Use Of Bauxite Residue in the Peel-Harvey Coastal Plain Catchment

Public Environmental Review

April 1993

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

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This document was largely written by Rob Summers and Keith Bradby, officers of the Western Australian Department of Agriculture based at the Community Catchment Centre in Pinjarra. A number of individuals and agencies have supplied data for this report, and have commented on the numerous early drafts. Assistance is particularly appreciated from:

Dr J. Barrow (CSIRO),
Dr M. Bolland (Department of Agriculture Western Australia),
S. Fitzpatrick (CSBP)
D. J. Glenister (ALCOA of Australia),
Dr G. E. Ho (Murdoch University),
H. Hofstede (Murdoch University),
Dr I. McPharlin (Department of Agriculture Western Australia),
G. Pickersgill (ALCOA of Australia),
W. J. Robertson (Department of Agriculture Western Australia),
D. D. Smirk (ALCOA of Australia),
K. J. Summers (ALCOA of Australia),
L. F. Toussaint (State Radiological Laboratories),
Dr S. Ward (ALCOA of Australia).

A number of landholders and organizations have provided land, facilities and their time to the trials mentioned in this document:

R. Blackburn,
H. Dilley,
O. Eastcott,
S. Henning,
P. Kargotich,
C. Kentish,
C. Kielman,
C. Maughan,
G. Maughan,
G. Moore,
P. Stacey,
Q. Treasure,
J. Tuckey,
R. Walmsley,
A. Wigg,
Alcoa Farmlands,
Westralian Carnations.

Please Note:

Ownership of residue

The residue discussed in this report is the product of Alcoa of Australia Limited, and is stockpiled on their property. The Department of Agriculture is grateful for Alcoa's permission to publicly discuss the possible future use of this material.

Nothing contained in this report should be construed as implying government control of the resource, or as infringing on Alcoa's right to decide the future uses of their material.

The Department would like to express its gratitude to Alcoa for the initiative they have shown in supporting investigations into alternative uses of residue, for the co-operation received in the preparation of this document, and for permission to quote from internal Alcoa reports. Gratitude is also extended to CSBP for the supply of gypsum used in trials.

Sites mentioned

A number of specific sites, and the names of individual landholders, are mentioned in this report. This has been done primarily to provide the EPA with accurate documentation of the issues discussed. Virtually all the sites are on private property, and are not open for public inspection, although a number of them are often the subject of field days and other such organised visits.

Further Information

Inquiries regarding the residue program in general, and the sites mentioned in this report should be directed to:

The Bauxite Residue Co-ordinator
Community Catchment Centre
P.O. Box 376, Pinjarra, WA, 6208
Ph. (09) 531 1788

INVITATION

The Environmental Protection Authority (EPA) invites people to make a submission on this proposal.

The Public Environmental Review (PER) proposes that bauxite residue be available for widespread use in the Peel-Harvey coastal plain catchment. In accordance with the Environmental Protection Act, a (PER) has been prepared which describes this proposal and its likely effects on the environment. The PER is available for a public review period of 8 weeks from **5th of April 1993,** closing on **28th of May 1993.**

Following receipt of comments from government agencies and the public, the EPA will prepare an assessment report with recommendations to the government, taking into account issues raised in public submissions.

Why write a submission?

A submission is a way to provide information, express your opinion and put forward your suggested course of action - including any alternative approach. It is useful if you indicate any suggestions you have to improve the proposal.

All submissions received by the EPA will be acknowledged. Submissions may be fully or partially utilised in compiling a summary of the issues raised or, where complex or technical issues are raised, a confidential copy of the submission (or part thereof) may be sent to the proponent. The summary of issues raised is normally included in the EPA's assessment report. Submittors would not be identified to the proponent without the submittors permission.

Why not join a group?

If you prefer not to write your own comments, it may be worthwhile joining with a group or other groups interested in making a submission on similar issues. Joint submissions may help to reduce the workload for an individual or group, as well as increase the pool of ideas and information. If you form a small group (up to 10 people) please indicate all the names of the participants. If your group is larger, please indicate how many people your submission represents.

