the point of entry the dilution factor is

$$(v_1 + v)/v \cong v_1/v \qquad \text{for } v_1 \gg v$$

Thus the concentration of the added pollutant becomes

$$C_1 = C\ v/v_1$$

The assumption here is that mixing is sufficiently rapid that no deposition or concentration in flora or fauna occur at the higher concentration level. Even if this were not so the area affected would be so small that the contribution to the diet of the critical group would be negligible.

Creek flow to floodplain

Between the point of input and the floodplain, loss of pollutant from the water can occur by absorption (e.g on phytoplankton or macrophytes) and by deposition on the creek bed and other surfaces. Although such processes are in general not going to be uniform the simplest assumption is to assume uniformity. In particular, we assume that the different physico-chemical behaviour of the various contaminants is not significant.

Thus at distance x downstream from the input point the mass in the water column becomes

$$m_2(x) = m \exp\{ -(\mu_a + \mu_d)\ x \}$$

where μ_a, μ_d are absorption and deposition attenuation coefficients. The water concentration and the mass per unit area deposited on the creek bed are given by

$$C_2(x) = m_2(x)/v_1$$

$$m_d(x) = \mu_d\ m_2(x)/w$$

where w is the effective width of the creek bed. A similar expression exists for the absorption mass density.

Once values for the attenuation coefficients μ_a and μ_d and for the total creek length have been specified an average value for the exponential factor, E, can be deduced. This is converted to an annual average creek water concentration $\bar{C}_c$ by

$$\bar{C}_c = C.\ \frac{Tv_{\emptyset}E}{365v_1} \qquad \times$$

where T is the discharge period in days.

Thus

$$\bar{C}_c = \frac{ME}{365v_1} \qquad 5.1$$

where v_1 is the average creek water flow rate in volume per day during the period of release.

Flood Plain dilution

Once the pollutant reaches the floodplain some fraction will continue out to sea, the balance remaining on the plain and mixing with the waters of the plain. The degree of mixing will depend critically on how well defined the creek is through the plain at the time of release, assumed here to be at the height of the wet season. For the Magela system the creek is ill-defined and most of the contaminant can be assumed to mix with floodplain waters. For the Cooper creek system a significant fraction will flow out to sea since the creek is well defined even at peak flood.

Let X be the distance to floodplain from the release point

f be the fraction remaining in the floodplain

V_f = flood plain volume at peak flood

Then the total mass entering the plain per unit time is

$$m_3 = f\ m\ \exp\{-(\mu_a + \mu_d)\ X\}$$

The residence time in the floodplain is assumed to be long compared with the release period T of the discharge. Hence the total mass in the floodplain is integrated to become, at the end of the release cycle,

$$\begin{aligned} M_3 &= f\ T\ m\ \exp\{-(\mu_a + \mu_d)\ X\} \\ &= f\ M\ \exp\{-(\mu_a + \mu_d)\ X\} \end{aligned}$$

and the concentration after mixing with floodplain waters is

$$C_3 = M_3/V_f$$

Similarly the deposited mass per unit area along the creek bed becomes, at the end of the release cycle,

$$M_d(x) = \mu_d \frac{M}{w} \exp\{-(\mu_a + \mu_d)\ x\}$$

with a similar expresion for $M_a(x)$

The floodplain annual cycle.

The water content of the floodplain will typically follow the pattern shown in figure 5.2. The three key volumes are:

V_f = peak volume as indicated earlier,

V_w = volume at the end of the wet season,

and V_d = volume at the end of the dry season.

Release is assumed to occur at or just after the peak of the wet season and to continue for a relatively short time (3 or 4 weeks at most). The first year after release is divided into four periods:

- February - April; late Wet, floodplain drainage to sea
- May - October; floodplain cut off from the sea, evaporation loss
- November; early Wet, no drainage to sea
- December - January; mid Wet, drainage to sea.

These periods are discussed separately at first and then the annual average concentration of contaminant in the water and in the soil are determined.

Late wet.

During this period drainage to the sea is the dominant process and results in a reduction in both the volume of water and the mass of contaminant in the system. Thus, ignoring deposition, the water concentration would remain constant. Deposition will, however, occur to some extent during this period thus reducing the contaminant mass lost from the system through drainage but also reducing the concentration in the remaining waters.

In principle, a knowledge of total annual loads of contaminants flowing into the floodplain, the effective area of the floodplain, soil concentrations on the plain, and the annual average sedimentation rate should allow the determination of the fraction of the annual load which is deposited each year on the floodplain sediment. Attempts to deduce this fraction have, however, been unsuccessful due to the large errors associated with each of the above variables. In the absence of this information an assumption of 50% deposition and 50% remaining in suspension has been made. This assumption implies that neither the water concentration nor the soil concentration can be low by more than a factor of two. For simplicity this deposition is assumed to occur at the outset of this period.

With the above assumptions the masses of contaminant in the water column at the beginning and at the end of this period (M_4 and $M^1{}_4$ respectively) become

$$M_4 = {}^1\!/_2\, M_3 \qquad , \; M^1{}_4 = {}^1\!/_2\, M_3 V_w / V_f$$

The water concentration thus remains at

$$C_4 = {}^1\!/_2\, M_3 / V_f$$

throughout the three month period.

If the floodplain area is A the contaminant mass per unit area, D, becomes

$$D_4 = \tfrac{1}{2} M_3/A$$

throughout the same period. Note that the contaminant water density would be higher if the evaporation rate were high compared with the drainage rate, but this is the period when evaporation is at its lowest and is neglected at this stage.

Dry season

The six month period from May until the end of October is dominated by evaporation and during this time the floodplain is considered cut off from the East Alligator River. Water bodies become isolated and the majority evaporate to dryness, leaving only the permanent billabongs and a few semi-permanent swamp areas. This process leads to both increasing concentrations in the residual waters and to deposition of the contaminant load on the soil of the floodplain.

Empirical evidence suggests that the extent to which water concentrations of heavy metals increase is not large, of the order of a factor of two. Since the water volume at the end of the Dry season, V_d, is very much smaller than at the end of the Wet season, at most one tenth, most of the contaminant load is deposited at a uniform rate on the sediment.

Thus, assuming a uniform increase in the water concentration, by an overall factor of 2 through the season, the average Dry season water and sediment concentrations become

$$C_5 = 3M_3/4V_f$$

$$D_5 = \tfrac{1}{2}\frac{M_3}{A}\ [1 + \tfrac{1}{2}\frac{V_w}{V_f} - \frac{V_d}{V_f}]$$

The extent to which evaporative concentration occurs is quite variable in the billabongs of the Magela floodplain, being clearly observed in Jabiluka, JaJa and Nankeen, but not very significant in Mudginberri and Island. Groundwater influx is thought to be a controlling influence. The average evaporative concentration factor of 2 used here is considered to be representative of the permanent water bodies and possibly slightly conservative for the billabongs closest to the area occupied by the critical group. For some metals a more substantial rise in billabong concentrations occurs just before the first flush but this is thought to be due to groundwater incursion rather than evapoconcentration.

Early Wet Season

During the first month of the Wet season resuspension of some of the deposited material occurs as the floodplain lagoon fills up from volume V_d to the lagoon volume V_w, giving rise to enhanced "first flush" concentrations in the water column. No discharge takes place to the sea. Assuming 50% resuspension of the deposited contaminant load occurs at a uniform rate throughout this period gives rise to average water and sediment concentrations of

$$C_6 = 1/8 \frac{M_3}{V_f} [5 + \frac{V_f}{V_w} + 2\frac{V_d}{V_w}]$$

$$D_6 = 3/8 \frac{M_3}{A} [1 + \frac{V_w}{V_f} - 2\frac{V_d}{V_f}]$$

The first flush through the billabongs is highly variable from one billabong to the next and from year to year. The present description may underestimate the concentrations obtained in some circumstances but the very high concentrations occur only for a short period so that the average concentration is unlikely to be significantly in error. For protection of man, rather than the ecosystem, it is the average concentration which is important rather than the instantaneous maximum.

Mid Wet Season

Once the volume of water on the floodplain exceeds the lagoon volume

V_w drainage to the sea begins and during the subsequent build up to maximum floodplain volume V_f the residual contaminants in the water column from the previous year are flushed out to sea. This flushing process in assumed to proceed uniformly throughout the period until the residual water concentrations are zero by the time volume V_f is reached. This does not imply that the actual water concentrations will be zero, merely that the contribution to the concentration arising from discharge during the previous Wet season will be zero. The incoming waters from the creek system will contain natural loads of each of the contaminants.

Under the circumstances the average water and sediment concentrations from the discharge of the previous wet season during this two month period are

$$C_7 = 1/8 \frac{M_3}{V_f} [1 + \frac{V_f}{V_w} + \frac{V_d}{V_w}]$$

$$D_7 = 1/4 \frac{M_3}{A} [1 + \frac{V_w}{V_f} - 2 \frac{V_d}{V_f}]$$

It should be noted that, given the assumptions of the model, the sediment concentration D_7 is the only remnant of the discharge which remains in the system during subsequent years.

Annual Average Concentrations

Annual average contaminant concentrations resulting from a single short term discharge may now be deduced from the concentrations given above using the time interval appropriate to each stage. The results for water and sediment are

$$C_w = 0.57 \frac{M_3}{V_f} [1 + 0.05 \frac{V_f}{V_w} + 0.01 \frac{V_d}{V_w}] \quad (5.2)$$

$$D_5 = 0.45 \frac{M_3}{A} [1 + 0.4 \frac{V_w}{V_f} - 0.9 \frac{V_d}{V_f}] \quad (5.3)$$

In principle an additional contribution to the water concentration arises from resuspension during the Early Wet season of material deposited on the creek bed. As will be discussed in detail later, this contribution has been estimated and is small. It is, therefore, not included here.

Figure 5.1

Figure 5.2

5.2 Diet of Critical Group

IAEA Safety Series 9 defines the critical group in the following way: "For a given source or group of sources, the group of members of the public whose exposure is reasonably homogeneous and is typical of individuals receiving the highest dose".

We propose that the groups of people who come nearest to satisfying this definition with respect to release of radionuclides into surface waters are those who live on predominantly bush diets in the lower ends of the Magela and Cooper Creek catchments. In the case of the Magela system the group most at risk appears to be the 50 or 60 Aboriginal people living at Mudginberri, about 12 km downstream of the Ranger mine site. The complications introduced by the existence of a significant number of children in this group were discussed at length in Chapter 4. It is sufficient here to state that we assume the child's diet to be made up in the same proportions as the adult diet, but to be about one third its mass. Only the adult diet is considered in this section.

We have some information on the composition of the bush component of the diet of Aboriginal people intermittently living closer to the mine site, based partly on hearsay and partly on the work of Bywater (private communication). This diet is assumed to apply to the people living at Mudginberri. Our estimate of the total mass consumed annually is based on data in the literature. By making use of further data kindly provided by the Gagadju Association, we have been able to derive figures for the total amounts of food brought in from the usual commercial outlets, and thus not at risk in the event of a deliberate water release. A detailed discussion of these assumptions and derivations is given in Appendix B.

In the case of the Cooper Creek system information is more scanty. We know of two relevant groups of people, one group of 20 to 30 adults who live on the Creek about 10 km from the start of the flood plain at Mount

Borradaile, and one group of similar size who have in the past lived on the south western side of the floodplain. It is expected that they will choose to live at this site again in the immediate future (A. Wilson, private communication). Unfortunately, we have no details as to the likely diet of these groups, and so we are forced to employ the Magela system diet, which is summarised in Table 5.1.

5.1.3 Transfer Functions

For this necessarily simplified discussion the transfer function is defined here as the ratio of the contaminant concentration in a major edible portion of the food item (e.g. buffalo or fish) to that found in soil or water, as appropriate. When defined with respect to water, the total water concentration (i.e. filtrate plus residue) is used whenever possible. In the case of radionuclides, the isotopes of interest are readily identified. The majority of these transfer functions have been determined directly for food items of local origin, especially for those items such as mussels and fish, which turn out to be the most significant transfer routes to man. For toxic metals the selection of elements was based primarily on the list of hazardous constituents given in table 3.1, but it has been limited by the availability of data on either transfer functions or annual limits on intake. The final list, consisting of cadmium, copper, lead, manganese, zinc, chromium and nickel, should therefore not be considered exhaustive.

The sources of data used in the derivation of all the transfer functions are given in Appendix C and the transfer functions are summarised in Table 5.2.

5.1.4 Limits for Magela Creek System

Limits on the annual loads of contaminants which may be released into Magela Creek at Ranger and which are based on the estimated risk to man may now be deduced by determining the appropriate values of the model parameters for the Magela Creek system.

The length of creek between the likely injection point at Ranger and the floodplain is short, about 10 km. The creek bed is sandy and the density of macrophytes is low compared to that on the floodplain. Hence the macrophyte absorption co-efficient is taken to be zero. Studies of gamma-ray dose rates on transects of the Magela Creek and floodplain (ARRRI annual report 1983-84) have shown that the natural deposition characteristics on the Magela are such that the creek deposition is negligible compared to that on the floodplain. Since release of contaminated waters will take place only under conditions of high creek flow the significance of creek deposition is expected to be even smaller than under natural conditions. The creek sedimentation co-efficient is, therefore, assumed to be zero.

Thus the average exponential factor, E, in equation (5.1) is 1.0, and the annual average creek water concentration becomes, using a mean creek flow of $50m^3s^{-1}$ during the release period, $\bar{C}_c = 6.3 \times 10^{-13}$ units/litre per unit released.

The above mean creek flow rate is the historical mean on those days when flow exceeded $20m^3s^{-1}$, the minimum flow considered appropriate for water release by the Fox inquiry.

The Magela has no well defined creek running through the floodplain at the peak of the Wet season so that mixing with floodplain waters will be high and little of the contaminant load will proceed directly to sea. A mixing coefficient, f, of 0.7 is therefore assumed.

Estimates of the lagoon volume, V_w, of the Magela floodplain and of the dry season volume, V_d, are given by Williams (Aust. Journal of Ecology (1979) 239-247) as $V_w = 60 \times 10^6m^3$, $V_d = 5 \times 10^6m^3$. An estimate of V_d based on Water Divisions Bathymetric survey of Magela floodplain billabongs in November 1981 is consistent with the above value.

The peak flood volume of the floodplain, V_f, may be estimated in any year by computing the time integrated input to the floodplain (by using hydrographic data for gauging station 821009 normalised to the total catchment area) and subtracting from it the time integrated output from the floodplain (using data for gauging station 921019). This method produced, using data for 1978/9 and 1979/80, values of V_f between 3×10^8 and $4 \times 10^8 m^3$. The slightly conservative value of $3 \times 10^8 m^3$ is used here but variations between 2×10^8 and 4×10^8 can be expected from year to year.

The Magela floodplain area can be estimated from aerial surveys. The value deduced by Williams of 150 km^2 is used below.

Insertion of the above values for the floodplain model variables into equations (5.2) and (5.3) gives model concentrations of the contaminants in water, C_w, and sediment, D_s, of

$$C_w = 1.7 \times 10^{-12} \text{ units/litre per unit released.}$$

$$D_s = 2.2 \times 10^{-9} \text{ units/m}^2 \text{ per unit released.}$$

The latter is converted into a concentration with respect to mass by use of an average soil density of 1.5×10^3 $kg.m^{-3}$ and by assuming uniform mixing within the predominant nutrification layer of 0.05m. Thus the sediment concentration becomes

$$D_s = 3 \times 10^{-11} \text{ units/kg per unit released.}$$

As has been noted before, the model used here contains a number of assumptions and unknowns for which estimates have been made. It is, therefore, instructive to compare the numerical results with simpler estimates of the annual average water concentration. Three such estimates have been made based upon the instantaneous maximum creek concentration after dilution, the mean creek concentration during the release period, and the mean wet season concentration based on integrated flow past the release point. A release period of 50 days was assumed, a wet season period of 120 days, minimum and mean flow rates of $20 m^3 s^{-1}$ and $50 m^3 s^{-1}$ respectively, and an integrated creek flow of $4 \times 10^8 m^3$. In order to obtain an annual average for Mudginberri billabong the resulting concentrations were averaged over 365 days. The results of this comparison are shown in table 5.3. The concentrations predicted agree within a factor of 3, with the model prediction being the highest. This arises from high floodplain mixing and dry season evapoconcentration. It is likely, therefore, that use of the model is not providing an underestimate of the annual average water concentration.

The annual intake, I_i, of each element i by a member of the Magela critical group may be deduced using the above concentration results for water and sediment combined with the dietary and transfer function data presented in sections 5.1.2 and 5.1.3. Thus

$$I_i = C_w \sum_k m_k T_{ki} + D_s \sum_j m_j T_{ji}$$

where the sum over k includes aquatic foods k of mass m_k consumed per annum, and the sum over j includes the terrestrial foods j of mass m_j consumed per annum by a member of the critical group. The factors T_{ki} and T_{ji} are the corresponding transfer functions.

