Standards and Procedures for Release of Uranium Mine Waste Waters into a World Heritage Area Physical Aspects

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ABSTRACT

The Northern Territory of Australia contains the UNESCO World Heritage listed Kakadu National Park and Aboriginal land; it also contains two active and two prospective uranium mines and is in the tropics with a seasonal monsoon rainfall. To ensure protection of the aquatic ecosystem of the National Park, there has been a requirement to operate mines with a water management system allowing very limited prospects for the release of water.

The aquatic pathway has the greatest potential to spread contaminants and the aquatic ecosystem is considered to be most at risk. The Office of the Supervising Scientist is charged by the Australian Government with developing standards and procedures, particularly to limit and control releases. These standards must protect the environment during the operating life of the mine and allow continued beneficial use of the area by the Aboriginal traditional owners after decommissioning of the mine site.

Both operating uranium mines have disposed of surplus water by irrigation within their respective project areas, with differing degrees of success. At one site the waste water has a high solute/salt content which has caused the death of some trees within the irrigation area and is believed to have affected the ecology of a local stream. The other site has less saline waste water so there has been no short-term impact. This site, however, is expected to operate for 30 years and there is concern that the build-up of radionuclides in the soil of the irrigation area could eventually reach unacceptable levels.

The collection and return of seepage from the tailings pond is used to minimise the spread of environmental contamination. The water collected however includes ground and rainwater as well as seepage; the problem of adding non-contaminated groundwater to the restricted release zones is discussed.

The Australian government recognised that it may not be possible to avoid releasing water in all climatic circumstances and has imposed the criterion that controlled releases, if permitted, shall be no more frequent than an average of once in 10 years. Analysis of rainfall records has led to the development of a regulatory mechanism to permit discharges only in those years that have a high probability of meeting this 1-year-in-10 requirement.

In addition, rigorous chemical and biological quality criteria have to be satisfied in the receiving waters. These criteria are described in paper by McBride *et al.* at this conference.

INTRODUCTION

The Northern part of the Northern Territory of Australia contains the UNESCO World Heritage listed Kakadu National Park, Aboriginal traditional land and a major area of uranium mineralisation (Fig. 1). The region is in the tropics and has an average monsoon rainfall of about 1500 mm falling mostly between December and April with an annual pan evaporation of about 2600 mm.

In this region there are currently two uranium mining operations; one in production (Ranger) within the National Park area and the other, on Aboriginal land, recently closed down and starting rehabilitation (Nabarlek). (See Fig. 1.) There are in addition several prospective mines.

Because Kakadu National Park contains significant natural wetland areas there has been great concern that mine waste waters from Ranger should not contaminate the local water system and in consequence there was an initial requirement for mines to operate on a no-release-of-waste-water management system. This has subsequently been modified to allow possible releases but at infrequent intervals and under very stringent regulating criteria. While Nabarlek is not within the Kakadu Park similar problems exist in that the area is Aboriginal land and the downstream area is utilised by Aboriginal people living partly by traditional hunting-gathering methods.

The regulations which control the operation of these uranium mines include the definition of a Restricted Release Zone (RRZ). This is a zone where material containing more than 0.02% by weight of uranium is exposed or about to be exposed by excavation, and from which no water may be released to the environment except in accordance with release standards determined by the Supervising Authority.

As a result, all rainfall and runoff on a significant area including the mine, mill ore stockpile and below ore grade waste (>0.02% U) must be collected and held within the RRZ. The ponds for holding the water are also within the RRZ, as in the tailings dam and its surrounds. (For example the area of the RRZ at Ranger is presently about 290 ha).

The nature of the Wet-Dry monsoon climate (with about 4 months intense rainfall, about 6 months with essentially no rain, and two months transitional) with the variability in magnitude and timing of the rainfall, together with the need to ensure adequate water supplies for mine and mill operation as well as complying with the severe limitations (possible prohibition) of any water releases, combine to make water management one of the greatest problems for the mine operators. Limited water resources from outside the RRZ can be available to make up any shortage for operating purposes, but the waste water arising must still be held within the RRZ. Some runoff from waste rock (<0.02% U) (not within the RRZ) is collected and after sediment control has been released in compliance with regulatory conditions regarding water quality. No direct releases from the RRZ have yet been authorised in over 10 years of operations at both mines. Apart from evaporation from the ponds, and unavoidable seepage the only method so far used to reduce the amount of water held in the RRZ has been irrigation - also called land application - on land surfaces within the RRZ during the dry season, which is discussed below.

The Office of the Supervising Scientist (OSS) was established by the Australian Government to ensure that a high standard of environmental protection is achieved in the Region. This paper describes some of the standards and procedures that have been developed for intentional disposal of surplus water by irrigation, by controlled release to the local river system, and inadvertent disposal by seepage from water and tailings impoundments.