Developing a submission

You may agree or disagree with, or comment on, the general issues discussed in the PER or the specific proposals. It helps if you give reasons for your conclusions, supported by relevant data. You may make an important contribution by suggesting ways to make the proposal environmental more acceptable.

When making comments on specific proposals in the PER:

- clearly state your point of view;
- indicate the source of your information or argument if this is applicable;
- suggest recommendations, safeguards or alternatives.

Points to keep in mind

By keeping the following points in mind, you will make it easier for your submission to be analysed:

- attempt to list points so that issues raised are clear. A summary of your submission is helpful;
- refer each point to the appropriate section, chapter or recommendation in the PER;
- if you discuss different sections of the PER, keep them distinct and separate, so there is no confusion as to which section you are considering;
- attach any factual information you may wish to provide and give details of the source. Make sure your information is accurate.

Remember to include:

- your name,
- address,
- date.

The closing date for submission is: 28th May, 1993

Submissions should be addressed to:

The Environmental Protection Authority
Westralia Square
38 Mounts Bay Road
PERTH WA 6000

Attention: **Gabby Corbett**

Contents

1. Summary

Introduction

The Western Australian Department of Agriculture, as the government agency responsible for the Peel-Harvey Catchment Management Program, proposes to enable the widespread use of bauxite residue on existing rural land uses in the Peel-Harvey coastal plain catchment.

The overall objective of the proposal is to decrease the amount of phosphorus that runs off the land and enters the Peel-Harvey estuary, and to enable landholders to increase their profitability in a sustainable manner.

Bauxite residue

Bauxite residue is a by-product of the alumina industry and is commonly referred to as red mud (the fine fraction) and red sand (the coarse fraction). Bauxite residue is primarily finely ground bauxite and ironstone gravel from the Darling Scarp with most of the alumina content removed.

The residue is mainly iron, aluminium and silicon oxides. The fine iron and aluminium oxides and alkalinity are responsible for the residue's high capacity for absorbing pollutants such as excess nutrients and heavy metals.

The proposal

Over the past 15 years, a range of pollution control and soil improvement uses for bauxite residue have been identified through research and trials in Western Australia.

Results have been impressive and the program has now moved beyond the research phase. The Department of Agriculture is proposing to facilitate the more widespread use of bauxite residue in the Peel-Harvey catchment.

This Public Environmental Review (PER) has been prepared to enable the EPA to assess the proposal and to allow for informed public discussion of the proposal.

This report includes recommendations for the use of bauxite residue, and reviews potential environmental impacts.

Based on examination of an extensive body of available information from laboratory, glasshouse and field trials, this proposal sets out the use of bauxite residue (as defined in Section 4 of this document) in a range of existing agricultural, horticultural and domestic situations. It includes rates of application for each of these uses, and guidelines for bauxite residue use.

Recommendations for bauxite residue use

- Standard health and safety precautions should be taken, eg. maintaining dust skirts on spreading equipment, keeping loads covered when trucking, and ensuring that eye and dust protection is worn when handling bauxite residue.

- Single applications of red mud to pasture at below 100 t/ha is recommended to avoid overliming the soil or creating dust problems, and is probably most economic at a rate between 20 to 80 t/ha. At these rates gypsum addition is not required. Applications of over 100 t/ha need to be mixed into the soil to avoid creating dust, and gypsum addition needs to be considered.

- Bauxite residue used for soil amendment to aid phosphorus retention in domestic garden situations should be well mixed into the soil, at a maximum of 80 t/ha, or incorporated into a soil blend or compost to minimise the nuisance effect of staining. To avoid these nuisance effects the maximum recommended proportion of red mud in soil blends and composts is 30% by weight.