The results of this procedure are given in Table 5.4 where both the individual dietary contributions and the totals are shown. All numbers refer to unit annual release. From an inspection of the individual contributions the importance of invertebrates (mussels and macrobrachium) and fish is apparent. Confidence in the overall results is therefore enhanced since most of the transfer functions for these dietary items have been obtained from local empirical data.

For each element the permitted annual release load, P_i, has been calculated using the annual limits on intake given in Chapter 4. Thus,

$$P_i = A_i / I_i$$

where I_i is the annual intake per unit release and A_i is the corresponding annual limit on intake. The results obtained for the Magela system are given in Table 5.5.

In general, a release of one contaminant will not occur in isolation and the combined permitted release of all radionuclides must satisfy the summation criterion given in Chapter 4. This can be rewritten as

$$\sum_i p_i / P_i \leq 1$$

where P_i are as given above and p_i are the corresponding combined limits. For a particular water body with contaminant concentrations C_i the maximum volume which could be released, V_A, is then given by

$$V_A \leq 1/\sum_i (C_i/P_i)$$

This procedure will be applied in Chapter 6 using artificial water bodies at Ranger.

5.1.5 Limits for the Cooper Creek System

The Cooper Creek is much longer than the Magela, approximately 75 km between Nabarlek and the floodplain, and there are many channel billabongs en route which support aquatic foods in the aboriginal diet. Two possible critical groups have been identified; those living near the creek and those living adjacent to the floodplain. For this reason it is important to assess the significance of creek bed deposition which has consequences not only for the terrestrial foods associated with the creek critical group but also for the floodplain group via resuspension in the early Wet season.

Like the Magela, the Cooper Creek is a sandy braided stream. Analysis of creek sands and floodplain sediments from the Magela catchment shows that the uranium and radium concentrations are typically 7 Bq/kg in the sands and 70 Bq/kg on the floodplain. The total inundated area associated with the creek is approximately 7.5 km^2 compared with that of the floodplain of 50km^2. Thus the natural deposition history shows that the ratio of integrated creek deposition of radionuclides to that of the floodplain is approximately 0.015. On this basis creek deposition can be neglected. In addition, release will take place under conditions of high flow when only deposition of the largest particulates will occur. The above ratio is, therefore, expected to represent a maximum.

The creek attenuation coefficient is, therefore, taken to be zero and the contribution to the intake of the creek critical group is assumed to arise only from the water concentrations during the release period. The channel billabongs will be thoroughly flushed out following release provided release is terminated well before the end of the wet season. Under these conditions the creek annual average water concentration becomes, using equation 5.1.,

$$C_c = 3.5 \times 10^{-12} \text{ units / litre per unit released}$$

A minimum flow rate of $5m^3s^{-1}$ has been assumed giving rise to a mean value on days of release of $9m^3s^{-1}$.

The Cooper Creek floodplain has a well defined channel through it even at the peak of the Wet season. For this reason the mixing fraction, f, is expected to be low. It is taken as 0.3. Estimates of floodplain volumes are taken from aerial photographs and mean depths giving the following values of the variables:

$$V_f = 7 \times 10^7 m^3 \quad , \quad V_w = 5 \times 10^6 m^3$$

$$V_a = 5 \times 10^5 m^3 \quad , \quad A = 50 \text{ km}^2$$

The resulting annual average floodplain concentration then become

$$C_w = 4.2 \times 10^{-12} \text{ units / litre per unit released}$$

$$D_s = 3.6 \times 10^{-11} \text{ units / kg per unit released}$$

The soil concentration, D_s, was deduced using the same assumptions on density and mixing depth as were considered appropriate for the Magela floodplain.

A comparison of the water concentration deduced from the model with annual average values obtained using the instantaneous maximum concentration, the mean creek concentration during the release period, and the mean Wet season concentration is given for Cooper Creek in Table 5.3. A release period of 40 days was assumed, a Wet season period of 120 days, minimum and mean flow rates of $5m^3s^{-1}$ and $9m^3s^{-1}$ respectively, and an integrated creek flow of $1.5 \times 10^8m^3$. In order to obtain an annual average for the channel billabongs the resulting concentrations were averaged over 365 days. As for the corresponding Magela comparison all figures agree within a factor of 3 but on this occasion the model results do not exceed the average based on the instantaneous maximum concentration. Effects arising out of evapoconcentration in the Dry season are partly compensated by direct loss to the sea.

Since the floodplain water concentration is higher than the creek concentration given earlier, the critical group becomes that group living off the floodplain waters rather than the creek group but the difference is so small that the results can be assumed to apply equally to both groups.

The procedure of calculating the annual intake of each element by members of the critical group and hence the permitted annual release load are the same as given for the Magela Creek system in section 5.1.4. The results are presented in Tables 5.6 and 5.7. Application of those limits to particular water bodies at Nabarlek is considered in Chapter 6.

Table 5.1

Assumed Diet for Critical Groups

Dietary Item	Consumption (kg a^{-1}
Buffalo	223
Magpie goose	14.5
File snake	3
Invertebrate	4
Turtle	1.5
Fish 38	
Goanna	3
Water lily	3
Imported	140
500	
Water - bore	2400
- surface	600

Note: for discussion of this diet see Appendix B

Radionuclide values checked Feb'87 ✓

Table 5.2

Transfer Functions[1]

	U	Th-230	Ra-226	Pb-210	Po-210	Cd	Cu	Pb	Mn	Zn	Cr	Ni	medium[3]
Buffalo	$4.4x10^{-3}$	$5.8x10^{-5}$	$6.0x10^{-3}$	$5.2x10^{-3}$	$2.1x10^{-2}$	S[2]	0.35	$3x10^{-2}$	S	8.4	$1x10^{-3}$	$2.4x10^{-3}$	soil
Magpie goose	50	20	60	20	620	S	770	30	10	2400	10	10	water
File snake	24	210	50	95	340	S	100	1303	50	6200	100	50	water
Invertebrate	100	500	19000	5100	10000	700	200	330	30000	3200	2000	100	water
Turtle	100	500	10	50	100	700	200	330	30000	3200	2000	100	water
Fish	140	230	370	150	680	130	620	50	350	2200	200	100	water
Goanna	140	230	200	150	680	S	2400	350	50	3900	200	100	water
Water lily	1900	140	230	150	720	S	2707	60	530	890	530	530	water

Note: 1. $(Bq/kg)_{food}/(Bq/litre)_{water}$ for U, Th-230, Ra-226, Pb-210 and Po-210. $(mg/kg)_{food}/(mg/litre)_{water}$ for Cd, Cu, Pb, Mn, Zn, except for buffalo, where the above units became $(Bq/kg)_{buffalo}/(Bq/kg)_{soil}$ and $(mg/kg)_{buffalo}/(mg/kg)_{soil}$. For further details see Appendix C

2. S indicates TF negligably small

3. Medium indicates the assumed most significant growth medium for the animal/plant 'diet'.

Table 5.3

Estimates of Annual Average Water Concentrations

Method of Estimation	Magela Concentration ($\times 10^{-12}$) (units/litre per unit released)	Cooper Concentration ($\times 10^{-12}$) (Units/litre per unit released)
Average based on Instantaneous Maximum	1.6	6.3
Average based on Mean Creek Concentration	0.6	3.5
Average based on Mean Wet Season Flow	0.8	2.2
Model	1.7	4.2

Table 5.4.

Intake by Member of Critical Group During Year Following Release: Magela System[1]

Food Item	U-238 Bq/Bq/a	Th-230 Bq/Bq/a	Ra-226 Bq/Bq/a	Pb-210 Bq/Bq/a	Po-210 Bq/Bq/a	Cd kg/kg/a	Cu kg/kg/a	Pb kg/kg/a	Mn kg/kg/a	Zn kg/kg/a	Cr kg/kg/a	Ni kg/kg/a
Buffalo	$2.9E^{-11}$	$3.9E^{-13}$	$4.0E^{-11}$	$3.5E^{-11}$	$1.4E^{-10}$	$0.0E^{+00}$	$2.3E^{-09}$	$2.0E^{-10}$	$2.7E^{-11}$	$5.6E^{-08}$	$6.7E^{-12}$	$1.6E^{-11}$
Magpie goose	$1.2E^{-09}$	$4.9E^{-10}$	$1.5E^{-09}$	$4.9E^{-10}$	$1.5E^{-08}$	$0.0E^{+00}$	$1.9E^{-08}$	$7.4E^{-10}$	$2.5E^{-10}$	$5.9E^{-08}$	$2.5E^{-10}$	$2.5E^{-10}$
File snake	$1.2E^{-10}$	$1.1E^{-09}$	$2.6E^{-10}$	$4.8E^{-10}$	$1.7E^{-09}$	$0.0E^{+00}$	$5.1E^{-10}$	$6.6E^{-10}$	$2.6E^{-10}$	$3.2E^{-08}$	$5.1E^{-10}$	$2.6E^{-10}$
Invertebrate	$6.8E^{-10}$	$3.4E^{-09}$	$1.3E^{-07}$	$3.5E^{-08}$	$6.8E^{-08}$	$4.8E^{-09}$	$1.4E^{-09}$	$2.2E^{-09}$	$2.0E^{-07}$	$2.2E^{-08}$	$1.4E^{-08}$	$6.8E^{-10}$
Turtle	$2.6E^{-10}$	$1.3E^{-09}$	$2.6E^{-11}$	$1.3E^{-10}$	$2.6E^{-10}$	$1.8E^{-09}$	$5.1E^{-10}$	$8.4E^{-10}$	$7.7E^{-08}$	$8.2E^{-09}$	$5.1E^{-09}$	$2.6E^{-10}$
Fish	$9.0E^{-09}$	$1.5E^{-08}$	$2.4E^{-08}$	$9.7E^{-09}$	$4.4E^{-08}$	$8.4E^{-09}$	$4.0E^{-08}$	$3.2E^{-09}$	$2.3E^{-08}$	$1.4E^{-07}$	$1.3E^{-08}$	$6.5E^{-09}$
Goanna	$7.1E^{-10}$	$1.2E^{-09}$	$1.0E^{-09}$	$7.7E^{-10}$	$3.5E^{-09}$	$0.0E^{+00}$	$1.2E^{-08}$	$1.8E^{-09}$	$2.6E^{-10}$	$2.0E^{-08}$	$1.0E^{-09}$	$5.1E^{-10}$
Water lily	$9.7E^{-09}$	$7.1E^{-10}$	$1.2E^{-09}$	$7.7E^{-10}$	$3.7E^{-09}$	$0.0E^{+00}$	$1.4E^{-09}$	$3.1E^{-10}$	$2.7E^{-09}$	$4.5E^{-09}$	$2.7E^{-09}$	$2.7E^{-09}$
Imported	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Water	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$	$1.0E^{-09}$
Total	$2.3E^{-08}$	$2.4E^{-08}$	$1.6E^{-07}$	$4.8E^{-08}$	$1.4E^{-07}$	$1.6E^{-08}$	$7.8E^{-08}$	$1.1E^{-08}$	$3.1E^{-07}$	$3.4E^{-07}$	$3.7E^{-08}$	$1.2E^{-08}$

Note: 1. units are Bq/(Bq a^{-1}) for radionuclides, and μg/(μg a^{-1}) for heavy metals

2. S indicates Transfer Function negligably small

Table 5.5

PERMITTED ANNUAL RELEASE LOADS - MAGELA SYSTEM

Element	**Permitted Release Load (P_i)**	
Uranium (238 + 234)	8.8×10^{10}	Bq
Thorium - 230	1.7×10^{11}	Bq
Radium - 226	1.3×10^{10}	Bq
Lead - 210	8.3×10^{9}	Bq
Polonium - 210	7.3×10^{9}	Bq
Cadmium	1.3×10^{3}	kg
Copper	8.8×10^{4}	kg
Lead	8.2×10^{3}	kg
Manganese	6.2×10^{3}	kg
Zinc	1.9×10^{5}	kg
Cadmium (C)	5.0×10^{2}	kg
Chromium (C)	2.7×10^{2}	kg
Nickel (C)	1.0×10^{4}	kg

Note:

1. These figures relate to protection of Man only
2. Radionuclide limits are subject to summation. See text
3. Elements marked (C) indicate carcinogenic limits.

Table 5.6

Intake Per Unit Release by Member of Critical Group: Cooper Creek Floodplain

Food Item	U-238 Bq/Bq/a	Th-230 Bq/Bq/a	Ra-226 Bq/Bq/a	Pb-210 Bq/Bq/a	Po-210 Bq/Bq/a	Cd kg/kg/a	Cu kg/kg/a	Pb kg/kg/a	Mn kg/kg/a	Zn kg/kg/a	Cr kg/kg/a	Ni kg/kg/
Buffalo	$3.5E^{-11}$	$4.7E^{-13}$	$4.8E^{-11}$	$4.2E^{-11}$	$1.7E^{-10}$	$0.0E^{+00}$	$2.8E^{-09}$	$2.4E^{-10}$	$3.2E^{-11}$	$6.7E^{-08}$	$8.0E^{-12}$	$1.9E^{-1}$
Magpie goose	$3.0E^{-09}$	$1.2E^{-09}$	$3.7E^{-09}$	$1.2E^{-09}$	$3.8E^{-08}$	$0.0E^{+00}$	$4.7E^{-08}$	$1.8E^{-09}$	$6.1E^{-10}$	$1.5E^{-07}$	$6.1E^{-10}$	$6.1E^{-1}$
File snake	$3.0E^{-10}$	$2.6E^{-09}$	$6.3E^{-10}$	$1.2E^{-09}$	$4.3E^{-09}$	$0.0E^{+00}$	$1.3E^{-09}$	$1.6E^{-09}$	$6.3E^{-10}$	$7.8E^{-08}$	$1.3E^{-08}$	$6.3E^{-1}$
Invertebrate	$1.7E^{-09}$	$8.4E^{-09}$	$3.2E^{-07}$	$8.6E^{-08}$	$1.7E^{-07}$	$1.2E^{-08}$	$3.4E^{-09}$	$5.5E^{-09}$	$5.0E^{-07}$	$5.4E^{-08}$	$3.4E^{-08}$	$1.7E^{-0}$
Turtle	$6.3E^{-10}$	$3.1E^{-09}$	$6.3E^{-11}$	$3.1E^{-10}$	$6.3E^{-10}$	$4.4E^{-09}$	$1.3E^{-09}$	$2.1E^{-09}$	$1.9E^{-07}$	$2.0E^{-08}$	$1.3E^{-08}$	$6.3E^{-1}$
Fish	$2.2E^{-08}$	$3.7E^{-08}$	$5.9E^{-08}$	$2.4E^{-08}$	$1.1E^{-07}$	$2.1E^{-08}$	$9.9E^{-08}$	$8.0E^{-09}$	$5.6E^{-08}$	$3.5E^{-07}$	$3.2E^{-08}$	$1.6E^{-0}$
Goanna	$1.8E^{-09}$	$2.9E^{-09}$	$2.5E^{-09}$	$1.9E^{-09}$	$8.6E^{-09}$	$0.0E^{+00}$	$3.0E^{-08}$	$4.4E^{-09}$	$6.3E^{-10}$	$4.9E^{-08}$	$2.5E^{-09}$	$1.3E^{-0}$
Water lily	$2.4E^{-08}$	$1.8E^{-09}$	$2.9E^{-09}$	$1.9E^{-09}$	$9.1E^{-90}$	$0.0E^{+00}$	3.4^{-09}	$7.6E^{-10}$	$6.7E^{-09}$	$1.1E^{-08}$	$6.7E^{-09}$	$6.7E^{-0}$
Imported	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+0}$
Water	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-09}$	$2.5E^{-8}$	$2.5E^{-09}$	$2.5E^{-0}$
Total	$5.6E^{-08}$	$5.9E^{-08}$	$3.9E^{-07}$	$1.2E^{-07}$	$3.4E^{-07}$	$3.9E^{-08}$	$1.9E^{-07}$	$2.7E^{-08}$	$7.6E^{-07}$	7.8^{-07}	$9.2E^{-08}$	$3.0E^{-0}$

Note: 1. units are Bq/(Bq a^{-1}) for radionuclides, and µg(µg a^{-1}) for heavy metals

2. S indicates Transfer Function negligably small

Table 5.7

PERMITTED ANNUAL RELEASE - COOPER SYSTEM

Element	**Permitted Release Load (P_i)**	
Uranium (238 + 234)	1.1×10^{11}	Bq
Thorium - 230	1.7×10^{11}	Bq
Radium - 226	1.5×10^{10}	Bq
Lead - 210	1.0×10^{10}	Bq
Polonium - 210	9.0×10^{9}	Bq
Cadmium	1.0×10^{3}	kg
Copper	3.6×10^{4}	kg
Lead	3.3×10^{3}	kg
Manganese	2.5×10^{3}	kg
Zinc	8.6×10^{4}	kg
Cadmium (C)	2.0×10^{3}	kg
Chromium (C)	5.5×10^{2}	kg
Nickel (C)	2.1×10^{4}	kg

Note:
1. These figures refer to protection of Man only
2. Radionuclide limits are subject to summation. See text
3. Elements marked (C) indicate carcinogenic limits

5.2 Preliminary Standards for Protection of the Ecosystem

The criteria developed in chapter 4 for the development of standards with respect to protection of the ecosystems of the ARR involved an iterative process. The first step in this iteration required the development of preliminary standards based on the observed fluctuations of the contaminant concentrations in the natural waters of the Magela and Cooper creeks. These preliminary standards are derived in this section.