IRRIGATION

Initially direct release of waste water to the local creek systems was prohibited. This left the operating companies with no simple way of removing any surplus water from their mine water management systems. Direct release even now would only permitted when a number of stringent criteria had been met (see below and separate paper at this congress). Thus some other means of reducing excess water held within the operating site was needed. To meet this need, irrigation of excess waters onto land adjacent to the mine by both spray and surface methods has been used by both companies.

The first trials of the irrigation technique were carried out at the Nabarlek Uranium mine in 1984. During the Dry season of that year excess water from one of the mine's evaporation ponds was spray irrigated onto a trial plot of approximately 2 ha. The area was the cleared and graded edge of the project site airstrip which was ripped and sown to Para Grass (Brachiaria mutica) a species well adapted to wet areas and capable of producing large quantities of dry matter, and taking up considerable quantities of solutes, particularly ammonium and nitrate. The soils of the area were derived from dolerite and considered to have a capacity to absorb the sulphate and ammonium solutes found in the waste waters. A soil sampling program was undertaken and shallow boreholes were installed as part of the monitoring program.

The trial continued throughout the Dry season and was accepted by the regulating authority as having been successful. As a consequence in 1985 the irrigation area was expanded to about 10 ha for the second half of the Dry season. The expanded area included more of the airstrip verge and a 'disturbed area' which had been cleared and compacted during construction of the adjacent evaporation ponds. The soils of these areas were all essentially dolerite derived. Monitoring of the surface soils showed that pH had begun to fall by between 1 and 1.5 units whilst electrical conductivity (EC) of extract had begun to rise. It was thought that the Wet season rains would flush solutes through the profile and dilute and disperse them with resulting improvements in the monitored parameters.

In the 1986 Dry season waste water was irrigated on an additional area of about 10 ha known as the forest irrigation area. This was an area of dry schlerophyll woodland with shallow to moderately deep gravelly yellow earth soils of high permeability. Water from the evaporation ponds was spray irrigated on this area during the Dry season at a rate to ensure that there was no runoff. At the end of the Dry season major impacts were observed: salt burn on vegetation, both trees and ground covers, and the formation of a saline groundwater mound under the irrigated forest area. The pH and solute levels of the groundwater in the other irrigated areas continued to change as before.

It was considered, after an assessment by the company's consultants, that these effects would be temporary and the Wet season flush of rainwater would restore conditions to those prevailing before the irrigation.

Some tree stress was observed early in 1987 in the forest irrigation area. As a consequence the irrigation of waste water was restricted to the non-forest areas. All spray irrigated areas and the forest irrigation areas were 'flushed' by irrigation with bore water in an attempt to reduce the levels of salt in the soil and to aid the dilution and dispersion of salts through the groundwater. At this time however, a further impact was observed in a seasonal creek down the hydraulic gradient from the forest irrigation area. Increased levels of nitrate and sulphate were detected in the waters of the creek and a special survey noted a reduction in fish species abundance and diversity.

In the 1988 Dry season, irrigation of the forest area continued using bore water whilst other plots continued to receive waste waters. The analyses of data from monitoring bores began to show a pulse of solute contaminated waters moving down gradient towards another creek in the vicinity although there was no evidence of vegetation stress in this area. Concern was expressed that the adsorption capacity of the dolerite derived soils had been almost exhausted. Within the forest area a number of trees had died and many others were showing signs of stress. It was decided that further irrigation could not be permitted in the forest area and that on other plots careful reassessment would be required before irrigation could be allowed to continue.

The impact on the forest area was further increased in the 1989 Dry season; a bush fire, fed by the high fuel load that was present as a result of the dead and stressed trees, swept through the area. In 1990, the dead trees and grasses were cleared to reduce fire hazard and to provide a better environment for regeneration. Regeneration is proceeding with many young trees and shrubs as well as annual grasses returning to the area. The groundwater, however, has not yet begun to show consistent signs of quality improvement and whilst it is most likely that it will eventually return to its former condition there is, at present, no way to be sure how long such a process may take. This will impact on the length of time the company has to maintain a presence at the site during and after the rehabilitation phase.

At the Ranger Uranium Mine irrigation has also been used as a means of disposal for waste waters since 1985. The company was authorised by the regulating authorities to irrigate up to 10 mm of water per day on an area of 34.8 ha of dry schlerophyll forest, designated the 'Water Treatment by Land Application area' (WTLA) during the Dry season, and on days in December and April when there was no rain. These conditions were set to preclude the possibility of runoff leaving the area into the surrounding environment. In contrast to Nabarlek, the Ranger waste water does not contain particularly high levels of solutes or salts, (typically EC of 1200 μS/cm. As a result the vegetation is healthy and no obvious visual detriment to the environment has occurred although the plant community is greener and lusher than the surrounding, unirrigated, vegetation. This could be construed as an impact on the environment.