- With adequate mixing, red mud can be applied to horticultural soils to the maximum of 250 t/ha.
- Mixing will not need to be as thorough in rural areas because of the low rates used and the natural mixing by stock and rain.
- For use in infiltrating filters the proportion of residue should be carefully designed to allow adequate infiltration.
- Residue is a useful liming agent in well drained sandy soil, but site specific testing of pH and buffering capacity is required to avoid over-liming.

Management commitments

Following public discussion of this document, and assessment by the EPA of the points contained within it, the West Australian Department of Agriculture will accept commitments binding it to:

1. Commencing negotiations with Alcoa of Australia Limited which, if successful, will produce a Code of Practice and management structure enabling the widespread use of bauxite residue for nutrient control in the Peel-Harvey coastal plain catchment.
2. Maintaining, in conjunction with other agencies and institutions, and to the satisfaction of the EPA, a program of strategic monitoring of residue use and its benefits and impacts, under the program established through the Codes of Practice.
3. Providing the EPA and the general public with regular reports outlining the use and distribution of bauxite residue, under the program developed above and produce a major review of the program for EPA assessment within ten years.

None of the above commitments should be read as impinging on any separate arrangements Alcoa of Australia Limited may choose to make between itself, other interested parties, and other government agencies, regarding the sale, use and distribution of bauxite residue.

Environmental impacts and management

The major benefit of the use of bauxite residue in the Peel-Harvey catchment is the reduction in phosphorus entering the estuary. There also are a number of associated benefits discussed in greater detail in the proposal.

The characteristics of bauxite residue which give cause for most environmental concerns are:

• Red mud and red sand, as by-products of the extraction of alumina from crushed bauxite by sodium hydroxide, are alkaline and saline.

• During processing, part of the alumina fraction is removed from the bauxite and there is a proportional increase in the concentration of naturally occurring trace materials such as heavy metals and radioactive elements.

Western Australia is a world leader in research into the use of bauxite residue. This PER draws on many sources of research both here and overseas. Based on this information, it is believed that any adverse environmental impacts of residue use will be minimal at the rates of application recommended here.

Following is a summary of the potential environmental impacts associated with the ongoing use of red mud.

Leachate

Groundwater and water quality

In a trial using many times (850 t/ha) the rates recommended in this document, the salts leached to groundwater were equivalent to 20 years of leaching by rainfall of an untreated soil and, would pose no significant threat when applied to the sandy agricultural soil in the catchment of an estuary (Ho *et al.* 1989). Therefore at the much lower rates recommended in this document the effect of leachates would be minimal.

The concentration of salts that left a small catchment (32 ha) treated with red mud has been shown to be low and well within drinking water concentrations (Summers *et al.* In Press). "As watershed size decreases, everything else being equal, the peak concentrations of sediments, nutrients and pesticides increase" Baker (1986). When larger catchments are treated, the cumulative effect of red mud on leachate concentration is actually expected to be less than on small catchments. Similarly the load per unit area will also be less. This principle also applies to trace elements and is discussed later.

Sulphate

Early research used rates of red mud ranging from 500 to 2000 t/ha that also required the addition of gypsum (gypsum is calcium sulphate) to enable plants to thrive (Barrow, 1982). Sodium sulphate was the major salt that leached from this type of amendment. More recently the use of red mud without gypsum has been successfully developed for broadacre use. This is generally at rates below 100 t/ha. Red mud not amended with gypsum does not contain appreciable sulphate and does not leach sulphate (Summers *et al.* unpublished). As a result sulphates will not be a major leachate from red mud applied to broad scale agriculture.

Trace elements

In a trial using Western Australian red mud and gypsum at 850 t/ha the concentration of the elements iron, aluminium, and cadmium in leachate was negligible (Ho *et al.,* 1989).

Another trial examined the potential pollutants: cadmium, aluminium, iron, arsenic, fluoride, sulphate, electrical conductivity, and pH in leachates for Western Australian red mud applied at between 5 and 80 t/ha. The leachate was within background levels or below maximum limits for drinking water, except fluoride when gypsum was applied (Summers *et al.* unpublished).