The chemical constituents considered are those which were identified in chapter 3 as being of environmental significance in the ARR and which are listed in table 3.1. Unfortunately, for three of the 29 variables listed (barium, nickel and vanadium) no data exist on the natural concentrations in creek waters. An assessment of suitable standards for these elements will be presented in chapter 6. Also, the radionuclides (with the exception of uranium) are not considered as an environmental threat other than to Man. A separate assessment of this risk has been given in section 5.1 and no further consideration of radionuclides will be presented in this section.

Considerable environmental data on water quality are available from the Northern Territory Department of Mines and Energy (Water Division), and from both Ranger Mines Pty Ltd, and Queensland Mines Pty Ltd. Unfortunately, both the mining companies only use an acid leach process to obtain total water concentrations, whereas Water Division separates the samples into filtrate and residue and then totally digests the residue before analysis. Thus it is considered that the Water Division data more truly reflects the total water concentrations. This argument is of course even more important when considering analyses of waterbodies proposed for release.

The only data ommitted from the Water Division data sets were those identified by the analytical laboratory as being suspect from the point of view of possible contamination and those identified below as first flush events. Occasional apparent outliers remain, (e.g. for copper and lead in

Magela Creek, see table 5.8) but these have little effect on the mean or standard deviation of the data set. A more serious problem with the data set is the frequency with which measurements were obtained, for some of the heavy metals, which were less than the recorded lower limit of detection. The details on how this problem was handled are explained in appendix E.

As was discussed in section 5.1 it is proposed that discharges would be limited to a period between that immediately following the peak filling of floodplain areas, and that time at which the creek flow at the point of discharge falls below some figure, e.g. $20m^3sec^{-1}$ in the case of the Magela. Although impossible to define exactly, in calculating the means and standard deviations of various parameters an attempt has been made to restrict the accepted data to that period during which these conditions apply. In practice, this has usually meant averaging between December and May in the five years for which data are available (1978 to 1983), but with the omission of 'first flush' data. In general it is believed that this provides an adequate basis from which to characterise the natural fluctuations.

5.2.1 Results for Magela Creek

The water quality data sets relating to three gauging stations were considered for the purpose of characterising the natural fluctuations of the water quality variables of Magela Creek at Ranger. These stations were:

(a) GS 821 - 028 Magela Creek, Arnhem Border site
(b) GS 821 - 009 Magela Creek, downstream of Ranger
(c) GS 821 - 018 Mudginberri Billabong

The maximum, minimum, mean and standard deviations obtained for each variable are listed for each of these sites in appendix E.

Inclusion of the Mudginberri data set can, however, be criticised because of the possibility of anthropogenic contamination of the water body due to, for example, the existence of a major settlement on its banks and a previous land fertilisation programme. Examination of the data set does reveal evidence for such contamination in, for example, a substantially enhanced total phosphorus mean concentration compared with that observed at the other sites. For this reason the Mudginberri data set was excluded from further consideration.

The raw data for each of the two remaining sites has been combined for each variable and the results of the statistical analysis of this combined set are presented in table 5.8. In addition to the results shown, the degree of skewness of each data set has been calculated as has the mean and standard deviation on an annual basis but these results are not presented here.

The preliminary receiving water standards deduced from these data are presented in table 5.10 as the maximum value of the mean concentration for each variable during the period of release. The discharge formula developed for the release of a particular water body should be such that these receiving water standards are not exceeded.

5.2.2 Results for Cooper Creek

The water quality data sets relating to four gauging stations on Cooper Creek were available and were included in the analysis. The stations were:

(a)	GS 821 - 024A	Cooper Creek, upstream Nabarlek
(b)	GS 821 - 024	Cooper Creek, downstream Nabarlek
(c)	GS 821 - 001	Cooper Creek, Nimbuwah
(d)	GS 821 - 038	Cooper Creek, Murganella Road crossing

The maximum, minimum, mean and standard deviation obtained for each variable are listed for each of these sites in appendix E.

The raw data for each of these sites has been combined for each variable and the results of the statistical analysis of this combined set is presented in table 5.9. The preliminary receiving water standards deduced from these data are presented in table 5.10 as the maximum recommended mean concentration for each variable during the period of release. As for Magela Creek, the discharge formula developed for the control of the release of any particular water body should be such that these receiving water standards are met.

Table 5.8

Water Quality - Wet Season Statistical Summaries: Magela Creek

Parameter	Units	No. of entries		Min	Max	Mean	S.Dev.
		Less than	Total				
pH		0	49	4.8	7.5	6.0	0.53
Turbidity	NTU	0	44	2	120	1419	
Dissolved Oxygen	mg/l	0	26	5.1	8.3	6.7	0.8
Calcium	mg/l	0	50	0.1	1.8	0.5	0.3
Magnesium	mg/l	0	50	0.08	1.1	0.61	0.19
Sulphate	mg/l	12	51	<0.1	0.5	0.27	0.15
Ammonia (N)	mg/l	41	49	<0.005	0.09	0.0025	0.0025
Nitrate + Nitrite (N)	mg/l	22	50	<0.005	0.08	0.014	0.016
Phosphate (P)	mg/l	41	51	<0.003	0.02	0.0015	0.0015
Total Phosphorus(P)	mg/l	16	51	<0.003	0.045	0.0072	0.0075
Total Alkalinity	mg/l	0	47	0.96	94.0	5.8	13.8
Total Organic Carbon	mg/l	0	37	1.0	11.0	3.5	2.1
Dissolved Organic Carbon	mg/l	0	38	1.0	9.0	3.3	1.9
Suspended Solids	mg/l	0	50	2	70	9 10	
Copper	µg/l	47	49	<0.09	10.3	0.4	0.4
Lead	µg/l	44	47	<0.6	22.5	0.3	0.3
Zinc	µg/l	13	49	<1.0	61.4	7.3	9.2
Manganese	µg/l	7	55	3	28	9.1	5.2
Uranium	µg/l	34	52	<0.01	0.3	0.1	0.09
Cadmium	µg/l	35	50	<0.04	0.6	0.06	0.09
Iron	µg/l	0	41	130	3550	660	562
Chromium	µg/l	5	8	<0.6	2.4	0.8	0.7

Table 5.9

Water Quality - Wet Season Statistical Summaries: Cooper Creek

Parameter	Units	No. of entries Less than	Total	Min	Max	Mean	S.Dev.
pH		0	81	4.7	8.0	6.1	0.69
Turbidity	NTU	0	76	1.5	95	16	17
Dissolved Oxygen	mg/l	0	51	4.5	9.9	7.1	0.9
Calcium	mg/l	0	92	0.2	2.0	0.8	0.5
Magnesium	mg/l	0	92	0.3	4.7	1.2	0.6
Sulphate	mg/l	12	92	<0.1	1.0	0.4	0.2
Ammonia (N)	mg/l	67	92	<0.005	0.05	0.007	0.009
Nitrate + Nitrite (N)	mg/l	38	91	<0.005	0.39	0.024	0.048
Phosphate (P)	mg/l	61	92	<0.003	0.06	0.004	0.008
Total Phosphorus(P)	mg/l	22	92	<0.003	0.08	0.009	0.011
Total Alkalinity	mg/l	0	87	0.64	19.0	5.8	3.6
Total Organic Carbon	mg/l	0	77	1.0	14.0	4.3	2.4
Dissolved Organic Carbon	mg/l	0	78	1.0	15.0	4.2	2.5
Suspended Solids	mg/l	0	95	1.0	85.0	14.8	16.2
Copper	µg/l	59	85	0.1	4.5	0.6	0.8
Lead	µg/l	62	89	0.4	3.5	0.6	0.7
Zinc	µg/l	24	85	<1	55	6.8	7.1
Manganese	µg/l	16	91	<1	39	9.8	7.0
Uranium	µg/l	65	89	<0.1	1.0	0.12	0.15
Cadmium	µg/l	61	84	<0.04	0.4	0.05	0.05
Iron	µg/l	1	78	50	5260	960	870
Chromium	µg/l	9	12	<0.4	1.5	0.4	0.4

Table 5.10

Preliminary Receiving Water Standards

Parameter	Units	Magela	Cooper
pH		5.5-6.5	5.4-6.8
Turbidity	NTU	33	33
Dissolved Oxygen	mg/l	<5.9	<6.2
Calcium	mg/l	0.8	1.3
Magnesium	mg/l	0.8	1.8
Sulphate	mg/l	0.42	0.6
Ammonia (N)	mg/l	0.005	0.016
Nitrate + Nitrite (N)	mg/l	0.03	0.07
Phosphate (P)	mg/l	0.003	0.012
Total Phosphorus (P)	mg/l	0.015	0.020
Total Alkalinity	mg/l	20	9.4
Total Organic Carbon	mg/l	5.6	6.7
Dissolved Organic Carbon	mg/l	5.2	6.7
Suspended Solids	mg/l	19	31
Copper	µg/l	0.8	1.4
Lead	µg/l	0.6	1.3
Zinc	µg/l	17	14
Manganese	µg/l	14	17
Uranium	µg/l	0.19	0.27
Cadmium	)g/l	0.15	0.10
Iron	µg/l	1200	1800
Chromium	µg/l	1.5	0.8

6. WATER RELEASE STANDARDS

As indicated earlier in this report, the use of a conservative criterion in the development of receiving water standards for the protection of the ecosystem (i.e. one based on natural fluctuations) should be viewed as a mechanism for the production of preliminary standards. Once obtained, these preliminary standards should be applied to the two practical release problems being considered in the Alligator Rivers Region in order to determine which contaminants are critical. These few critical contaminants can then be assessed from a strictly toxicological and ecological point of view and a final set of recommended receiving water standards produced on the basis of the combined assessment. This iteration is carried out in the present chapter.

Although the above comments apply only to the limits deduced on the basis of protection of the ecosystem, an assessment will also be given of the consequence of the limits on load deduced on the basis of protection of man.

6.1 Application of Preliminary Standards to Ranger

Several artificial water bodies at Ranger could be considered by the company as candidates for the source of contaminated water for release, but under existing regulations Retention Pond No. 2 (RP2) is the only one which may be considered appropriate. The present assessment is, therefore, restricted to RP2 but may easily be extended to other ponds or storage pits.

Protection of Man

The allowable annual release volume of RP2 waters may be deduced from the limits on contaminant load obtained in Chapter 5 and assumed concentrations for each contaminant. These are listed in Table 6.1. for both radionuclides and heavy metals. The limits listed for the latter are those based on NHMRC recommendations. The concentrations assumed are the mean values of concentrations for RP2 waters recorded between December 1983 to June 1984, with the exception of ^{230}Th, ^{210}Pb and ^{210}Po. These radionuclides are not routinely assayed and the concentrations listed are estimates based on at most two measurements. No information is available on Cd concentrations. The allowable annual release volume deduced from the figures is listed for each contaminant and can be compared with the maximum volume of RP2, namely $7 \times 10^5 m^3$.

None of the heavy metals for which data are available presents a risk to man even if the full volume of RP2 is released each year, manganese with a safety factor of 10 being the most significant. The most limiting of the individual radionuclides is (using the assumed concentrations) ^{226}Ra, again with a safety factor of 10, and the combined radionuclide volume limit, that is is approximately $3 \times 10^{6} m^3$.

$$V_L = 1/\sum (1/V_{Ai})$$

This combined limit is still four times the maximum volume of RP2.

Bearing in mind that the above assessment is based entirely on annual average concentrations resulting from the released loads of contaminants, it is of interest to compute maximum increase in concentrations of these elements in the creek beyond the mixing zone. If the full volume of RP2 were released over a period of 50 days using a minimum flow criterion of $20 m^3 s^{-1}$ (as recommended by the Fox Report) the maximum increase in creek concentrations would be as listed in column 5 of Table 6.1. The metal concentrations obtained are all significantly below recommended drinking water standards, manganese again being the most significant but with a safety factor of 6.

The release of RP2 waters in a single wet season should, therefore, provide no unacceptable risk to man provided the assumed concentrations for the radionuclides of Th, Pb and Po are not significantly in error and provided the concentration of Cd in RP2 does not prove to be significant. Measurements of these uncertain concentrations should be provided by the company.

Protection of the Ecosystem

The significance of the preliminary receiving water standards based on assessment of the risk to the ecosystem may be assessed by making an estimate of the number of days required to release the full volume of RP2 under specified creek flow conditions and assuming typical RP2 concentrations for the listed contaminants.

A simple model of dilution is obtained by using the mean creek flow rate on those days when flow exceeds the specified minimum. Using a minimum flow of $20m^3s^{-1}$, the historical average flow rate is $50m^3s^{-1}$ for the Magela Creek. Thus, an approximate value for the quantity of any contaminant which may be released each day and yet satisfy the criterion that the creek mean concentration will not increase by more than one standard deviation is

$$m = 4.3 \times 10^6 \sigma \text{ (kg/day)}$$

Using known RP2 concentrations the allowed volume release per day may then be calculated and an estimate made of the number of days required to release the full volume of RP2, taken as $7 \times 10^5 m^3$.

The results of such a calculation are shown in Table 6.2. The concentrations assumed for RP2 are the mean values obtained during the period December '83 to June '84. Since approximately 50 days each year satisfy the minimum flow criterion it is clear that, of the contaminants for which RP2 data exist, only sulphate and uranium do not satisfy the receiving water preliminary standards although manganese and magnesium are sufficiently close to warrant further discussion.

These, then, are the only critical contaminants (for RP2 waters) whose toxicity need be assessed in order to see whether a relaxation of the standard is justified. This assessment is delayed until the critical contaminants for Nabarlek are obtained.

6.2. Application of Preliminary Standards to Nabarlek

The only artificial water body at Nabarlek which contains signficant contaminant loads and which is being considered by QML as a source of release waters is Evaporation Pond No. 2 (EP2).

Protection of Man

The allowable annual release volume of EP2 waters is deduced from the limits on contaminant load obtained in chapter 5 and the assumed concentration of each contaminant. The results are shown in Table 6.3. The concentrations assumed for copper, zinc, and manganese are QML predictions for May 1988, the planned decommissioning year. Other concentrations are those measured in March 1983 with the exception of the radionuclides ^{230}Th, ^{210}Pb and ^{210}Po for which recent estimates have been used.

None of the radionuclides provides a significant limitation on discharge volume compared with the EP2 volume of approximately $4.0 \times 10^5 m^3$ in 1988. Even the combined radionuclide limit of $1.5 \times 10^7 m^3$ has a safety factor of 40 associated with it. The heavy metals Cd, Cu, Pb and Zn provide no significant limitation on the release of EP2 waters but the limit for Mn is of importance since it is approximately equal to the volume of EP2.

The manganese limit warrants further discussion since the annual limit on intake used here is not one based on NH and MRC limiting food concentrations but is based on the maintenance of Mn intake by the critical group close to existing ingestion rates. A full discussion of this point is given in Appendix D but the reasons for taking this approach should be stressed here. These are that Mn is known to be toxic at water concentrations above 1 mg/l and that the existing ingestion via bush foods by the critical group is high compared to the intake by Reference Man. Despite its known toxicity NH and MRC makes no recommendation on dietary intake. The Mn annual limit on intake used here is, therefore, not soundly based on medical recommendations, but a further assessment can be made on the basis of maximum drinking water concentrations.

If the full volume of EP2 were released over a 40 day period using a minimum creek flow rate condition of $5m^3s^{-1}$, the maximum increase in water concentrations beyond the mixing zone would be as listed in Table 6.3. Considered from the point of view of drinking water quality non of these increases is significant with the singular exception of Mn. The USEPA recommends a maximum Mn concentration in drinking water of 50 µg/l. The predicted maximum concentration of Mn in Cooper Creek is significantly above this and even the mean concentration increase (based on mean flow of $9m^3s^{-1}$) would be greater than 70 µg/l.

Deaths from Mn poisoning have occurred at concentrations in drinking water of 8 mg/l (see Appendix D). It would not be reasonable to allow concentrations in potable water to increase beyond one hundredth of a known lethal concentration. For these reasons it is argued that the limit on Mn release deduced in Chapter 5 be adhered to and that, in addition, the maximum receiving water concentration should be 50µg/l.

Protection of the Ecosystem

Determination of the critical contaminants for Cooper Creek may be carried out in a manner similar to that used for Magela Creek.