The concern at Ranger is due to levels of metals and particularly radionuclides such as radium and uranium. Concentration of radium for example has ranged from 0.3 to 3 Bq/L over recent years and average concentration of uranium exceeds 3000 μg/l. Early work indicated that the soils of the WTLA would have the capability to adsorb the radionuclide load from the applied waters for several years; the exact time being a function of how often the company decided to irrigate and what radiological conditions could be accepted in the area. Ultimately the soils capacity to adsorb metals could become exhausted and there is currently work in progress to evaluate the timing of such an event. Some current research suggests that for most of the site the adsorption capacity will not be exhausted for about 80 years, but some parts may only have 2 or 3 years capacity(1).

Loss of soil adsorption capacity would allow solutes to spread and eventually reach the local creek system and this might require the current WTLA area to be closed and another suitable area selected. On the other hand the retention of radionuclides in the top few centimeter of the soil profile may eventually result in unacceptable radiological conditions in the area. In this case the option would either be to select a new site for further irrigation or to continue irrigating on the same site until mine closure when the soil would be scraped up and removed to a safe repository. Such a program would obviously have a considerable local environmental impact as well as increasing the area to be rehabilitated which would in turn increase the company's costs.

CONTROLLED RELEASE

The Government Environmental Inquiry that was held before the Ranger mine commenced operation(2) made as one of the conditions of approval that 'Deliberate releases should only be permitted under conditions of high flow in Magela Creek.... and when there is continuous flow...' to '...the Northern end of the Magela plains'. Other conditions required that water quality criteria to control releases should be set.

The flow criteria limit the period available for release to February to March in most years.

The Research Institute of the OSS developed water quality criteria based on toxicity tests using local aquatic fauna and on the existing water quality in the local creek. (See separate paper by McBride *et al.* at this Congress).

The Australian Federal Government decided as part of the environmental protection of Kakadu National Park that in addition to meeting water quality and flow criteria, release of waste water from the RRZ at Ranger should only be considered when the rainfall is greater than that which occurs, on average, 1-year-in-10.

Although some of the excess water on the Ranger site is derived from groundwater, the majority of it is clearly accumulated rainfall. Thus volumes of stored water are closely related to rainfall, and that volume which would be expected to occur once in ten years, on average, is closely related to the 1-in-10 exceedance rainfall. The Governments '1-in-10' policy decision could thus have either been based on the volume of stored water on the Ranger site or on the rainfall.

Although there are conceptual advantages in using a volume criterion(3), as it is the volume of water that needs to be reduced, there are practical disadvantages from the regulator's standpoint. Firstly, the volume and particularly the distribution of water held on site depends on water management decisions made by the Company. Thus poor water management decisions could increase the frequency of discharge if discharge were permitted once a certain volume in any critical ponds was reached. Secondly, volume measurement is, of necessity, done by the Company within its own site, and thus is not readily monitored by regulatory authorities nor open to public scrutiny. Thirdly the value of the volume criterion would have to be based on a relatively complex model that relates rainfall, evaporation and various runoff factors to the volume accumulated.

A release criterion based on rainfall does not have these disadvantages; it was therefore decided that the criterion used to give effect to the Government's decision be based on cumulative rainfall within each Wet season.

The OSS Supervisory and Assessment Branch carried out an analysis of the rainfall records of the North of the Northern Territory in order to develop a regulatory mechanism that could be used to limit releases to this 1-in-10 year requirement(4).

All data were plotted as cusum graphs against their individual long-term means so that changes in mean rainfall would be more easily seen than they would be on plots of the raw data (Fig. 4). (On a cusum graph a constant slope indicates an unchanging mean value. Where the long-term mean is used as the basis of the cusum graph, sections with a negative slope indicate periods with means less than the long-term mean and sections with a positive slope indicate periods with means more than the long-term mean.) For clarity only the rainfall data for Darwin, Oenpelli, Katherine and Pine Creek have been plotted; the other data sets however show the same general trends. From Fig. 4 it can be seen that from about 1920 to 1960 the rainfall throughout the Region was below the long-term average, and from 1960 to the present (say 1985) all sites have had rainfall above the long-term average. It appears that there may now be a change to a lower average. Certainly the rainfall at Ranger over the past few years has been lower. On more detailed examination short term patterns of about 6 years and possible longer-term cycles of 15 to 20 years are also discernible, superimposed on the long-term rainfall pattern.

If these patterns are typical of the NT monsoonal climate, it illustrates the difficulty in devising a regulatory mechanism that will work for the next 20 or 30 years at Ranger. The long-term average may not be the appropriate basis and the shorter term averages would only be useful if the pattern were sufficiently regular to be predictable. All that can be said is that up to about 1985 the region has had about 20 years at a higher average but since that date appears to be changing to a lower average and that there is some evidence of both short-term and longer term cycles. Thus we could expect a lower regional average for the next few years and this may also be seen at Ranger. The analysis showed that, due to the strong seasonality of the monsoon rainfall pattern, the shape of the annual cumulative rainfall graph is reasonably robust, (Fig. 2) and once the Wet season is sufficiently advanced, the cumulative rainfall trend gives some basis for estimating the likely total rainfall at the end of the season.