Bauxite, like soils in the Darling Range, naturally contains many trace metals which if mobilised could pose environmental risks. However, most of these elements are tightly bound in mineral compounds and require exceptional circumstances to be released, such as being immersed in concentrated acid. They will not leach under the circumstances likely following soil amendment. In fact the absorbent qualities of red mud for heavy metals can be utilised. Red mud has been described as a good absorbent for arsenic from industrial wastewaters (Parekh and Goldberger, 1976) and is being used to absorb heavy metals in municipal compost (Hofstede and Ho, 1991).

Radiation

Many soils and rocks contain naturally occurring radioactive minerals, such as thorium and uranium, in trace amounts. These minerals also occur in bauxite ore. When bauxite is processed, about a third of the material is removed as alumina, which is low in radioactivity. Subsequently, there is a proportional increase in concentration of radioactive materials in the residue.

The recommended rates of application covered here result in backgound levels that are low and difficult to differentiate from existing background radiation on the Swan Coastal sandplain. This applies even when dose rates are calculated for continuous exposure, and are well below a number of naturally occurring levels in the Perth region.

Drains, streams, estuarine or freshwater lakes/wetlands
When bauxite residue is applied at the rates discussed in this document, the major concern to freshwater environments is salt that may leach from the residue. The amount of salt that leaches from the residue is comparable to that supplied each year by precipitation (based on Ho *et al.* 1989). Field trials on a catchment of a freshwater lake have confirmed that the maximum concentrations of salts leaching from bauxite residue is below that of much of the superficial groundwaters of the coastal plain (Summers *et al.* in press). The superficial groundwaters make up much of the freshwater lakes and wetlands.

Marine environment
Bauxite residue has been disposed of in marine environments in some countries. The main effect on marine and freshwater life has been through the physical effects of smothering and accumulation of particles on gills (Sigmond *et al*, 1980). Under the techniques recommended in this document very little, if any, actual residue will reach waterways, and physical disturbance will not occur.

Soluble salts such as those that runoff from soil treated with bauxite residue are common in aquatic systems. The application of bauxite residue to soil does not result in runoff at levels likely to cause any impacts on aquatic organisms.

Soils
Red mud and gypsum amended red mud affects soils in the following ways:
• Nutrients are retained in the topsoil and not leached.
• Acid soils are neutralised by the alkaline materials in red mud.
• Trace and minor elements in red mud are added, which are not present in sandy soils.
• The absorbent properties of red mud improve the water retention of sandy soils.

Flora, fauna and ecosystems
The uses of bauxite residue proposed in this document are restricted to application on cleared land. Dispersal by dust is not expected to occur. Because the amended soils are sandy, the bauxite residue does not move horizontally due to a combination of water percolating rapidly and the fact that the paddocks are very level. Hence, flora and fauna adjacent to the areas of application will not be exposed to residue.

The biological communities which are likely to be exposed to the effects of bauxite residue are downstream of run-off from amended areas. Field trials and laboratory trials have shown that leachates from bauxite residue treated soils have concentrations of salt less than those commonly found in groundwater and runoff (Deeney, 1989).

Landscape and recreation values
The levels of bauxite residue proposed in this document are difficult to visually detect in the year after application. The major effect of bauxite residue is to reduce the flow of nutrients which feed algal blooms in the Peel-Harvey estuary, which will result in improved landscape and recreation values.

Surface water drainage patterns

The rates of bauxite residue proposed here will not change soil permeability enough to significantly affect overland flow. Aside from this, most of the catchment is very flat and is inundated during the winter. The extent of inundation is not affected as much by the permeability of the soils as by the ability of drains to remove the surface water.

Transport and safety

Bauxite residue does not fall into a hazardous category for transport set down by the Department of Mines (1983, 1985). While bauxite residue is not hazardous by regulation, people handling bauxite residue should follow normal safety procedures for eye and respiratory protection. Although the main hazard is dust, it is important to be wary of flecks of unmixed alkaline particles.