A simplified dilution model is obtained by using the mean creek flow rate on those days when flow exceeds the minimum specified flow conditions. A minimum volume flow rate of $5m^3s^{-1}$ in Cooper Creek corresponds approximately to the same linear velocity as occurs in Magela Creek at a volume flow rate of $20m^3s^{-1}$. For this reason $5m^3s^{-1}$ has been taken as the specified minimum flow condition although it is recognised that a more rigorous derivation of a suitable minimum flow for discharge of contaminated waters ought to be obtained on hydrological grounds. There are approximately 40 days per annum when this minimum is exceeded and the corresponding average flow rate is

$9m^3s^{-1}$. Thus, an approximate value for the quantity of any contaminant which may be released each day and yet satisfy the criterion that the mean concentration will not increase by more than one standard deviation is

$$m = 7.8 \times 10^5 \ \sigma \ (kg/day)$$

Using known EP2 concentrations the allowable volume release each day may be calculated and an estimate made of the number of days required to release the full volume of EP2, taken here as the predicted 1988 volume of $4 \times 10^5 m^3$.

The results of such a calculation are shown in Table 6.4. The assumed EP2 concentrations for sulphate, ammonia, copper, zinc and manganese are those predicted by QML for May 1988, whereas the remaining concentrations were values recorded on 2/3/83. Inspection of the final column in this table shows that a number of contaminants are critical and will require detailed toxicological and ecological assessment. Primary among these are ammonia and sulphate, but also of significant are calcium, magnesium, nitrate, manganese, and uranium. This assessment follows.

6.3 Examination of Critical Constituents

Ammonia

The toxicity of solutions of ammonia is attributable to the un-ionised molecule NH_3 and not to the ammonium ion. The proportion of any given total concentration of ammonia which is present as NH_3 is largely a function of pH and temperature and under typical Wet season conditions in ARR of pH 6.5 and temperature 30^0C the proportion is 0.25 percent. Ammonia is quick-acting at acutely lethal concentrations and if it is to kill, does so within a matter of 4 hours. However, at concentrations only a little below the acutely lethal level a population of fish can survive for weeks with only a small percentage of deaths in this time. A criterion of 20 µg/l of unionised ammonia has been set by the USEPA but there is evidence to show that 10 µg/l may be a more acceptable value for long term exposure (i.e. 3 months or more) for some species (rainbow trout). It is recommended, therefore, that the mean value of un-ionised ammonia in the creeks of the ARR should not exceed 10 µg/l during the period of contaminated water release. This value, together with the consideration of pH and temperature outlined above, results in a receiving water standard for ARR waters of 4 mg/l of total ammonia.

Sulphate

Sulphate is a common anion of natural surface waters not regarded as a toxic compound. To increase the concentration of sulphate it is necessary to increase the concentration of some cation, the effects of which are likely to mask the effects of the increase in anion concentration. Consequently to seek to know the toxicity of sulphate is to ask a biologically meaningless question. Comparison of the toxicity (96h - LC50) of three sulphates to a single species of fish, for example, showed that for calcium sulphate the sulphate concentration was 1765 mg/l, for potassium sulphate the sulphate concentration was 1950 mg/l, while for sodium sulphate the result was 8670 mg/l. In other studies, however, it has been shown that when copper sulphate is the salt involved tolerable levels of sulphate may not be much greater than 0.05 mg/l. What in fact is being assessed, is the toxicity of the cation, not of the anion. Thus organisms can tolerate sulphate at concentrations of the order of g/l provided the associated cation is of low toxicity.

An analysis of the ionic balance in the waters of RP2 at Ranger and EP2 at Nabarlek shows that the cations associated with sulphate in RP2 waters are predominantly calcium and magnesium, whereas in EP2 waters the associated cation is predominantly the ammonium ion. As has been indicated above and will be separately discussed below, calcium and magnesium are not normally considered to be toxic to aquatic life. Again, it is not the ammonium ion per se which is toxic but the un-ionised molecule NH_3 whose toxicity has been considered separately and for which a separate standard has been recommended. Under these circumstances it is considered that the presence of sulphate in the particular artificial water bodies being discussed here does not constitute a toxicological hazard to aquatic life and that the standard set should rather be based on human health grounds. Thus the limit of 200 mg/l is recommended as the receiving water standard for sulphate.

Nitrate/Nitrite

Nitrate is of low toxicity except in conditions where reduction to nitrite can occur. The 96-h median lethal concentration of nitrate to rainbow trout was determined to be 1360 mg/l and a safe level for fish is therefore probably of the order of 100 mg/l. Under certain circumstances, however, increased levels of nitrate can accelerate the process of eutrophication of waters. Walker and Tyler (in press) have concluded that phosphorus is the limiting nutrient in the Magela Creek system and the extremely low concentrations of phosphorus in the Cooper Creek system also. Thus enhanced concentrations of nitrate in these systems are unlikely to result in accelerated eutrophication.

Nitrite has been found to be of fairly high toxicity and for the protection of salmonid fishes a limit of 0.06 mg/l has been recommended by the USEPA. It is, however, nitrate which is enhanced in EP2 at Nabarlek so that revision of the preliminary standard should be such as to specify Nitrate at 100 mg/l.

Calcium

Little information is available on the toxicity of calcium per se because this metal is not normally considered to be a toxic substance. Baudouin and Scoppa (1974) report a 48 hour LC50 of 3000 mg/l to a microcrustacean, Daphnia hyalina, whilst a 16% reduction in reproduction of Dahnia sp. after 3 weeks exposure at 116 mg/l was reported by Bersinger and Christensen (1972). On the other hand the USEPA quotes a minimum value for alkalinity of 20 mg/l as $CaCO_3$ for freshwater aquatic life except where the natural concentrations are less. On the basis of this evidence it is considered that the recommendation of a receiving water standard for Ca of 20 mg/l would result in no adverse effects to the environment of the ARR and it is probable that this limitation is still conservative.

Magnesium

As with calcium, this metal is not normally considered to be toxic to aquatic life. Baudouin and Scoppa (1974) report a 48 hour LC50 of 3200 mg/l to Daphnia hyalina whilst Bersinger and Christensen (1972) reported a 16% reduction in reproduction at 82 mg/l in Daphnia sp. Again, a 20 mg/l limit for receiving waters of the ARR is recommended.

Manganese

Manganese is rarely found in freshwaters at concentrations above 1 mg/l and the tolerance values to aquatic life range from 1.5 mg/l to over 1000 mg/l. Thus manganese is not considered to be a problem in freshwaters from the toxicological point of view. As has been discussed in Section 6.2. a more stringent limit of 50 μg/l results from human health considerations.

Uranium

For aquatic life and wildlife the chemical toxicity of uranium is more important than the radiotoxicity and a standard of 300 μg/l is recommended (Inland Waters Directorate, 1983). The limitations, however, imposed by consideration of the protection of man result in lower water concentrations than this limit and the maximum concentrations achievable by release of RP2 and EP2 waters in one Wet season are considerably lower than this value. The toxicity of uranium to aquatic life is, therefore, not considered significant in the ARR.

Table 6.1

Release Standards - Application to RP2 Waters - Risk to Man

Contaminant	Limit Bq or kg	Concentration Bq m^{-3} or kg m^{-3}	V_A m^3	δC(Max) mBq/l or μg/l
$^{238}U + ^{234}U$	8.8×10^{10}	4200	2.1×10^7	34
^{230}Th	1.7×10^{11}	600*	2.8×10^8	5
^{226}Ra	1.3×10^{10}	2000	6.5×10^6	16
^{210}Pb	8.3×10^9	600*	1.4×10^7	5
^{210}Po	7.3×10^9	600*	1.2×10^7	5
Cd	1.3×10^3	-	-	-
Cu	8.8×10^4	5.0×10^{-6}	1.8×10^{10}	0.04
Pb	8.2×10^3	3.0×10^{-6}	2.7×10^9	0.02
Mn	6.2×10^3	1.0×10^{-3}	6.2×10^6	8
Zn	1.9×10^5	1.2×10^{-5}	1.6×10^{10}	0.1

Notes:

1. Radionuclide data marked * indicates estimates only.
2. Combined radionuclide limit $V_L = \sum_i (1/V_{Ai}) = 2.8 \times 10^6 m^3$
3. Maximum volume of RP2 = $7.0 \times 10^5 m^3$
4. δC is the maximum increase in creek concentration beyond the mixing zone if the full volume of RP2 were released over a period of 50 days using a minimum creek flow of 20 $m^3 s^{-1}$.

Table 6.2.

Release Standards - Application to RP2 - Risk to Ecosystem

Contaminant	S.D. Kg m^{-3}	Mass/Day kg	Conc. (RP2) kg m^{-3}	Volume/day m^3	Days Required
Calcium	3.0×10^{-4}	1300	1.8×10^{-2}	7.2×10^{4}	10
Magnesium	1.9×10^{-4}	860	4.0×10^{-2}	2.2×10^{4}	32
Sulphate	1.5×10^{-4}	650	0.21	3100	225
Fluoride	1.0×10^{-5}	45	-	-	?
Ammonia (N)	2.5×10^{-6}	11	2.4×10^{-4}	4.6×10^{4}	15
NO_2+NO_3(N)	1.6×10^{-5}	70	8.3×10^{-4}	8.4×10^{4}	8
Phosphate (P)	1.5×10^{-6}	6	3.0×10^{-5}	2×10^{5}	4
Tot. Phos (P)	7.5×10^{-6}	32	-	-	?
Susp. Solids	1.0×10^{-2}	4.3×10^{4}	-	-	?
T.O.C	2.1×10^{-3}	9000	-	-	?
D.O.C	2.0×10^{-3}	8600	-	-	?
Copper	4.0×10^{-7}	1.7	5.0×10^{-6}	3.4×10^{5}	2
Lead	3.0×10^{-7}	1.3	3.0×10^{-6}	4.3×10^{5}	2
Zinc	9.0×10^{-6}	40	1.2×10^{-5}	3.3×10^{6}	0.2
Manganese	5.0×10^{-6}	21	1.0×10^{-3}	2.1×10^{4}	33
Uranium	9.0×10^{-8}	0.4	1.7×10^{-4}	2.4×10^{3}	290
Cadmium	9.0×10^{-8}	0.4	-	-	?
Iron	5.7×10^{-4}	2500	-	-	?
Chromium	7.0×10^{-7}	3.0	2.0×10^{-6}	1.5×10^{6}	0.5

Table 6.3.

Release Standards - Application to EP2 Waters - Risk to Man

Contaminant	Limit Bq or kg	Concentration Bq m^{-3} or kg m^{-3}	V_A m^3	δC(Max) mBq/l or µg/l
$^{238}U + ^{234}U$	1.1×10^{11}	720	1.5×10^8	17
^{230}Th	1.7×10^{11}	200*	8.5×10^8	5
^{226}Ra	1.5×10^{10}	270	5.6×10^7	6
^{210}Pb	1.0×10^{10}	200*	5.0×10^7	5
^{210}Po	9.0×10^9	200*	4.5×10^7	5
Cd	1.0×10^3	2.0×10^{-7}	5.0×10^9	0.005
Cu	3.6×10^4	1.9×10^{-5}	2.0×10^9	0.44
Pb	3.3×10^3	5.0×10^{-6}	6.6×10^8	0.12
Mn	2.5×10^3	5.7×10^{-3}	4.4×10^5	130
Zn	8.6×10^4	1.3×10^{-5}	6.6×10^9	0.3

Notes:

1. Radionuclide data marked * indicates estimates only
2. Combined radionuclide limit $V_L = \sum(1/V_i) = 1.5 \times 10^7 m^3$
3. Estimated volume of EP2 om 1988/89 is $4 \times 10^5 m^3$
4. δC is the maximum increase in creek concentration beyond the mixing zon if the full volume of EP2 were released over a period of 40 days using minimum creek flow of 5 $m^3 s^{-1}$.

Table 6.4.

Release Standards - Application to RP2 - Risk to Ecosystem

Contaminant	S.D. kg m^{-3}	Mass/Day kg	Conc. (EP2) kg m^{-3}	Volume/day m^3	Days Required
Calcium	5.0×10^{-4}	390	0.48	810	490
Magnesium	6.0×10^{-4}	470	0.22	2100	190
Sulphate	2.2×10^{-4}	170	3.7	46	8700
Fluoride	1.0×10^{-5}	8	-	-	?
Ammonia (N)	9.0×10^{-6}	7	1.5	4.7	85000
NO_2NO_3(N)	5.0×10^{-5}	40	0.04	1000	400
Phosphate (P)	8.0×10^{-6}	6	-	-	?
Tot. Phos. (P)	1.1×10^{-5}	9	-	-	?
Susp. Solids	1.6×10^{-2}	1.2×10^4	-	-	?
T.O.C.	2.5×10^{-3}	2000	-	-	?
D.O.C.	2.5×10^{-3}	2000	-	-	?
Copper	8.0×10^{-7}	0.6	1.9×10^{-5}	3.1×10^4	13
Lead	7.0×10^{-7}	0.55	5.0×10^{-6}	1.1×10^5	4
Zinc	$7.0 X 10^6$	6	1.3×10^{-5}	4.6×10^5	1
Manganese	7.0×10^{-6}	6	5.7×10^{-3}	1050	380
Uranium	1.5×10^{-7}	0.1	2.0×10^{-5}	5000	80
Cadmium	5.0×10^{-8}	0.04	2×10^{-7}	2×10^5	2
Iron	8.7×10^{-4}	680	-	-	?
Chromium	4.0×10^{-7}	0.3	-	-	?

Table 6.5

RECOMMENDED RECEIVING WATER STANDARDS - MAGELA CREEK

Constituent		Mean	Maximum	Annual Load	Origin
pH		5.0 (Min)	7.5		E,N
Turbidity (NTU)		33			E,N
Dissolved Oxygen	mg/l	>6.0			E,N
Calcium	mg/l		20		E,T
Magnesium	mg/l		20		E,T
Sulphate	mg/l		200		E,T,M
Fluoride	mg/l	0.02			E,N
Ammonia (NH_3)	μg/l		20		E,T
Nitrate (N)	mg/l		10		E,T,M
Phosphate (P)	mg/l	0.003			E,N
Tot. Phosphorus (P)	mg/l	0.015			E,N
Alkalinity	mg/l	20			E,N
Susp. Solids	mg/l	20			E,N
T.O.C.	mg/l	6			E,N
Copper	μg/l	1.0		9×10^4 kg	E,N,M
Lead	μg/l	0.6		8×10^3 kg	E,N,M
Zinc	μg/l	17		2×10^5 kg	E,N,M
Manganese	μg/l		50	6×10^3 kg	M
Cadmium	μg/l	0.15		1.3×10^3 kg	E,N,M
Iron	μg/l	1200			E,N
Chromium	μg/l	1.5			E,N
Uranium	μg/l	*		3.5×10^3 kg	M
^{230}Th				1.7×10^{11} Bq	M
^{226}Ra				1.3×10^{10} Bq	M
^{210}Pb				8.0×10^9 Bq	M
^{210}Pb				7.0×10^9 Bq	M

E. = Protection of Ecosystem
N. = Natural Fluctuations
T. = Toxicity
M. = Protection of Man

* U concentration to be based on current toxicity experiments.

Note: Radionuclide limits are subject to summation

Table 6.6

RECOMMENDED RECEIVING WATER STANDARDS - COOPER CREEK

Constituent		Mean	Maximum	Annual Load	Origin
pH		4.7 (Min)	8.0		E,N
Turbidity (NTU)		33			E,N
Dissolved Oxygen	mg/l	>6.0			E,N
Calcium	mg/l		20		E,N
Magnesium	mg/l		20		E,T
Sulphate	mg/l		200		E,T,M
Fluoride	mg/l	0.02			E,N
Ammonia (NH$_3$)	µg/l		20		E,T
Nitrate (N)	mg/l		10		E,T,M
Phosphate (P)	mg/l	0.012			E,N
Tot. Phosphorus (P)	mg/l	0.02			E,N
Alkalinity	mg/l	10			E,N
Susp. Solids	mg/l	30			E,N
T.O.C.	mg/l	7			E,N
Copper	µg/l	1.4		3.6 x 10^{4} kg	E,N,M
Lead	µg/l	1.3		3.3 x 10^{3} kg	E,N,M
Zinc	µg/l	14		9 x 10^{4} kg	E,N,M
Manganese	µg/l		50	2.5 x 10^{3} kg	M
Cadmium	µg/l	0.1		1 x 10^{3} kg	E,N,M
Iron	µg/l	1800			E,N
Chromium	µg/l	0.8			E,N
Uranium	µg/l	*		4.4 x 10^{3} kg	M
^{230}Th				1.7 x 10^{11} Bq	M
^{226}Ra				1.5 x 10^{10} Bq	M
^{210}Pb				1.0 x 10^{10} Bq	M
^{210}Po				9 x 10^{9} Bq	M

E. = Protection of Ecosystem

N. = Natural Fluctuations

T. = Toxicity

M. = Protection of Man

* U concentration to be based on current toxicity experiments.

Note: Radionuclide limits are subject to summation.

6.4 Pesticides

Pesticides are anticipated to be present at vanishingly low levels in the Magela and Coopers Creek systems. However water quality criteria (Table 3.1) show that toxic limits for pesticides are generally very low.