To be of practical value, the release criterion must be able to be applied well before the end of the Wet season, since there is also a requirement that any release must be into the local creek when running at high flow and likely to continue at high flow for at least some days. Thus the release criterion must anticipate the total Wet season rainfall by some weeks. Because of the anticipatory nature of this regulatory mechanism it is described as a 'trigger', that is a condition which when reached will initiate other activities.

As the rainfall record, local to the Ranger minesite, only went back 16 years, records from other weather stations in the region which went back 77 and 117 years were used, firstly to improve the statistics of the annual cumulative rainfall pattern, and secondly to create 77 years of synthetic rainfall data for the mine site.

From the synthetic minesite rainfall data, rainfall with a return frequency of 10 years was calculated. Examination of these data and other data in the region indicated that the distribution was normal rather than lognormal[5] (Fig. 3). For this reason the return frequency calculation was based on a normal distribution. (Calculation using a log-Pearson distribution, however, produced very similar results.)

Many authors have demonstrated cyclic patterns in annual rainfall statistics (Lamb 1982, Pittock 1975, Mandelbrot & Wallis 1968, Cornish 1977, Graham & White 1988, Stahle et al. 1988, Doran & McGilchrist 1983) and this analysis confirms the presence of such patterns in the regional rainfall of Northern Australia. The cyclic pattern means that there does not appear to be any evidence that very long-term data sets will provide better predictions for near future rainfall patterns than will relatively short-term data sets. The World Meteorological Organisation[6] supports the use of 30-year means ('normals'), updated each decade for the study of climate. Lamb & Changnon[7] have suggested that 5-year normals may be the best predictors for rainfall in the short-term future and Sabin & Shulman[8] found the 'most efficient' normal to be between 35 and 40 years. On this basis it was decided to use a period of 30 years for analysing the Jabiru data.

Using the most recent 30 years of synthetic data the mean annual rainfall becomes 1500 mm and the 1-in-10 exceedance rainfall becomes 1850 mm (or 1900 if the Student's t-statistic is used due to the small size of the data set. Note: in order not to suggest that such analyses as these produce results of great precision these values are rounded to 50 mm).

From this analysis of the synthetic Jabiru data it was concluded that for trigger mechanism design purposes a 1-in-10 exceedance rainfall of 1850 mm should be used.

Finally from the synthetic data for a given rainfall before the end of the Wet, the probable range of Wet season total rainfall was calculated. This allowed a predictive regulation to be drawn up, such that if an agreed 'trigger' value of cumulative rainfall were reached before the end of the Wet season, the probability that the 1-in-10 Wet season rainfall would be exceeded was known and release could be permitted (provided the other criteria were met) before the 1-in-10 rainfall total had been reached. (Fig. 5).

SEEPAGE

The tailings pond at Ranger is approximately 1 km square with an earth AND rockfill embankment currently ranging from about 10 m to 25 m above natural ground level. The embankment has been raised in a series of lifts and prior to the latest lift included a toe drain over about 75% of its length to collect seepage. The seepage collected was pumped back into the tailings dam. Although the seepage collector system was estimated to collect about 90% of the seepage it also collected infiltrating rainfall from the outer embankment walls and some groundwater seeping back into the foundation trench. The result was that only about 10% of the water collected was seepage and the rest originated as uncontaminated rain and groundwater. This additional water coming into the tailings dam increased the company's water management problem.

As a consequence of this problem, the most recent embankment lift included a modified seepage collector system which acted upon only those sections of the dam perimeter judged to be critical in assessing seepage. Those lengths of the embankment adjacent to these sections were given an infiltration limiting cover to reduce rainwater collection into the seepage collector. In addition a clay cut-off barrier was constructed within the foundation trench to reduce groundwater ingress into these sections of foundation covered by the collector system. However, large volumes of non-seepage water continue to be collected as the rockfill foundation provides a reasonably permeable hydraulic path around the dam perimeter and the earlier stages cannot now be effectively isolated from the latest construction. Research is in progress to establish what impacts such seepage might have on the environment were collection to cease. Associated studies are attempting to determine the best practicable way to manage seepage in the future.

DISPOSAL OF MINE WATER AT DECOMMISSIONING

When a mine within the ARR is finally decommissioned all waste water will have to be disposed of in a manner satisfactory to the regulatory authorities and traditional owners and also in a way which is environmentally acceptable. Wherever possible it had been intended that the basic methodology would the principle of 'Dilute and Disperse'. That is to say the water and contained salts would be released into the environment in a controlled manner based on a range of biological toxicity and chemical tests incorporating both dilution and safety factors.