2. Introduction

The waters of the Peel-Harvey estuary (see Figure 1.) are eutrophic. Algal blooms are a nuisance to residents and the depletion of oxygen caused by the blooms has killed fish and crustacea (DCE, 1985). Algal blooms also have made crabs and mussels toxic to eat and, because of skin irritation, people have been advised not to swim in affected water.

Eutrophication has been attributed, in part, to the leaching of phosphorus from fertilisers applied to pastures on the very sandy and easily leached soils of the surrounding coastal plain catchment (Birch, 1982). Phosphorus from point sources such as piggeries, dairies and sewage treatment plants are also major contributors to eutrophication.

This eutrophication problem has led to the development of a major government strategy to restore the estuary to health and resilience. As well as major public works such as the Dawesville Cut, this strategy includes the development of a number of measures designed to reduce the tonnage of phosphorus reaching the estuary from its catchment (EPA 1992).

The agency responsible for the Peel-Harvey Catchment Management Program is the West Australian Department of Agriculture. In the period 1984-1990 the Department of Agriculture focused its work on assisting landholders to improve the efficiency of fertiliser use. This is believed to have led to reductions in overall fertilizer applications, particularly in the early stages of the program. However, soil phosphorus levels in the catchment are now such that further reductions in fertilizer efficiency are unlikely unless improved fertilizers become available.

The Department has also worked with the owners of a number of point sources of phosphorus, and has achieved significant reductions in phosphorus loads from these. The remaining point sources are, with one notable exception, small industries that require low cost solutions.

A number of other measures for reducing phosphorus loads have been investigated in the past ten years. In 1988 an Environmental Review and Management Program was prepared for the Peel-Harvey program (Kinhill, 1988). This document formalised EPA approval for the Dawesville Cut, and discussed a number of catchment management measures.

The major "new" method discussed was the large scale conversion of farmland on sandy soils to plantations of *Eucalyptus globulus*. This has now been trialed, and the plantings have not, to date, come up to early expectations.

Soil amendment with bauxite residue was also discussed in the ERMP, but discarded because, at that time, the tonnages involved and techniques used made amendment extremely expensive and impractical. However, investigations into the use of bauxite residue have continued, and viable techniques are now proven for a number of land-use situations.

Additionally, urban and rural development in the catchment is now guided by a "Statement of Planning Policy", produced by the Department of Planning and Urban Development (DPUD, 1992). This document specifies soil amendment in a number of situations, where it can reduce the phosphorus load leaving new development.

Actions are now being taken to enable landholders to make much greater use of residue than has been possible in the past. Production of this document is one of those actions.

2.1. Role of the Department of Agriculture

The Department has two complementary roles in the development of uses for bauxite residue. In its traditional role it has responsibilities for the further development of sustainable agricultural systems on the coastal plain.

As the State Government's "lead agency" for the Peel-Harvey catchment management program, the Department has a broader responsibility to reduce overall phosphorus loads leaving the catchment. This has involved the Department in a number of situations, such as sewerage management and design of sub-divisions, which are beyond its normal roles.

To facilitate the work of catchment management, a Community Catchment Centre has been established in Pinjarra. This serves as the operational base for the program. Staff at the Centre are working with a range of landholder groups in devising and implementing techniques which improve the sustainability of land-use in the catchment.

This work includes a range of general land-care measures specifically designed to reduce phosphorus loads reaching the estuary. They include water management techniques, such as building small swamps which serve as waterbird habitats and nutrient filters, fencing off and revegetating drains and natural watercourses, establishing high water-using perennial pastures, agro-forestry, and cost-effective effluent containment systems for intensive animal industries.

Most of these techniques involve the use of bauxite residue, in one form or another. The most effective wetland filters are those that have residue mixed into their soils. In the process of revegetating drains and watercourses it is relatively simple to strategically incorporate small amounts of residue into depressions or filters parallel to the drains.