During construction at Ranger, the herbicides 2,4,5 - T and 2, 4 -D, as mixture, may have been used but dieldrin apparently was never used. Insecticide-treated materials, e.g. timbers containing unspecified insecticides, have been used on site. White ant sprays containing chlordane have been used on site but larger quantities have been used at Jabiru East and Jabiru townsite. In general, workers have been used to chop down trees and to mow grass rather than the use of insecticides or pesticides. Polychlorinated biphenyls (PCBs) occur in transformer oil used in the electricity generating station.

At Nabarlek some herbicides (not known) are used on site but no pesticides are used. Malathion is used occasionally via fogging to kill mosquitos.

The rate of disappearance of various pesticides from soil can vary widely. In general chlorinated pesticides are highly persistent whereas organo-phosphorus pesticides degrade rapidly. Properties of some pesticides are as follows:

Pesticide	**Type**	**Time for50% applied dose to disappear from soil**	**Time to reach residue level of 0.1 ppm in soil (3% of applied dose)**
Aldrin	Chlorinated Hydrocarbon	2 months	40% remained after 5 months.
Carbaryl	Carbamate	1 month	-
Parathion	Organophosphorus	20 days	90 days
Malathion	Organophosphorus	-	8 days

High soil temperature increases the rate at which pesticides in soil vaporise and escape and the rate at which they decompose. The example of Aldrin (Chlorinated pesticide) is as follows:

Temperature	**7°C**	**26°C**	**46°C**
Amount of Aldrin and dieldrin remaining in soil after 4 weeks.	92%	82%	40%

Thus vaporisation of chlorinated pesticides, from soil is likely to be a key removal mechanism in the Alligator Rivers Region because of the sustained ambient temperatures.

Pesticides used during the construction phase at Ranger were likely to have found their way into retention ponds. Chlorinated pesticides such as chlordane and PCBs have long persistence and would not have degraded within mill sites. Release of waters may therefore introduce pesticides into the natural systm at levels far in excess of natural concentrations. Exclusion of pesticides as contaminants cannot be overlooked unless it is clearly established that the chemicals were never used. In the absence of other criteria, we recommend those listed in Table 6.7.

Table 6.7

U.S. Water Quality Criteria (1976) for Pesticides and other Organic Chemicals

Pesticide	Final mixed concentrations in receiving waters µg/L
Aldrin-Dieldrin	0.003
Chlordane	0.01
Chlorophenoxy Herbicides	Various - see USEPA
DDT	0.001
Demeton	0.1
Endosulphan	0.003
Endrin	0.004
Guthion	0.01
Heptachlor	0.001
Lindane	0.01
Malathion	0.1
Methoxychlor	0.03
Mirex	0.001
Parathion	0.04
Toxaphene	0.005
Polychlorinated Biphenyls	0.001
Phenol	1
Phthalate esters	3

Appendix A. **Retention factors for a Log-normal Distribution**

If x is a variable of the natural waters of a system such that

$$y = \ln (x - x_0)$$

is normally distributed with mean μ and standard deviation σ then x itself is log-normally distributed with a distribution function f(x) given by

$$f\ (x) = \frac{1}{(x-x_o)\sigma\sqrt{2\pi}} \exp \left\{-\tfrac{1}{2} [\ln(x-x_o) - \mu]^2/\sigma^2\right\} \qquad (A.1)$$

The mean, M, standard deviation, Σ, and median, m, of f(x) are given by:

$$M = x_0 + e^{\mu} e^{\frac{1}{2}\sigma^2} \qquad (A.2)$$

$$\Sigma = e^{\mu} e^{\frac{1}{2}\sigma^2} (e^{\sigma^2} - 1)^{\frac{1}{2}} \qquad (A.3)$$

$$m = x_0 + e^{\mu} \qquad (A.4)$$

It is convenient to work with the standardised distribution g(z) obtained by the transformation

$$z = (x - x_0)\ e^{-\mu}$$

The function g (z) is then dependent on σ only and is given by

$$g(z) = \frac{1}{z\sigma\sqrt{2\pi}} \exp \left\{-\tfrac{1}{2}(\ln z)^2/\sigma^2\right\}$$

If contaminated waters are added to the natural waters such that the measured concentration of a contaminant increases by a displacement D, i.e. x -> x + D for all x, then the altered distribution $f_A(x)$ is given by

$$f_A\ (x) = f_N\ (x - D)$$

and any integral over the altered distribution between limits L_1 and L_2 becomes

$$\int_{L_1}^{L_2} f_A(x)\ dx = \int_{L_1 - D}^{L_2 - D} f_N(x)\ dx$$

The retention factor, r (D, L_1, L_2), of the altered distribution for limits L_1 and L_2 of the natural distribution is, therefore, given by

$$r\ (D,\ L_1,\ L_2) = \int_{L_1}^{L_2} f_A(x)\ dx\ /\ \int_{L_1}^{L_2} f_N(x)\ dx$$

$$\int_{z_3}^{z_4} g_N(z)\ dz\ /\ \int_{L_1}^{L_2} g_N\ (z)\ dx$$

$$\text{where } z_{1,2} = (L_{1,2} - x_0)\ e^{-\gamma}$$

$$\text{and } z_{3,4} = (L_{1,2} - x_0 - D)\ e^{-\gamma}$$

Hence by using the logarithimic transformation

$$w = (en\ z)/\sigma$$

the retention factor becomes

$$r(D,\ L_1, L_2) = [F(w_4) - F(w_3)]/[F(w_2) - F(w_1)]$$

where $F(w)$ is the cumulative distribution function for a normal distribution and

$$w_i = (\ell n\ z_i)/\sigma \quad \text{for } i - 1,2,3,4.$$

If the limits L_1 and L_2 are chosen to be the 95% limits of the natural distribution then

$$Z_1 = e^{-2\sigma},\quad Z_2 = e^{2\sigma}$$

and, by letting $D = v\Sigma$ where Σ is the standard deviation of the natural distribution and v is a variable multiplicative factor, Z_3 and Z_4 become

$$Z_3 = e^{-2\sigma} - v\ e^{\frac{1}{2}\sigma^2}\ (e^{\sigma^2} - 1)^{\frac{1}{2}}$$

$$Z_4 = e^{2\sigma} - v\ e^{\frac{1}{2}\sigma^2}\ (e^{\sigma^2} - 1)^{\frac{1}{2}}$$

The retention factors $r(D,\ L_1,\ L_2)$ can now be calculated as a function of σ, the standard deviation of the log-transformed distribution.

The results of the calculations of the retention factor are shown in figure

A.1 for values of σ from 0.25 to 1.0. From these data the value of D/Σ which gives rise to a retention factor of 0.88 (i.e. the value of r for a normal distribution and $D/\Sigma = 1$) can be determined for each value of σ. This critical value of (D/Σ) is denoted by $(D/\Sigma)_c$. Since σ is the parameter which determines the degree of asymmetry of the distribution f(x), it is desirable to express $(D/\Sigma)_c$ as a function of a readily defined parameter of the measured distribution which reflects the asymmetry. A convenient asymmetry parameter, A, is defined by

$$A = (\text{Mean} - \text{Median})/(\text{Standard deviation})$$

which can be expressed in terms of σ by using equations (A.2), (A.3) and (A.4). Thus

$$A = e^{-\frac{1}{2}\sigma^2} \left(e^{\frac{1}{2}\sigma^2} - 1\right) \left(e^{\sigma^2} - 1\right)^{\frac{1}{2}} \tag{A.5}$$

The critical displacement, $(D/\Sigma)_c$, is plotted against the asymmetry parameter, A, in figure A.2. It can be seen from these data that under conditions of extreme asymmetry, namely A 0.3, the critical displacement approaches two standard deviations compared with the value of one obtained in the case of a gaussian distribution.

Appendix B **Hypothetical Critical Group Diet**

It is clearly important to establish with some certainty the dietary habits of persons potentially exposed to water-borne contaminants, in order to evaluate their degree of exposure. It is usually assumed that the group most at risk from this exposure pathway is that which consumes the most locally derived foodstuffs; in the case of the Magela Creek system this is taken to be the group of about 57 aborigines living at Mudginberri Station (Gillespie, Levitus, Smith, compiled Oct. 1983), in the case of the Cooper Creek system two hypothetical groups are considered, one using the floodplain as a food source, and one the creek downstream of Nabarlek.

Davy (1983) derives an average annual food intake for an Arnhem Land Aborigine of 430 kg a^{-1} from Meehan (1977) and McArthur (1960). For comparison, annual intakes given in ICRP 23 (1975) are for example, Africa - 460 kg a^{-1}, Latin America - 500 kg a^{-1} and Europe - 683 kg a^{-1}.

The annual water intake is again taken from Davy (1983) as 8 l day^{-1} (not including water taken in as solid food).

Some fraction of this intake (food and water) will come from the bush, and some from foodstuffs imported to the region and from water taken from bores supplying town and station water supplies. These are presumed isolated from any contaminants discharged to surface waters, and so water consumed from these is also considered as imported.

We estimate the imported fraction of the diet from data presented in table B.1., supplied by Gagadju Association. This table lists the stores bought by the Aboriginal population of Mudginberri Station over 4 separate two week periods. We combine these items into animal products, plant food items and water based drinks (i.e. not including milk). We further assume that the total diet of 430 kg may be divided as 75% animal products and 25% plant foods corresponding to 322 kg and 108 kg respectively. From the totals of Table B.1, this suggests that all the plant food items in the Mudginberri diet are imported compared with only about 10% of the animal product component.

We now require to subdivide this total bush diet of approximately 290 kg animal products into the various animals eaten. We take as a starting point the diet proposed by Bywater (private communication) given in table B.2. We delete the plant food items Red Apple, Green Plum and Sand Palm, partly because we believe little or no plant food is taken in the bush, but mainly because these plants are expected to be little affected by contamination of the aquatic system. However the Water Lily component is retained. This is an aquatic plant, and so may be contaminated, and it is also known to concentrate radionuclides. Thus even a small intake may prove significant. We also add to the list a small intake of turtles, in view of their apparent popularity when available and their possible significance as a contaminant concentrator.

This revised bush diet, normalised to a total of 290 kg and with some simplifications in classification is given in table B.3. In particular, all fish have been grouped together, the shrimps combined with the mussels and the pig with the buffalo.

Finally, we assume that only a small fraction (20%) of the 8 l day $^{-1}$ water consumption is derived from surface water. This gives a bush intake of 600 l a^{-1}.

Unfortunately we have no information on the dietary habits of people living off the Cooper Creek system, and so this diet is presumed to apply to both the Magela and Cooper Creeks.

Table B.1. **Fortnightly Food Deliveries to Mudginberri Station**

	7/10/83	20/10/83	13/1/83	26/1/84
	kg	kg	kg	kg
Sugar	29	18	18.25	10.5
Flour	140	126	84	56
Bread	30.6	30.6	38.1	21.8
Camppie	9.5	8.2	2.4	5.8
Stew	8.5	7.7	4.7	9.4
Beef	56	40	50	26
Potato	18	14	12	2
Onion	9	2	6	0
Rice	64	42	74	30
Milk	37	40	27	19
Spaghetti & Meat	7.6	8	4	3.6
Weetbix	13.5	13.5	6	4.5
Oats	30	-	20	6
Oil	7.6	9.5	26.6	11.4
Beans	7	-	-	2.6
Spaghetti	1.5	1.5	14.3	6
Jam	2	1.4	1.4	1.0
Syrup	3.0	3.0	0	0
Drink	-	54	21	30.4

Table B.2. **Hypothetical Diet Proposed by Bywater (private communication)**

	%
Buffalo	68
Pig	4
Magpie Goose	5
File Snake	1
Mussels	1
Shrimp	0.2
Barramundi	1
Fork-tailed Catfish	4
Eel-tailed Catfish	1
Sleepy Cod	2
Long Tom	1
Bony Bream	1
Spangled Grunter	1
Saratoga	1
Red Apple	1
Green Plum	1
Water Lily	1
Sand Palm	1
Goanna	1
Total	96.2

Table B.3. **Assumed Diet For Hypothetical Critical Group**

	kg a^{-1}
Buffalo	223
Magpie Goose	14.5
File Snake	3
Invertebrate	4
Turtle	1.5
Fish	38
Goanna	3
Water Lily	3
Imported	140
	430

Water - Bore	2400
- Surface	600

Appendix C. **Transfer Functions**

For the purposes of this simplified discussion, the Transfer Function (TF) used here is defined as the ratio of contaminant concentration in the various components of the diet set out in Appendix C, to the contaminant concentration in the medium from which the diet item derives its major nutrient intake (e.g. soil in the case of buffalo, or water in the case of fish). This is, of course, a gross simplification in that many of the food items considered here will drive their intake in some proportion from both media. We shall consider these TF in two groups, those applicable to radionuclides, and those applicable to heavy metals.

C.1 **Transfer Functions for Radionuclides**

The values used for radionuclides, presented in table C.1, are taken predominantly from Davy et al (1982) and follow the assumptions set out there. The principal exceptions to this are buffalo and magpie geese. Transfer Functions for the latter were based upon data presented in "Birds on Nabarlek Ponds", an internal OSS memo by M. Carter (1983). Those for buffalo are drived from data presented in the ARR Fact Finding Study (Conway et al, 1974) and in Rayno (1982).

C.2. **Transfer Functions for Heavy Metals**

Information of local relevance is available for very few contaminants other than radionuclides. Data for cadmium, copper, lead, manganese and zinc has been collated from the ARR Fact Finding Study (Conway et al, 1974) and Environmental Monitoring Review (R.U.M., 1982). No information was available for turtle, and so the assumption made by Davy et al (1982) was repeated, i.e. that the TF for turtles are half those of mussels, on the basis of diet. The resulting TF are given in table C.2.

Table C.1. **Transfer Functions - Radionuclides**[1]

	U	Th-230	Ra-226	Pb-210	Po-210	Medium
Buffalo[2]	4.4×10^{-3}	5.8×20^{-5}	6.0×10^{-3}	5.2×10^{-3}	2.1×10^{-2}	soil
Magpie goose[3]	1.0×10^{-2}	0.12	5.0×10^{-2}	0.3	5.0×10^{-2}	water
File snake[4]	10	30	40	300	50	water
Invertebrate[5]	100	500	350	7000	4000	water
Turtle[6]	50	250	170	3500	2000	water
Fish	10	30	40	300	50	water
Goanna[7]	3	8	10	75	13	25% water 75% soil
Water lily	10	30	700	200	300	water

Note 1. Units are $(\text{Bq kg}^{-1})_{\text{foodstuff}}/(\text{Bq litre}^{-1})_{\text{water}}$, except for buffalo, which are $(\text{Bq kg}^{-1})_{\text{buffalo}}/(\text{Bq kg}^{-1})_{\text{soil}}$. Values derived from Davy et al (1982) except for

2. derived from ARR Fact Finding Study (1974) and Rayno (1982),
3. derived from M. Carter (1983), "Birds on Nabarlek Ponds", internal OSS memo
4. assumed same as fish
5. assumed entirely mussel
6. assumed half of mussel data on basis of diet
7. assumed same as fish and file snake

Table C.2 **Transfer Functions - Heavy Metals**[1]

	Cd	Cu	Pb	Mn	Zn	Medium
Buffalo	S	0.35	0.03	S	8.4	soil
Magpie goose	S	0.77	0.03	0.01	2.4	water
File snake	S	0.10	0.13	0.05	6.2	water
Invertebrates	0.3	0.81	0.55	22	6.7	water
Turtle[2]	0.15	0.40	0.28	11	3.3	water
Fish	0.13	0.62	0.05	0.35	2.2	water
Goanna	S	2.4	0.35	0.05	3.9	25% water 75% soil
Water Lily	S	0.27	0.06	0.53	0.89	water

Note: 1. Units are $(\text{ppm})_{\text{foodstuff}}/(\mu\text{g litre}^{-1})_{\text{water}}$, except for buffalo, which are $(\text{ppm})_{\text{buffalo}}/(\text{ppm})_{\text{soil}}$

2. taken as half of values for Invertebrates (mussels) on the basis of turtle diet.

3. Values derived from data presented in Environmental Monitoring Review, (R.U.M., 1982), and ARR Fact Finding Study, (Conway et al, 1974)

Appendix D. Annual Limits on Intake for Metals

D.1 Concentration Limits

Unfortunately, there are no internationally derived and accepted limits on intake available for metals other than radionuclides. For some of the contaminants of interest the National Health and Medical Research Council (NHMRC) has recommendations on concentration limits and these are summarised in Table D.1 for four elements (cadmium, copper, lead, zinc). NHMRC have no recommendations for manganese, chromium or nickel. The Australian Water Resources Council drinking water standards, proposed by Hart (1982), are also shown in Table D.1.

It should not be assumed that these individual food concentrations have been set following consideration of only scientific evidence of response/dose curves. Separate NHMRC limits exist for the same foodstuff but dependent on its packaging for sale (e.g. limit on lead content of meat or fish in tinplate container is 2.5 mg kg^{-1}, but for fresh meat or fish is 1.5 mg kg^{-1}). Clearly commercial considerations influence these relative concentrations. These concentration limits are intended to be used as they stand, i.e. no attention is paid to the origin of contamination or to the total consumption of individual items. Limits are set sufficiently low that in the case of metals with a long biological half life (eg. lead) continued ingestion over long periods of time should not lead to accumulation of harmful levels.