In the case of Ranger the conditions that have already been set down in relation to the one-in-ten release concept provide a working framework for the final release of waters. Ponds will be emptied to the maximum extent possible by evaporation and operational use. The eventual rehabilitation plan has not yet been finalised but, in principle, ponds will be demolished and the area rehabilitated rather than leave them as water retaining structures. Waters that accumulate during the rehabilitation program will be released to the creek subject to conditions determined by suitable toxicity testing and hydrological conditions. Once the ponds have been dried, any contaminated sediments will be scraped up and taken away for burial in an approved location, possibly the mine pit.

At Nabarlek however, the situation is different. There is not a suitable water body or stream into which residual water, with its contained salt load, could be released at environmentally acceptable levels of dilution. This is because the creek system adjacent to the mine cannot be guaranteed to have sufficient volume and duration of flow for safe dilution and dispersion to occur. The creeks only flow during and shortly after the Wet season. The intention is to remove as much water as possible by evaporation and to concentrate this operation in only one of the ponds on site. This would eventually leave brine and a volume of crystallised salts in one pond. This residue, together with the salt saturated clay floor of the pond would be scraped up and removed to a clay lined containment structure which will be designed to last for the period required by the appropriate code of practice.

CONCLUSION

Over the past eleven years uranium mining has been undertaken in the Alligator Rivers Region without significant environmental impact being detected outside the immediate project areas.

The initial prohibition on release of mine waste water has undoubtedly contributed to this lack of environmental impact. In a monsoon climate however, excess water will collect in the mine water management system in some years and there must be means available to deal with this. Irrigation of waste water within the mine project area has been used as one solution but is not without problems and may not be able to be used for long periods.

Regulations have been devised to control the release of waste water but due to a series of Wet seasons that have received average or below average rainfall no releases have yet taken place. The need to continually adapt procedures and develop standards for dealing with the disposal of mine waste waters remains a major priority in pursuing economically sustainable development in an environmentally responsible manner. This paper has indicated how we in Australia are dealing with these issues.

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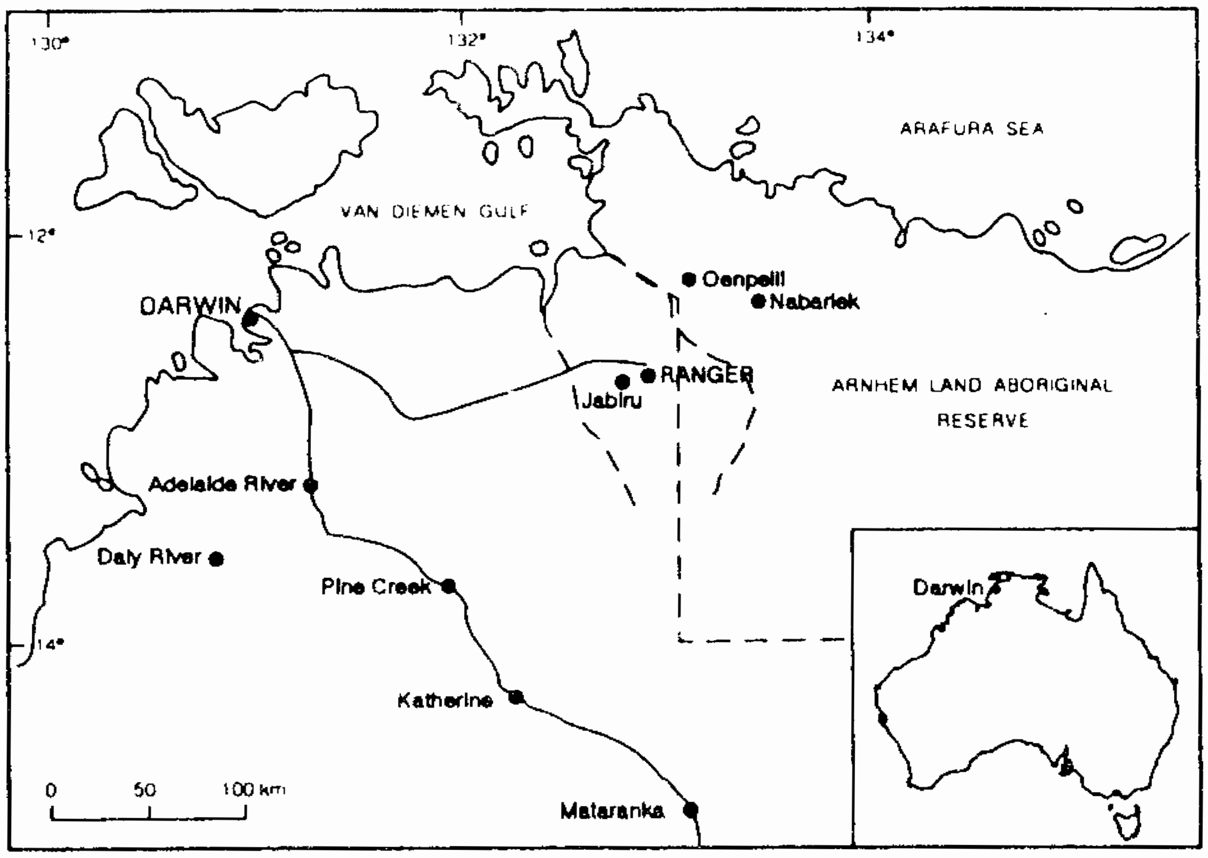