Deep rooted perennial pastures are very difficult to establish on the coastal plain, largely because of the acidity of the sub-soils. Amendment of the soils with bauxite residue shows considerable potential for reducing sub-soil acidity.

Additional to the techniques outlined above, soil amendment of farmland offers the prospect of significant improvement in pasture production, along with similarly significant reductions in phosphorus loss.

Achieving wider availability of residue, for the variety of uses outlined in this document, is essential if the Department of Agriculture is to achieve the targets for phosphorus load reductions set by Govement. Because of its economic advantages, residue use can make significant improvements to the economic viability of existing land-uses.

It is one of the few techniques available to land managers in the catchment that is capable of achieving significant reductions in nutrient loss in the year of application. Soil amendment is the only technique capable of giving the landholder significant short-term economic benefit.

The Department of Agricutlure is committed to achieving sustainable land-use on the coastal plain. Residue use is an integral part of achieving that.

2.2. Scope of this review

This review presents current information on the use of bauxite residue (red mud and red sand) for soil amendment and effluent control in the catchment of the Peel-Harvey estuary. It follows extensive work by landholders, government agencies, university based researchers, and Alcoa of Australia Limited on the beneficial uses of bauxite residue. This work has led to numerous requests by landholders for residue to be made more freely available.

The Department now wishes to see a framework developed which will allow the more widespread use of residue. Three major obligations need to be met if this is to happen.

Firstly, the Department, and others involved, need to be sure that widespread use of residue can be classed as "environmental friendly".

Secondly, it was felt that widespread use of residue should only proceed with general public acceptance. Consequently, all known facts, many of which are located in obscure scientific papers, should be available for public scrutiny and discussion, though it must be borne in mind that there are over 300 scientific publications on residue use available. While this document can only summarise the relevant work contained in these, its findings are consistent with that large body of research.

Thirdly, the producers of the residue, Alcoa of Australia Limited, cannot be expected to pick up responsibility for catchment management in the Peel-Harvey. Alcoa is committed to managing its own holdings, and the land that its operations affect, in an environmental responsible manner. It also already supports a range of environmental initiatives. Catchment management is a whole community problem and if widespread bauxite residue use can help solve it then the support of government and the community is necessary.

Following initial discussions with senior staff at Alcoa, and with officers of the EPA and other involved agencies, it was decided to submit the use of bauxite residue for formal EPA assessment. This allows independent appraisal to be combined with public scrutiny and discussion in the one operation, and provides a solid and publicly visible starting point for formal negotiations between Government and Alcoa.

The formal appraisal process does, however, have the difficulty that EPA procedures are generally set for firm site-specific proposals, and are not designed to give general endorsement to the use of materials or products, such as is required for residue use. During discussions with EPA officers, agreement was reached that assessment of residue use could proceed, providing conditions and constraints applicable to general use were listed. The Department of Agriculture appreciates the flexibility and co-operation shown by the EPA in this matter.

A formal approach was made to the EPA in early October, 1992, and the level of Public Environmental Review (PER) was set for the proposal. This was publicly advertised on 24/10/92. In subsequent discussions with EPA officers, it was decided to limit the scope of the PER to the use of bauxite residue to an existing land use. Where the land is subject to a proposal to change the land use through redevelopment or subdivision, bauxite residue should not be considered as a replacement for existing land use planning mechanisms.

The Department also decided to restrict this PER to the area covered by the Peel-Harvey coastal plain catchment (see Figure 1). This is primarily because this is the area of greatest need, and the area where stockpiles of residue are readily available. It is also the area where the Department of Agriculture has overall land-use responsibilities. It is anticipated that future use in areas outside the Peel-Harvey will proceed based on experience gained in the Peel-Harvey catchment.