D.2 Public Annual Limits on Intake - non stochastic effects.

Because only fresh foods are considered and because the individual food limits have been set with attention paid as to what is technologically achievable, both in fresh and processed foods, it is considered that the above limits , if used directly, are unnecessarily restrictive. In particular, in a situation where the diet is known it seems reasonable to sum the maximum permitted individual food concentrations over the diet, and then use this sum as an overall limit on intake. This presupposes that the efficiency of absorbtion of a particular element (the gut transfer factor) is not significantly dependant on food type. This summation can be written as

$$\sum_i C_{Li} F_i \quad \text{...........(D.1)}$$

where C_{Li} is the individual NHMRC concentration limit on the "i"th different food category or type. F_i is the ingestion rate of that food type.

The totals derived from this equation are given in Table D.2. This summation is clearly legitimate if the ingestion is considered over a time scale comparable with the shortest likely biological half life of a particular hazardous material, e.g. intake per day.

However, neither the available dietary information (Appendix B) nor the pathway model (section 5.1) have this level of temporal resolution. In both cases our information is valid only on an annual basis. Thus we are forced to consider our ingestion rate in terms of food intake per year and the summation produces an annual total ingestion limit on a particular element.

The annual total ingestion limit derived from equation D.1 cannot be considered independently of the existing intake of the critical group. This is because the biological effects of the metals considered by NHMRC are assumed to be non-stochastic, and thus the response/dose curve exhibits a threshold, below which no effect is observed. This implies that a small increase above some existing intake may be sufficient to move the point on the response/dose curve from below the threshold to a point at which an effect would be observed. This is implicitly recognised in the NHMRC limits which apply to all sources of exposure to the general public, both natural and man made.

Thus the Public Annual Limit on Intake for non-stochastic effects from

Table D.1 **Summary of Relevant NHMRC Recommended Limits**

	Maximum Permitted Concentration (mg kg^{-1})						
	Ni	Cr	Cd	Cu	Pb	Zn	Mn
Fish	-	-	0.2	-	-	-	-
Molluscs	-	-	2	70	2.5	1000 (oysters)	- -
Vegetables	-	-	-	-	2	-	-
Other Foods	-	-	0.05	10	1.5	150	-
Beverages, Liquid Foods	-	-	0.05	5	0.2	5	-
Water^2	0.1	0.05	0.005	1	0.05	5	0.05

Note 1. for simplicity, only those categories of food items relevant to the critical group diet (Appendix B) are given here.

2. taken from Recommendations to the Australian Water Resources Council, by Hart (1982), except for manganese, which is from Quality Criteria for Water (USEPA, 1976).

Table D.2 **Derived Non Stochastic Limits on all Sources of Intake for Some Heavy Metals**[1]

Potentially contaminated Foodstuff	Intake $kg\ a^{-1}$	Cd $mg\ kg^{-1}$	Cu $mg\ kg^{-1}$	Pb $mg\ kg^{-1}$	Zn $mg\ kg^{-1}$
Fish	38	7.6	380	57	5700
Molluscs	4	8.0	280	10	4000
Vegetables	3	0.2	30	6	450
Other Foods[2]	385	19.3	3850	578	57800
Water	3000	15	3000	150	15000
Total Limit ($mg\ a^{-1}$)		50	7540	801	82950

Note:
1. These total limits only apply to the diet given here and include background contributions.
2. Imported foodstuffs are included in Other Foods, for simplicity.

heavy metals is given by

$$ALI_p = \sum_i (C_{Li} - C_{Ni}) F_i \quad \text{........(D.2)}$$

where C_{Ni} is the natural concentration in the "i"th food category or type.

D.3 Application to the Alligator Rivers Region

Knowing the diet (Appendix B) and the existing environmental concentrations, C_{Ni}, of the relevant contaminants (Conway et al, 1974; R.U.M.,1982) existing annual intakes can be estimated. This is done in Table D.5 for the Magela System. It is to be regretted that the absence of a biological monitoring programme at Nabarlek precludes similar estimates for Cooper Creek. We are therefore obliged to apply the Magela data to both systems. It is instructive to compare the natural intakes so calculated with those of Reference Man (ICRP 23), which are also shown in Table D.3. Both manganese and zinc are well above the typical intake, as is lead. The latter figure merits some discussion.

On close examination of the source data (mainly from R.U.M. 1982), two very high lead contents in buffalo flesh were distinguished amongst a generally low data set. Upon enquiry, it was discovered that these values were presumed to be associated with lead contamination of the animal when shot with uncased lead bullets which apparently fragment on impact. Ranger have since taken to collecting animals with sheathed bullets which remain intact (Bywater, private communication). From the point of view of calculating Transfer Functions clearly the uncontaminated figures form the relevant data set. These were the concentrations used in section 5.1.3. However, from the point of view of existing intake this is not the case. Most if not all the large animal collection (buffalo, pig) by Aboriginal hunters is by shooting,

Table D.3 **Mean concentration (mg kg^{-1}) and standard deviation**

Food Item	kg a^{-1}	Cd	Cu	Pb	Mn	Zn
Buffalo	223	$0.05_?$	1.5_{16}	26_{120}	0.2_2	43_{30}
Magpie goose	14.5	N/D	2.0_1	$0.1_?$	$0.2_?$	15.3_{18}
File snake	3	N/D	0.3_1	0.3_2	1.0_6	34_{11}
Invertebrate	4	0.1_1	2.1_{40}	1.7_4	560_{165}	42_{25}
Turtle^2	1.5	$0.05_?$	1.0_{20}	0.8_2	281_{82}	21_{12}
Fish	38	$0.05_?$	0.9_{14}	0.1_2	8_{10}	17_4
Goanna	3	N/D	1.3_4	1.1_{12}	1.2_4	29_8
Water lily	3	N/D	0.4_6	0.1_1	14_{10}	4.3_{29}
Total + 33%(mg)^3	430	$20_?$	610	8680	4570_{1860}	16200
Water(μg litre^{-1})	3000	$3_?$	2_1	2_2	15_8	6_2
Total intake (mg)		30	620	8700	4600	16200
Total s. devn(mg)						

For comparison, Reference Man Annual Intake(mg) and Range (ICRP 23)

55	1280	160	1350	4750
(36-360)	(260-1800)	(55-250)	(800-3300)	(3600-5475)

Note: 1. Data taken from Environmental Monitoring Report, R.U.M. Pty. Ltd., (1982), Conway et al, 1974.

2. No data, so assumed half of mussels (Invertebrate) on basis of diet

3. 33% increase for Imported Food not included in contaminated data

4. In the absence of detailed analysis of potable bore water, concentrations of surface waters are used, taken from R.U.M. (1982)

5. subscripted values are errors in the least significant figures, N/D means below detection limit.

undoubtedly with the cheaper uncased bullets (or even lead shot). This contamination, although man made, is then part of the existing diet, and by employing Ranger's buffalo data we may well be underestimating the true background intake. Certainly the two contaminated values should not be discarded, and it is recommended that more attention should be paid to local methods of collection of food items. It may well be that, for instance, spearing fish is a significant contamination source.

The ratio of background manganese intake to that of Reference Man emphasises the need for the derivation of some limit on intake. That dietary manganese can be toxic above certain concentrations is known. Sixteen cases of severe manganese poisoning (including 3 deaths) resulted from drinking contaminated water of 8 to 14 mg/litre (Kawamura et al; 1941); (c.f. Australian Water Resources Council recommended limit of 50 μg/litre). Environmental Health Criteria 17 (WHO 1981) indicates that drinking water contributes between 0.1 and 2.5% of the total dietary intake. In the absence of even an NHMRC limit, a completely different approach is adoptedhere. Bearing in mind the conclusion of chapter 3 in respect of the protection of the ecosystem, in which it was stated that in the absence of biological data on response/dose curves, limits should be set based on natural variation, we propose a similar working limit for manganese based on the natural variation in the diet. Using the concentrations and standard deviations given in Table D.5, the overall standard deviation in dietary manganese has been calculated (also in Table D.5). This upper one standard deviation bound corresponds to about five times the Reference Man average intake, and is nearly twice his maximum range. Whether or not this is cause for concern is unknown. Until medical evidence to the contrary appears, the use of mean plus one standard deviation as an operational total intake for manganese is suggested on the grounds that this variation, as far as is known, does not cause untoward effects in the exposed population. Because of the probability of a threshold, this of course is no guarantee that moving the mean by this amount will not cause such effects. It is recognised that this is an unsatisfactory derivation, and that a limit based on public health grounds would be preferable. Of course any release figures derived using these limits will also be subject to the AWRC drinking water limits mentioned above.

It is now possible to calculate effective ALI_p derived from all future sources not at present contributing heavy metals to the diet. Uranium mining is assumed to dominate such sources. These ALI_p derived for contaminant release are obtained by subtracting the present average intake (Table D.3) from the total limits of Table D.2, and in the case of manganese from the mean plus one standard deviation derived in Table D.3. These effective non stochastic ALI_p are presented in Table D.6.

Again the lead figure of 90 mg a^{-1} needs explanation. The existing intake of 8700 mg a^{-1}, is very much greater than the NHMRC derived limit of 910 mg a^{-1}. Clearly if the formalism presented here is rigorously adhered to no release of lead whatsoever would be permitted. This is clearly unrealistic and it is considered reasonable, for the purpose of discussion, to permit an additional intake of up to 1% of the existing diet. As can be seen in the discussion of chapter 6 this is not a critical assumption.

D.4 Public Limits on Intake - stochastic effects

There is good evidence that chromium, nickel and cadmium are carcinogenic, and it is considered that iron and lead are possible carcinogens. The U.S. Environmental Protection Agency (USEPA) has adopted a linear no-threshold dose-response relationship for carcinogens, and Cohen (1981) derives cancer risk estimates from various sources, in particular the Carcinogen Advisory Group (CAG) of the USEPA. His risk data are summarised in Table D.5. If we apply the levels of risk used to protect the critical group from carcinogenic effects of radionuclides appropriate to the two mines (1×10^{-5} for Ranger, 5×10^{-5} for Nabarlek) then the ALI_p shown in Table D.5 are derived. As with radionuclide stochastic risk, background levels are not considered here, because the risk is assumed linear no-threshold.

Table D.4 **Public Annual Limits on Intake for Heavy Metals -Non Stochastic Limits**

ALI_p	(mg a^{-1})
Cadmium	20
Copper	6900
Lead	90
Manganese	1900
Zinc	67000
Chromium	-
Nickel	-

Note: Apply only to persons ingesting the background totals of table D.5 via the diet of Appendix B.

Table D.5 **Risk from Oral Ingestion of Carcinogenic Elements**

	Cr	Ni	Cd
Risk of Death (per gram ingested)	1×10^{-3}	8×10^{-5}	1.3×10^{-3}
ALI_p - Ranger (mg)	10	120	8
- Nabarlek (mg)	50	620	40

Note: These are stochastic limits only.

APPENDIX

Table 1 : **Summary of Acceptable Contaminant Concentrations Based on Acute Toxicity Data and Application Factors**

Toxicant	Test species	ARR Data	Test Specification[b]	Acute lethal Concentration µg/L	A.F.[c]	MATC[d] µg/L	Recommended Criteria µg/L	Ref.
Alamine					No value (NV)		NV	
Aluminium	(F) [a].S gairdneri		acute lethality	500	assume	5	16	
				assume ILC50			0.01	
Ammonia as free NH_3	(F) Salmonids		acute lethality assume ILC50	200	0.1	20	12	
Arsenic	(C) S. Serrulatus		LC50–48hr	812	0.01	8.12	50	21
Barium					NV	NV		
Cadmium	(C) A. australis		LC50 96hr	15	0.01	0.15	0.2	21
Chromium	(C) D. pulex		LC50 24hr	560	0.01	5.6	10	8
Colour						Natural Variation	12	
Copper	(F)C. stercusruscarum	*	LC50 96hr	17	0.05	0.85	5	11
Iron	(M) Planibaras sp.		LC50 48hr	73,170	assume	3,659		1
				0.05				
Lead	(F)Craterocephalus sp	*	TLM 96hr	180	0.01	1.8	5	9
Manganese				assume				
as Mn 04	(F)Craterocephalus sp	*	TLM 96hr	22,000	0.05	1,100		9
as Mn			10,000		500			
Mercury	(C)F. clypeata		LC50–96hr	0.02	0.1	0.002	0.1	21
Nickel	(F)P. promelas		LC50–96Hr	5160	0.05	258	25	21
Nitrate					NV	NV		
Non-Filterable Residue					Natural variation		12	
Organics					see sect. 4.4.5 table 2			
pH	fish			5 – 9		12		

Appendix Table 3 **Summary of Some Available Toxicity Data**

Contaminant	**Concentration (mg/l)**	**Test Spec.**	**ARR**	**Taxa**	**Test Conditions**					**Ref**
					Temp	**pH**	**Tot. Alk**	**Tot. Hard**	**Other**	
							(as mg/L CaCo$_3$)			
Phosphate				NV	NV					
Raffinate (neutra)				NV	NV					
Selenium	(F)S. gairdneri	LC50-96hr		128	0.01	1.28	10	21		
Sulphate				NV	NV					
Sulphide	(I)B. vagus	LC50 90hr		28 0.05	assume	1.4		7		
Uranium	(F)A. percoides *	TLM - 96hr		2500 0.05	assume	125		9		
Zinc	(F)C.stercusmuscarum *	LC50 - 96hr		600	0.01	6	50	11		

a,b see key for definitions
c,e Hart 1974, Hart 1982
d Maximum acceptable toxicant concentration (MATC) = Application Factyor (AF) x 96hr LC50 (Hart 1982) (other time intervals for LC50's taken for some species due to lack of suitable data).
* See Hart 1982 for exceptions.

Appendix Table 3 **Summary of Some Available Toxicity Data**

Contaminant	Concentration (mg/l)	Test Spec.	ARR	Taxa	Test Conditions Temp	pH	Tot. Alk (as mg/L $CaCo_3$)	Tot. Hard	Other	Ref
Alamine 336	18	TLM-96h *		(F)craterocyshalus sp.						9
Aluminium										
$AlCl_3$	5.2	TL50 3 days		(F)S. gairdneri		9			16	
$AlCl_3$	5.2	TL50 39 days		(F)S. gairdneri		7.0			16	
$Al_2(SO_4)_3$	5.0	serious in 5 min		(F)S. gairdneri					16	
$Al_2(SO_4)_3$	1.0	no effect		(F)S. gairdneri					16	
$AlCl_3$	27	TLM-96 hr		(F)Gambusia affinis		4.3-7.2			turbid 16	
Al^{3+}	4	not toxic		(F)Japanese kill fish		6.3-7-8			16	
$AL(OH)_4^-$	0.05	chronic weight loss no effect		(F)S. gairdeneri fingerlings		7.0			16	
$Al(OH)_4$	0.5	acutely toxic		(F)S. gairdneri		7.0			16	
		fingerlings								
$Al_2(SO_4)_3$	22	immoblized		(C)Daphnia magna		6.5-7.5			16	
$AlCl_3$	3.9	48 hr LC50		(C)Daphnia magna						
$AlCl_3$	1.4	3 week LC50		(C)Daphnia magna		6.5-7.5			16	
$AlCl_3$	0.68	50% RI 3 weeks		(C)Daphnia magna		6.5-7.5			16	
$AlCl_3$	0.32	16% RI 3 weeks		(C)Daphnia magna		6.5-7.5			16	
Total Aluminium	0.02	99% survival 14 days		(F)Fontinalis salvelinus		5.2			17	

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	**Concentration (mg/l)**	**Test Spec.**	**ARR**	**Taxa**	**Test Conditions**					**Ref**
					Temp	**pH**	**Tot. Alk**	**Tot. Hard**	**Other**	
							(as mg/L $CaCo_3$)			
		(brook trout)								
	.042	28% survival 14 days		(F)<u>Fontinalis salvelinus</u>		5.2			17	
Ammonia										
NH_3	0.3	LC50 96 hour		(F)guppy	27-28	7.2-7.8 mg/L 6.8-7.4	140-170	130-150	D.O.	15
NH_3	0.04	no effect		(F)<u>S. gairdneri</u>					14	
NH_3	8.0	Lethal conc.		(C)<u>Daphnia</u> sp.					13	
NH_3	0.2	Lethal conc.		(F)Salmonids				12		
NH_3	0.2-2.0	Lethal conc.		(F)trout-carp				12		
NH_3	0.025	safe		(F)trout-carp				12		
NH_3	0.005	GI		(F)chinook salmon					12	
Arsenic										
As(v)	7.4	LC50-48hr		(C)<u>D. magna</u>				21		
As(v)	0.853	Lifecycle		(C)<u>D. magna</u>				21		
AsO_3	0.961	LC50-7d		(C)<u>G. pseudolimnaeus</u> Crust					21	
As(III)	0.812	LC50-48hr		(C)<u>s. serulatus</u>					21	