Figure 1. Map showing location

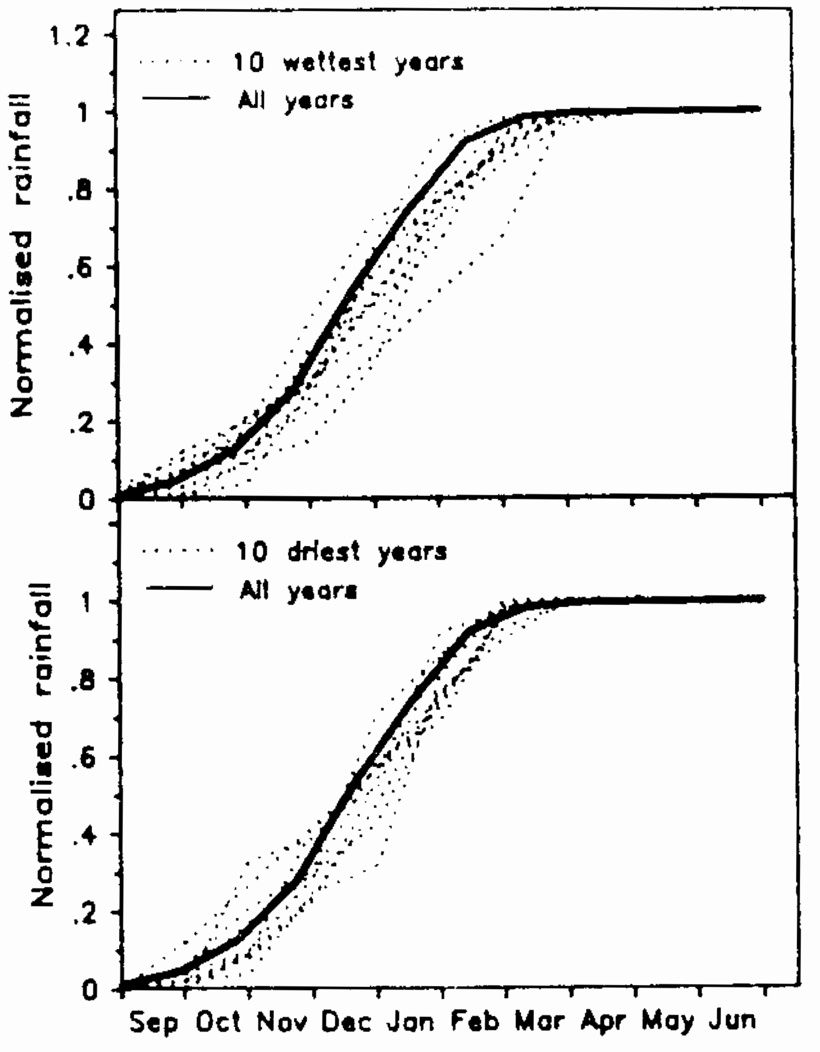

Figure 2. Normalised annual cumulative rainfall for (a) the ten wettest years and (b) the ten dryest years compared to the average for all years