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	**Concentration (mg/l)**	**Test Spec.**	**ARR**	**Taxa**	**Test Conditions**					**Ref**
					Temp	**pH**	**Tot. Alk**	**Tot. Hard**	**Other**	
							(as mg/L $CaCo_3$)			
As(III)	10.8	LC50-96hr		(F)<u>S.</u> <u>gairdneri</u> (juvenile)					21	
	10.44	LC50-11d		(F)<u>S.</u> <u>fontinalis</u> (adult)						21
	41.76	LC50-96hr		(F)<u>L.</u> <u>macrochirus</u> (juvenile)					21	
	2.32	Reduc. survival & growth in 16 weeks		(F)<u>L.</u> <u>macrochirus</u> (juvenile)					21	
Barium	5.8	16% RI		(C)<u>D.</u> <u>magna</u>				7		
Cadmium										
	0.015	LC50-96hr		(C)<u>A.</u> <u>australis</u>				Soft		21
	0.007	LC50-192hr		(C)<u>A.</u> <u>australis</u>				Soft		21
	0.001	no effect		(C)<u>A.</u> <u>australis</u>				Soft		21
	0.015	LC50-96hr		(C)<u>P.</u> <u>australiensis</u>				Soft		21
	0.0015	LC50-96hr		(F)<u>S.</u> <u>fontinalis</u>				44	21	
	0.0017-0.0034	MATC		(F)<u>S.</u> <u>fontinalis</u>				44	21	
	0.0018	LC20-96hr		(F)<u>S.</u> <u>gairdneri</u>				31	21	
	0.0013	LC50-390hr		(F)<u>S.</u> <u>gairdneri</u> (adult)				20		21
	1.94	LC50-96hr		(F)<u>L.</u> <u>macrochirus</u>			20	21		

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	Concentration (mg/l)		Test Spec.	ARR	Taxa	Test Conditions Temp	pH	Tot. Alk (as mg/L $CaCo_3$)	Tot. Hard	Other	Ref
Chromium											
Cr VI	0.2	GI			(F)O. kitsutch					7	
Cr^{3+}	0.6	50% RI			(C)D. magna				7		
Chromium	0.56	LC50–24h			(C)D. pulex	25			8		
	0.76	LC50–24h			(C)D. magna	25			8		
	5.6	LC50 – 24h			(C)Aeolosoma sp.		25			8	
Chromium	5.0	LC50 – 24h			(C)Nitrocris sp.		25			8	
Cr(VI)	0.05	LC50–96hr			(F)D. magna				21		
	59	LC50–96hr			(F)S. fontinalis					21	
	0.35	LC70–3month			(F)S. fontinalis					21	
	69	LC50–96hr			(F)S. gairdneri					21	
	0.34	LC10–3month			(F)S. gairdneri					21	
	0.037	MATC			(F)S. gairdneri					21	
Cr(III)	5.07	LC50–96hr			(F)P. promelas				20	21	
	17.60	LC50–96hr			(F)P. promelas				20	21	
Copper (total)	0.46	LC50 – 96hr	*		(F)M. splendida						
			innornata		25	7.5	27 54	150	20		
	0.16	LC50 – 96hr	*		(C)Machrobrachium		25 7.5	27	54 150	20	

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	Concentration (mg/l)	Test Spec.	ARR	Taxa	Test Conditions					Ref
					Temp	pH	Tot. Alk (as mg/L CaCo$_3$)	Tot. Hard	Other	
	0.14 LC50 - 96hr	*		(F)Ambassis sp.	25	7.5	27	54 150	20	
	0.077 LC50 - 96hr	*		(F)D. bandata	27±0.8±0.15			31.1	Sulphate	10
						(Calcilated	mg/L			
						Mg+Ca)				
	0.168 LC50 - 96hr	*		(F)M. splendida	27±0.3		6±0.15	31.1	24	10
		innornata								
	0.085 LC50 - 96hr	*		(F)P. rendahli	27±0.3		6±0.15	31.1	24	10
	0.003; LC50 - 95hr	*		(C)Caridina sp	27±0.3		6±0.15	31.1	24	10
	0.005					cond.µS/cm				
	0.06; LC50 - 96hr	*		(F)M. splendida		26.9±0.2	6.7	7.0, 3	40, 28.5	11
	0.25									
	0.12; LC50 - 96hr	*		(F)M. nigrans	27	7.2±.3	17.4	25.5	57.5	11
	0.14									
	0.017; LC50 - 96hr	*		(F)Craterocephalus	27.3±.5			6.6		11
	0.021	stercusmuscarum								
	0.04 TLm - 96hr	*		(F)Craterocephalus sp.						9
	>0.1 TLm - 96hr	*		(F)A. percoides					9	
	0.17 TLm - 96hr	*		(C)Macrobrachium sp.						9
	0.001- ML			(C)Macroinverts				10	7	
	0.005									
	0.01 LC50 - 24hr			(C)D. pulex	25					

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	Concentration (mg/1)	Test Spec.	ARR	Taxa	Test Conditions					Ref
					Temp	pH	Tot. Alk (as mg/L CaCo$_3$)	Tot. Hard	Other	
	8.0 GI			(A)*S. quadricauda*	25				8	
Cu^{++}	15 CD			(H)*E. canadersis*	20				1	
	0.13– LC50 – 24hr 0.67			(F)*B. nerio*	25	7.8–8.3	81–253	130–373		19
Copper	0.1–0 ML – 24hr 1.0			(F)*S. gairdneri*	5–18		6.3–7.8	36		18
	0.62 LC50 – 96hr			(F)*R. saxatilis*	21	8.2	35	64	19	
						cond µS/cm				
	0.041 LC50 – 96hr			(M)*Physastea*	25	7.5	27	54 150	20	
	0.7 LC50 – 24h			(F)*N. barbatulus*		8.2		240		19
	0.036– LC50 – 24h 0.138			(F)*L. reticulatus*	25	7.5	18–36	20–88		19
	1.24– LC50 – 96h 1.70			(F)*L. gibbosus*	20	7.8	83	125		19
Copper	0.66– LC50 – 96h 1.0			(F)*L. macrochirus*	20–25		4.5–8.0	3–48	10–52	19
	0.05– LC50 – 24h 1.76			(F)*P. promelas*	18–25		7–8.2	18–300	18–360	19
	1.15 LC50 – 24h			(C)*Philodina*	25			8		
	1.14 LC50 – 24h			(F)*J. floridie*	25	6.0–8.3	200–253	350–375		19
	1.6 LC50 – 24h			(C)*Aeolosama* sp.	25				8	
	1.24– LC50 – 96h 2.53			(F)*L. Macrochirus*	20–24		7.8–8	48–85	125–365	19
	1.5– ML – 24h 3.0			(F)*C. auratus*	5–30	6.3–7.8		36	18	
	2.5– ML – 24h 4.0			(F)*C. macrochirus*	5–30		6.3–7.8	36		18

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	Concentration (mg/1)	Test Spec.	ARR	Taxa	Test Conditions Temp	pH	Tot. Alk (as mg/L CaCo$_3$)	Tot. Hard	Other	Ref
	1.6-21.0 LC50 - 96h			(F)<u>P</u>. <u>promelas</u>					7	
Cu^{++}	32.08 CL50 - 48h			(C)<u>A</u>. <u>aquaticus</u>	20				1	
Cu^{++}	36.36 CL50 - 48h			(M)<u>Planibarus</u> sp.	20				1	
Cu^{++}	41.32 CL50 - 48h			(F)<u>L</u>. <u>reticulatus</u>	20				1	
Iron										
Fe^{+++}	30 CD			(H)<u>E</u>. <u>canadensis</u>	20				1	
Fe^{+++}	73.17 CL50 - 48h			(M)<u>Planibaras</u> sp.	20				1	
Fe^{+++}	81.08 CL50 - 48h			(C)<u>A</u>. <u>aquaticus</u>	20				1	
Fe^{+++}	117.18 C150 - 48h			(F)<u>L</u>. <u>reticulatus</u>	20				1	
Lead										
(total)	1.17 LC50-96hr			(F)<u>S</u>. <u>gairdneri</u>			28		21	
	0.2 LC50-14d			(F)<u>S</u>. <u>gairdneri</u>			28			
	0.0072 20%BR			(F)<u>S</u>. <u>gairdneri</u>				28	7	
	0.025 20%BR			(M)<u>L</u>. <u>palustris</u>				139		7
	0.030 16%RI			(C)<u>D</u>. <u>magna</u>			45.3	7		
	0.18 TLm - 96hr	*		(F)<u>Craterocephalus</u> sp.						9
	0.3 TLm - 96hr	*		(F)<u>A</u>. <u>percoides</u>					9	
	0.5 TLm - 96hrs	*		(F)<u>L</u>. <u>unicolor</u>					9	

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	Concentration (mg/l)	Test Spec.	ARR	Taxa	Test Conditions					Ref
					Temp	pH	Tot. Alk (as mg/L $CaCo_3$)	Tot. Hard	Other	
	0.45	LC50-48hr		(C)<u>D.</u> <u>magna</u>			45	21		
	0.3	LC50-3week		(C)<u>D.</u> <u>magna</u>	c		45	21		
	0.03	GI		(C)<u>D.</u> <u>magna</u>			45	21		
	0.1	LC50-48hr		(C)<u>A.</u> <u>meridianus</u>		c		25	21	
	0.124	GI		(C)<u>A.</u> <u>meridianus</u>		c		25	21	
	0.004- **0.0076**	MATC		(F)<u>S.</u> <u>gairdneri</u>				28	21	
Manganese										
MnO_4	22	TLm - 96hr *		(F)<u>Craterocephalus</u> sp.						9
Mercury										
Hg	.00002	LC50-96hr		(C)<u>F.</u> <u>clypeata</u>		c			21	
Hg	0.005	LC50-48hr		(C)<u>D.</u> <u>magna</u>	c			21		
Hg	0.001	lifecycle study		(C)<u>D.</u> <u>magna</u>	c			21		
Hg	0.075	LC50-96hr		(F)<u>S.</u> <u>fontinalis</u>					21	
	0.0005	MATC		(F)<u>S.</u> <u>fontinalis</u>					21	
Nickel										
	0.13	LC50-21d		(C)<u>D.</u> <u>magna</u>			44	21		
	0.03	16% RI		(C)<u>D.</u> <u>magna</u>			44	21		
	5.16	LC50-96hr		(F)<u>P.</u> <u>promelas</u>				44	21	
	0.109	MATC		(F)<u>P.</u> <u>promelas</u>				44	21	

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	Concentration (mg/1)	Test Spec.	ARR	Taxa	Test Conditions					Ref
					Temp	pH	Tot. Alk (as mg/L $CaCo_3$)	Tot. Hard (as mg/L $CaCo_3$)	Other	
	5.36 LC50-96hr			(F)*L. macrochirus*			20	21		
Raffinate										
(neutral)	$88x10^3$ TLM-96hr	*		(F)*Craterocephalus* sp.						9
Selenium										
Se(IV)	1.2 LC50-96hr			(C)*D. magna*				21		
	0.24 lifecycle study			(C)*D. magna*				21		
Se(IV)	12.5 LC50-96hr			(F)*S. gairdneri*					21	
Se(IV)	0.04-0.08 MATC			(F)*S. gairdneri*					21	
Se(IV)	0.128 LC50-96hr			(F)*S. gairdneri*					21	
Se(IV)	0.94 LC50-96hr			(F)*P. promelas* (juvenile)					21	
Se(IV)	0.11 chronic			(F)*P. promelas* (embryo-larval)					21	
Sulphide H_2S	0.028 LC50-96hr			(I)*B. vagus*				7		
Sulphide	1.46 LC50-96hr			(C)*A. militaris*					7	
Uranium	2.5 TLm-96hr	*		(F)*A. percoids*					9	
	4.1 TLm-96hr	*		(F)*L. unicolor*					9	
	4.0-4.5 TLm-96hr	*		(F)*Craterocephalus* sp.						9
	5 TLm-96hr	*		(C)*Macrobracticum*					9	
	72 TLm-96hr	*		(F)*catfish*				9		
Zinc	0.14 TLm-96hr	*		(F)*Craterocephalus* sp.						9

Appendix Table 2 **Summary of Some Available Toxicity Data (continued)**

Contaminant		Concentration (mg/1)	Test Spec.	ARR	Taxa	Temp	pH	Tot. Alk (mg/L)	Tot. Hard (mg/L)	Other	Ref
	0.20	TLm-96hr	* (F)A. percoides				9				
	>.2	TLm-96hr	* (F)L. unicolor				9				
Zinc	0.43	TLm-96hr	* (C)Macrobrachium sp.				9				
					cond. µS/cm						
	0.60	LC50-96hr	* (F)C. stercusmuscarum	27	7.2±0.1	41.72±3.5		11			
	6.8, 13.9	LC50-96hr	* (F)M. nigrans	27	6.9±0.5	15.0	22.0	40.3±3.9	11		
	4.8	LC50-96hr	* (F)M. splendida inornata	27	6.6±0.2	7.0	7.3	22	11		
	6.2	LC50-96hr	* (F)M. splendida inornata	27	7.0±0.2	2723.3±1.1		11			
	0.04	LC50-48hr	(C)D. hyalina			20	7				
	0.09	LC50-96hr	(F)S. gairdnerii			24 20	7				
	0.09	LC50-96hr	(F)S. clarkii			24 30	7				
	0.46	LC50-24hr	(C)D. pulex	25			8				
	0.54	LC50-24hr	(C)Philodina sp.	25			8				
An^{++}	1.8	LC50 - 24h	(C)Nitrocris sp.	25			8				
	2 - 3	ML - 24h	(F)S. gairdneri	5-18	5.6-7.8	36	18				

Appendix Table 3 **Summary of Some Available Toxicity Data (continued)**

Contaminant	**Concentration (mg/l)**		**Test Spec.**	**ARR**	**Taxa**	**Test Conditions**					**Ref**
						Temp	**pH**	**Tot. Alk (mg/L)**	**Tot. Hard (mg/L)**	**Other**	
	4.6	LC50 - 5D	(F)S. gairdnerii	14.5-15.8		7.3-7.9	Hard		2		
	5.6	LC50 -	(F)S gairdnerri	-	-	- -	5				
Zinc	7-13	ML - 24h	(F)N. crysolencus	5-30	5.8-7.8	36	18				
	14.2	LC50 - 24h	(C)D. magna	25			17				
	14.3	LC50 - 5D	(F)A. trama	10-12.6	7.2-7.9	Hard	2				
	16.0	LC50 - 5D	(F)P. fluviatilus	10.4-13.8		7.2-7.8	Hard		2		
	16.3	LC50 - 24h	(C)Aeolosoma sp.	25			8				
	17.3	LC50 - 5D	(F)R. rutilus	10-12.6	7.2-7.9	Hard	2				
	10-25	ML - 24h	(F)L. macrochiras	5-30	5.8-7.8	Hard	2				
	33.3	LC50 - 24h	(F)R. daniconius	23-26	7.2-7.7	195-260	230-280		3		
	35.2	LC50 - 144h		(F)R. daniconius		23-26	7.2-7.7	195-260	230-280		3
	0.056	Avoidance	(F)S. gairdnerii	9.5-17	7-7.5	13-15		5			
	0.102	50% RI	(C)D. magna			45.3	7				
	0.078-0.145	ED	(F)P. promelas	25	7-8	40-42	44-47		3		
	1.25	96h ED	(F)S. gairdneri	-	-	- -	6				
	0.180	83% RI	(F)P. promelas			200	7				
	0.295	HD	(F)P. promelas	25	7-8	40-42	44-47		3		
	5.0	GR	(A)S. meneghinina	25			8				

Appendix Table 3 **Summary of Some Available Toxicity Data continued**

Contaminant	Concentration (mg/l)	Test Spec.	ARR	Taxa	Test Conditions Temp	pH	Tot. Alk (mg/L)	Tot. Hard (mg/L)	Other	Ref
Zn^{++}	6.25 Chron - 19D	'Higher animals'	20		1					
	10 GR	(A)S. quadricsuada	25			8				
	15 GR	(A)Chlamydomonas sp.	25			8				
Zinc	25 CD	(H)E. canadensis	20		1					
	38.1 LC50 - 96h	(F)R. daniconius	23–26	7.2–7.7	195–26[illegible]0–280			3		
	42.56 LC50 - 48h	(F)R. daniconius	23–26	7.2–7.7	195–26[illegible]0–280			3		
Zn^{++}	54.05 C150 - 48h	(C)A. aquaticus	20		1					
Zn^{++}	61.48 C150 - 48h	(M)Planibarus sp.	20		1					
Zn^{++}	80.21 CL50 - 48h	(F)L. reticulatus	20			1				
Zinc	25–1[illegible]0 - 24h	(F)C. auratus	5–30	5.8–7.6	36	18				

APPENDIX E. **Water Quality - Statistical Summaries**

The water quality data used in this report has been abstracted from the N.T. Department of Transport and Works (Water Division) tabulation of "Alligator Rivers Region - Regional Water Quality Data - Nov. 1978 - April 1981" together with additional unpublished data up to Aril 1983. The data set consists of the results of both field and laboratory analyses performed on samples collected at intervals of approximately one month from 3 sites on the Magela Creek and 4 sites on Cooper Creek. All sites except Mudginberri Billabong (Magela Creek) dried out completely towards the end of the dry season.