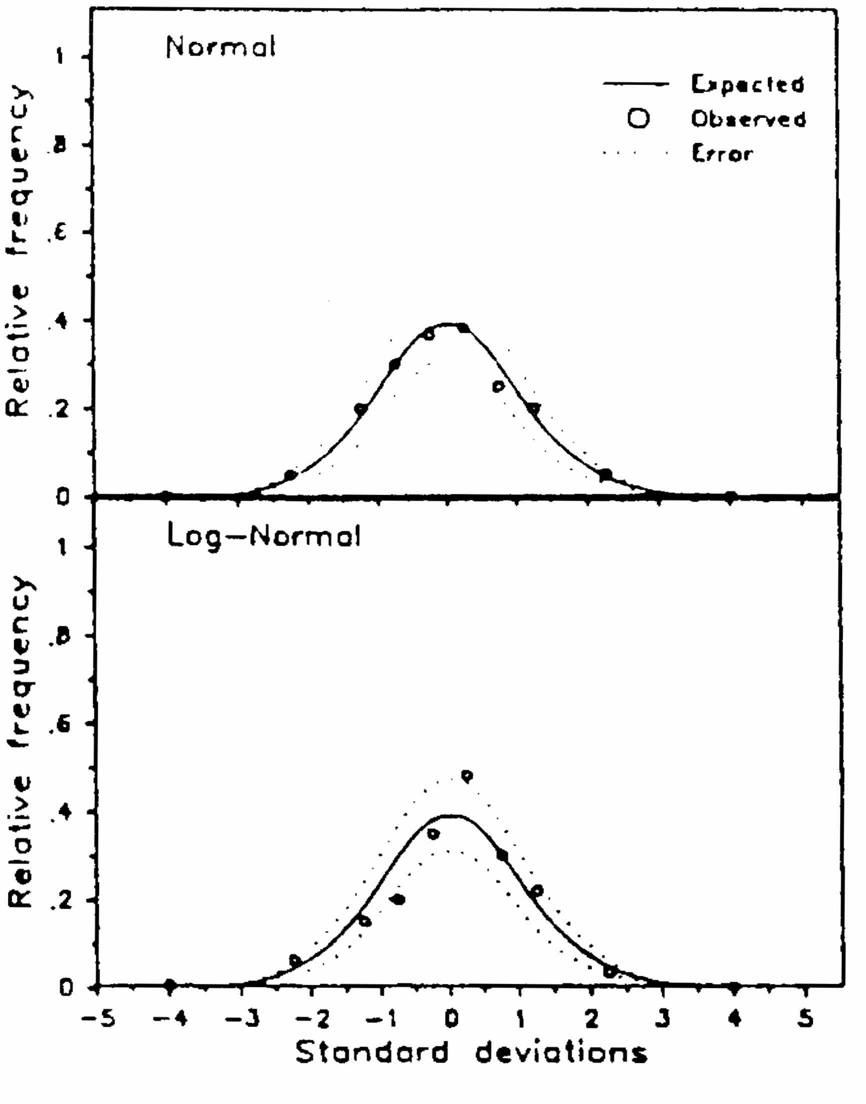

Figure 3. Expected and observed annual rainfall distributions for Darwin

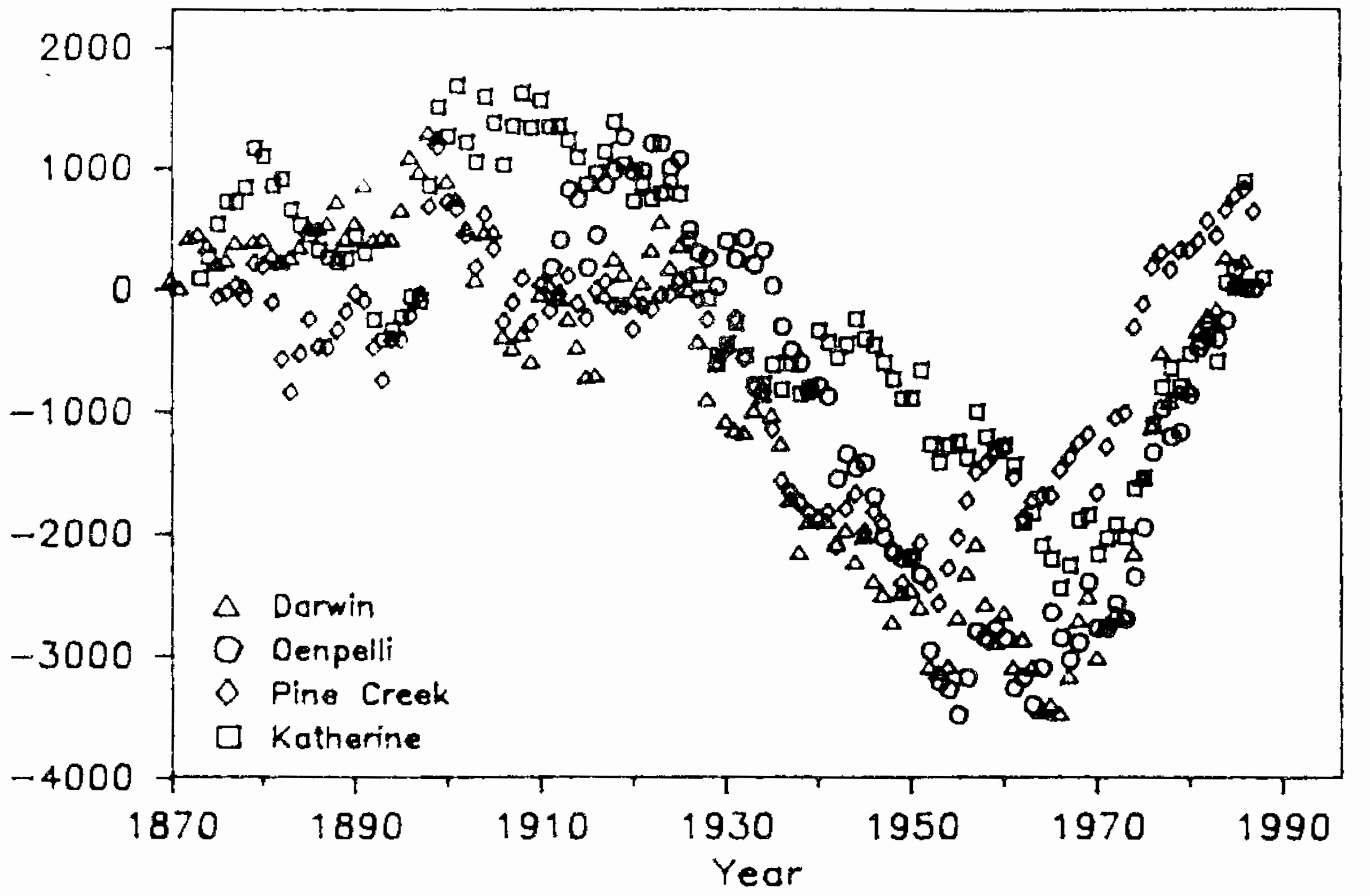

Figure 4. Cusum plots of rainfall data from four sites in the Region

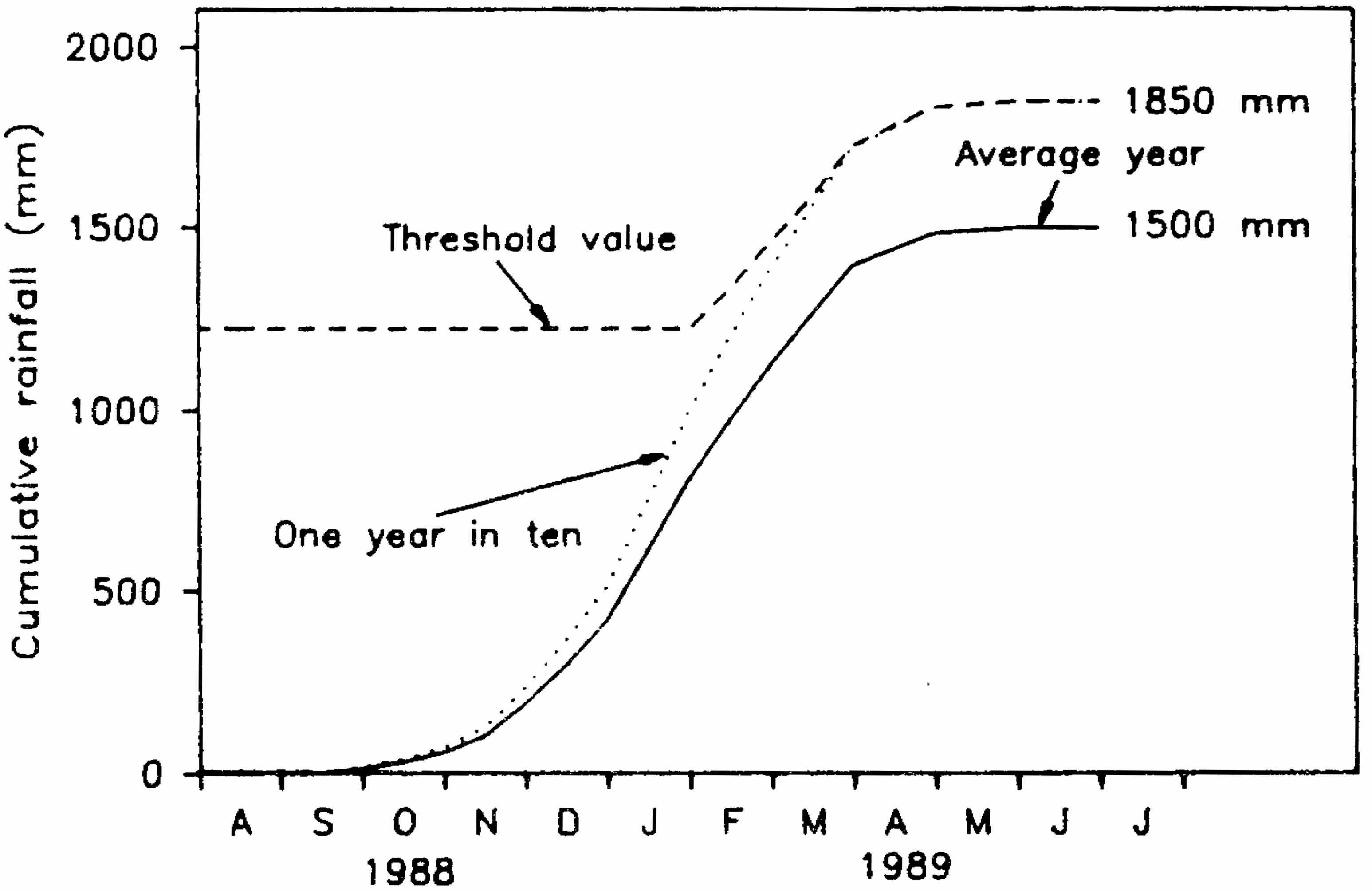

Figure 5. Comparison between the trigger values and the cumulative rainfall in an average year and in a 1-in-10 year