Because of our demands upon the data set, such as the need to only consider wet season variations, and also because of its inherent limitations, particularly the large number of results below detection limit, there are a number of processing criteria used to prepare the data before calculation of mean and standard deviation. The most important of these are summarised below.

1. We are interested in describing the natural fluctuations from the peak of the wet season until the creek flow drops below some cut off value, perhaps 20 m^3sec^{-1} for the Magela and 5 m^3 sec^{-1} for Cooper Creek. After examination of the data it was realised that in practice it was sufficient to accept all data between 1st December and 31st May each year, but then to reject all zero values and also the first non zero value of each year. This ensured that the occasional enhanced concentrations present as flow commences were rejected. With this exclusion the mean and standard deviation of each parameter is insensitive to alterations in the subsequent period accepted. Any results identified in the data set as of doubtful

reliability by Water Division (eg. contamination suspected) were also rejected.

2. Heavy metal analyses are given as in filtrate and in residue. To prepare a result relating to total concentrations, these analyses were simply added for each site on each sampling occasion.

3. For the purposes of calculating means and standard deviations, all results below the detection limit were replaced by the detection limit. If more than 80% of the values were derived in this manner, then the mean and standard deviation were both set to half the detection limit, but a "less than" sign is placed in front of the standard deviation in the listing. If 80% of the values were "total" results derived from the summation of a "filtrate" and "residue", both below detection then the sum of detection limits was divided by 2/¯2 to give mean and standard deviation (again with a "less than" sign). This approach still leaves some inconsistencies in those heavy metal analyses where the majority of total results lie below detection limits. On some occasions it was found that a mean and standard deviation derived from significant residue or filtrate data were greater than the corresponding numbers derived from total data, **because the latter were based on half the summed detection limits.** In such cases judgement was used, an in general the data set with the largest mean was employed. Such selections are distinguished in the tables summarising the results on a site by site basis (Table E1 to E7) by "*" for residue or "#" for filtrate.

To prepare the summary tables presented in the main text (Tables 5.2.? and 5.2.?) all the raw data from the Magela Creek (excluding

Mudginberri) was combined and again processed as above. Cooper Creek data was handled similarly. Mudginberri data was omitted from this process because of high maximum values of total conductivity, sulphate and total phosphorus compared with the two Creek sites. It was felt that these data may reflect anthropogenic sources, and in any case the ommission of this data did not signficantly affect the mean and standard deviations found.

Finally it should be emphasised that in no way should the standard deviations derived here be considered exact. In those cases where the data is largely above detection limits the standard deviations will in general be underestimates, depending on the skew of the distribution. However in no case should they underestimate by more than a factor of two (see section 3.?.?.). On the other hand where there are a significant number of detection limit values, the standard deviations will be overestimates, in many cases of an unknown degree. These are unavoidable limitations of the data sets.

Table E.1 **Water Quality - Wet Season Statistical Summaries**
Magela Creek, Downstream Jabiru **G.S.: 821-009**

Parameter	Units	No. of entries Less than	Total	Min	Max	Mean	S.Dev.
Specific Conductivity	μS/cm	0	29	9	26	16.3	4.1
pH		0	27	4.8	7.3	6.0	0.53
Turbidity	NTU	0	26	2.5	120	15.8	22.7
Dissolved Oxygen	mg/l	0	16	5.1	7.7	6.82	0.77
Calcium	mg/l	0	29	0.14	0.75	0.39	0.12
Magnesium	mg/l	0	29	0.08	1.10	0.57	0.16
Sulphate	mg/l	11	30	<0.1	0.40	0.30	0.16
Fluoride	mg/l	9	10	<0.02	0.1	0.01	<0.01
Ammonia (N)	mg/l	23	29	<0.005	0.06	0.007	0.01
Nitrate + Nitrite (N)	mg/l	14	30	<0.005	0.08	0.013	0.018
Phosphate (P)	mg/l	24	30	<0.003	0.02	0.015	<0.015
Total Phosphorus(P)	mg/l	11	30	<0.003	0.045	0.007	0.008
Total Alkalinity	mg/l	0	27	1.3	30.0	4.1	5.3
Suspended Solids	mg/l	0	29	3	70	10.2	12.5
* Copper	μg/l	21	30	<0.05	10.0	0.83	1.8
* Lead	μg/l	23	32	<0.04	3.0	0.5	0.7
Zinc	μg/l	9	31	<1.5	61.4	8.3	11.2
Manganese	μg/l	3	34	<4.0	25.8	8.7	4.6
# Uranium	μg/l	19	33	<0.01	0.3	0.12	0.09
# Cadmium	μg/l	23	30	<0.02	0.9	0.066	0.17
Iron	μg/l	0	41	130	3550	660	568
Chromium	μg/l	5	8	<0.6	2.4	0.79	0.71

Table E.2 **Water Quality - Wet Season Statistical Summaries**
Magela Creek, Arnhem Border **G.S. 821-028**

Parameter	Units	No. of entries		Min	Max	Mean	S.Dev.
		Less than	Total				
Specific Conductivity	μS/cm	0	21	14	25	19.4	3.2
pH		0	22	5.3	7.5	6.0	0.54
Turbidity	NTU	0	18	2.0	36	11.7	9.9
Dissolved Oxygen	mg/l	0	10	5.6	8.3	6.58	0.83
Calcium	mg/l	0	21	0.1	1.8	0.67	0.36
Magnesium	mg/l	0	21	0.39	1.0	0.66	0.17
Sulphate	mg/l	1	21	<0.1	0.5	0.22	0.12
Fluoride	mg/l	3	3	<0.2	0.2	0.1	<0.1
Ammonia (N)	mg/l	18	20	<0.005	0.09	0.0025	<0.0025
Nitrate + Nitrite (N)	mg/l	8	20	<0.01	0.04	0.015	0.012
Phosphate (P)	mg/l	17	21	<0.003	0.02	0.0015	<0.0015
Total Phosphorus(P)	mg/l	5	21	<0.003	0.03	0.0072	0.0068
Total Alkalinity	mg/l	0	20	0.96	94.0	8.1	20.3
Suspended Solids	mg/l	0	21	2	17	7.1	4.0
* Copper	μg/l	11	20	<0.05	3.0	0.89	0.92
* Lead	μg/l	12	20	<0.5	3.0	0.58	0.68
Zinc	μg/l	4	18	<1.0	15.3	5.6	3.8
Manganese	μg/l	0	21	3.0	28	9.8	6.1
# Uranium	μg/l	15	19	<0.01	0.3	0.074	0.067
* Cadmium	μg/l	15	20	<0.05	0.6	0.071	0.13
Iron	μg/l	0	21	13	1630	552	316
Chromium	μg/l	0	0	-	-	-	-

Table E.3 **Water Quality - Wet Season Statistical Summaries**
Cooper Creek, Murganella Road Crossing G.S.: 821-038

Parameter	Units	No. of entries Less than	Total	Min	Max	Mean	S.Dev.
Specific Conductivity	µS/cm	0	18	12	77	39	14
pH		0	17	5.1	6.9	6.0	0.55
Turbidity	NTU	0	18	5.0	65	23	17
Dissolved Oxygen	mg/l	0	11	4.5	7.6	6.5	1.1
Calcium	mg/l	0	18	0.59	2.0	1.3	0.37
Magnesium	mg/l	0	18	0.32	2.1	1.2	0.44
Sulphate	mg/l	0	18	0.1	0.9	0.33	0.19
Fluoride	mg/l	0	0	-	-	-	-
Ammonia (N)	mg/l	10	18	<0.005	0.05	0.009	0.011
Nitrate + Nitrite (N)	mg/l	5	18	<0.01	0.39	0.040	0.089
Phosphate (P)	mg/l	8	8	<0.003	0.02	0.0044	0.0058
Total Phosphorus(P)	mg/l	0	18	<0.003	0.085	0.016	0.020
Total Alkalinity	mg/l	0	17	2.8	11	7.4	2.3
Suspended Solids	mg/l	0	18	3.0	61	20	16
* Copper	µg/l	9	14	<0.5	1.0	0.48	0.35
* Lead	µg/l	11	16	<0.5	1.5	0.39	0.32
Zinc	µg/l	4	15	<1.0	17	7.3	5.2
Manganese	µg/l	3	18	<1.5	38	15	9.9
Uranium	µg/l	16	17	<0.2	0.55	0.08	<0.08
* Cadmium	µg/l	9	14	<0.05	0.4	0.068	0.10
Iron	µg/l	0	18	310	3720	1430	825
Chromium	µg/l	0	0	-	-	-	-

Table E.4 **Water Quality - Wet Season Statistical Summaries**
Cooper Creek, Downstream Nabarlek G.S.: 821-024

Parameter	Units	No. of entries		Min	Max	Mean	S.Dev.
		Less than	Total				
Specific Conductivity	µS/cm	0	28	12	170	34	28
pH		0	28	4.7	71	6.0	0.64
Turbidity	NTU	0	24	2.0	40	9.7	8.4
Dissolved Oxygen	mg/l	0	18	6.1	9.9	7.5	0.86
Calcium	mg/l	0	29	0.2	0.58	0.35	0.10
Magnesium	mg/l	0	29	0.3	1.3	0.92	0.23
Sulphate	mg/l	6	29	<0.1	1.0	0.50	0.24
Fluoride	mg/l	9	10	<0.02	0.06	0.01	<0.01
Ammonia (N)	mg/l	22	29	<0.005	0.03	0.006	0.007
Nitrate + Nitrite (N)	mg/l	14	29	<0.005	0.07	0.016	0.020
Phosphate (P)	mg/l	19	29	<0.003	0.06	0.006	0.011
Total Phosphorus(P)	mg/l	9	29	<0.003	0.05	0.008	0.010
Total Alkalinity	mg/l	0	28	0.64	5.0	2.8	0.89
Suspended Solids	mg/l	0	28	3.0	43	11	8.2
* Copper	µl	22	28	<0.1	2.5	0.52	0.60
* Lead	µg/l	18	29	<0.4	3.0	0.59	0.65
Zinc	µg/l	9	28	<1.0	26	6.2	5.5
Manganese	µg/l	3	29	<3.0	22	8.1	4.4
# Uranium	µg/l	20	28	<0.1	1.0	0.16	0.22
* Cadmium	µl	21	29	<0.04	0.15	0.039	0.035
Iron	µg/l	0	22	190	1390	0.063	0.028
Chromium	µg/l	2	7	<0.2	0.4	0.25	0.10

Table E.5 **Water Quality - Wet Season Statistical Summaries**
Cooper Creek, Nimbuwah **G.S.: 821-001**

Parameter	Units	No. of entries		Min	Max	Mean	S.Dev.
		Less than	Total				
Specific Conductivity	μS/cm	0	17	17	61	39	12
pH		0	16	5.1	7.1	6.3	0.54
Turbidity	NTU	0	17	5.0	70	21	17
Dissolved Oxygen	mg/l	0	11	6.1	8.8	7.1	0.77
Calcium	mg/l	0	17	0.85	1.7	1.2	0.25
Magnesium	mg/l	0	17	0.33	1.9	1.2	0.36
Sulphate	mg/l	0	17	0.1	0.5	0.32	0.23
Fluoride	mg/l	0	0	-	-	-	-
Ammonia (N)	mg/l	14	17	0.005	0.015	0.0025	0.0025
Nitrate + Nitrite (N)	mg/l	1	17	<0.05	1.1	0.31	0.24
Phosphate (P)	mg/l	13	17	<0.003	0.025	0.003	0.006
Total Phosphorus(P)	mg/l	5	17	<0.003	0.025	0.008	0.006
Total Alkalinity	mg/l	0	16	4.8	1.1	7.3	1.6
Suspended Solids	mg/l	0	21	1.0	85	20	21
* Copper	μg/l	7	17	<0.5	4.5	1.2	1.2
* Lead	μg/l	12	17	<0.5	3.5	0.79	1.1
Zinc	μg/l	6	15	<1.0	55	8.8	14
Manganese	μg/l	2	16	<2.5	20	12	5.4
# Uranium	μg/l	13	16	<0.2	0.3	0.08	<0.08
* Cadmium	μg/l	10	16	<0.05	0.25	0.056	0.059
Iron	μg/l	0	16	350	5260	1580	1240
Chromium	μg/l	0	0	-	-	-	-

Table E.6 **Water Quality - Wet Season Statistical Summaries**
Cooper Creek, Upstream Nabarlek **G.S.: 821-024A**

Parameter	Units	No. of entries		Min	Max	Mean	S.Dev.
		Less than	Total				
Specific Conductivity	µS/cm	0	21	14	62	34	13
pH		0	20	4.8	8.0	6.1	0.93
Turbidity	NTU	0	17	1.5	950	13	22
Dissolved Oxygen	mg/1	0	11	5.2	7.9	6.9	0.76
Calcium	mg/1	0	28	0.23	1.6	0.78	0.33
Magnesium	mg/1	0	28	0.41	4.7	1.6	0.94
Sulphate	mg/1	6	28	<0.1	1.0	0.39	0.24
Fluoride	mg/1	7	8	<0.02	0.02	0.01	<0.01
Ammonia (N)	mg/1	21	28	<0.005	0.04	0.007	0.010
Nitrate + Nitrite (N)	mg/1	13	28	<0.005	0.23	0.024	0.044
Phosphate (P)	mg/1	21	28	<0.003	0.02	0.003	0.004
Total Phosphorus(P)	mg/1	8	28	<0.003	0.02	0.006	0.005
Total Alkalinity	mg/1	0	26	1.3	19	7.0	4.8
Suspended Solids	mg/1	0	28	1.0	64	12	18
# Copper	µg/1	47	49	<0.09	10.3	0.4	0.4
* Lead	µg/1	21	27	<0.4	3.5	0.47	0.70
Zinc	µg/1	5	27	1.2	13.5	5.9	3.6
Manganese	µg/1	8	28	<1.0	26	6.9	5.7
# Uranium	µg/1	17	27	<0.1	0.5	0.12	0.12
Cadmium	µg/1	22	24	<0.06	0.18	0.03	<0.03
Iron	µg/1	1	22	50	1900	460	410
* Chromium	µg/1	3	5	<0.4	1.1	0.44	0.4

Table E.7 **Water Quality - Wet Season Statistical Summaries**
Magela Creek - Mudginberri Billabong G.S.: 821-018

Parameter	Units	No. of entries		Min	Max	Mean	S.Dev.
		Less than	Total				
Specific Conductivity	µS/cm	0	22	8.0	81	26	16
pH		0	21	4.9	7.2	5.8	0.59
Turbidity	NTU	0	18	4.0	30	12	7.9
Dissolved Oxygen	mg/l	0	10	4.8	6.6	5.9	0.52
Calcium	mg/l	0	22	0.30	0.84	0.50	0.12
Magnesium	mg/l	0	22	0.28	0.88	0.61	0.17
Sulphate	mg/l	2	22	<0.1	2.4	0.33	0.48
Fluoride	mg/l	3	3	<0.02	<0.02	0.01	<0.01
Ammonia (N)	mg/l	14	21	<0.005	0.045	0.009	0.011
Nitrate + Nitrite (N)	mg/l	10	19	<0.01	0.2	0.022	0.046
Phosphate (P)	mg/l	13	20	<0.003	0.005	0.003	0.002
Total Phosphorus(P)	mg/l	2	20	<0.003	16	0.81	3.6
Total Alkalinity	mg/l	0	20	1.4	5.7	3.8	1.1
Suspended Solids	mg/l	0	25	1.0	17	9.4	4.1
* Copper	µg/l	13	21	<0.05	4.0	0.87	1.1
Lead	µg/l	16	20	<1.0	1.8	0.4	<0.4
Zinc	µg/l	2	20	<1.0	32	6.8	7.6
Manganese	µg/l	1	21	<1.5	14	7.8	3.5
# Uranium	µg/l	14	21	<0.1	0.5	0.09	0.10
* Cadmium	µg/l	15	20	<0.05	0.3	0.064	0.070
Iron	µg/l	0	21	140	5960	900	1200
Chromium	µg/l	0	0	-	-	-	-

Key to Tables 1 and 2

Test specification:

BR, Biomass reduction; CD, cell damage; ED, Egg damage; GD, Gill damage; GI, Growth impariment; HD, Hatchling damage; RI, Reproductive Impariment.

Chron, chronic; ML, Median lethal.
TLM, median threshold lethal.
MATC, maximum acceptable toxicant concentration.
LC, lethal concentration.

ARR: *, present in Alligator Rivers Region

Taxa: A, Algae; C, Crustacean; F, Fish; H, Hydrophyte; I, Insect; M, Mollusc; W. Worm.

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Appendix