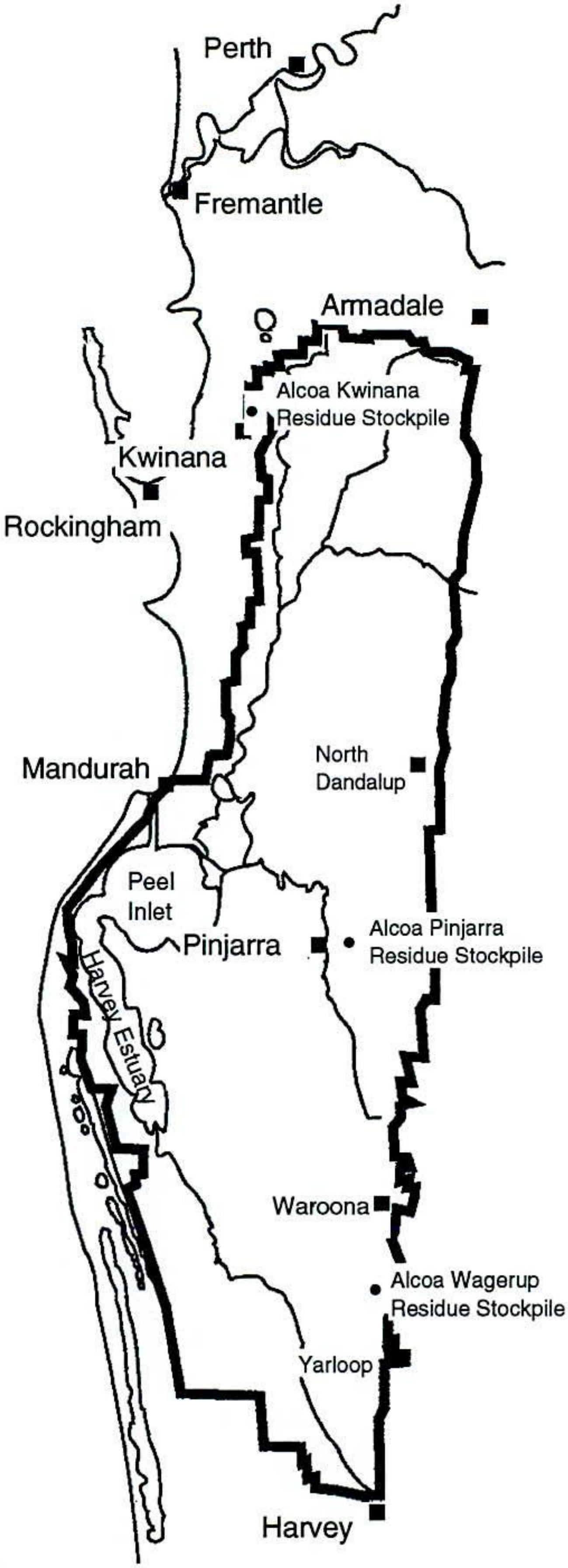

Figure1. The coastal catchment of the Peel-Harvey Estuary

Consequently this document:

- reviews all available information on the use of bauxite residue as a soil amendment, and a filter for effluents.
- outlines existing uses, trials and demonstrations underway in the Peel-Harvey catchment.
- investigates and documents all known environmental impacts, both beneficial and adverse.
- makes recommendations on future use of residue for existing land-uses in the Peel-Harvey coastal plain catchment.

Following public discussion of this document, and subject to the approval of the Environmental Protection Authority, a framework to facilitate more extensive use of bauxite residue will be established by the Department of Agriculture, in conjunction with other government agencies, Alcoa of Australia Limited and CSBP. It is envisaged that this framework will include arrangements for the distribution, transport and application of residue.

2.3. Social and economic patterns in the catchment

The Peel-Harvey coastal catchment extends from near Kwinana and Armadale in the north to Harvey in the south (see Figure 1). The area is predominantly rural, with a rapidly growing urban area around the City of Mandurah. Other major population centres within the region include Kwinana, Byford, Serpentine, Pinjarra, Waroona, Harvey, Mundijong, Rockingham and Mandurah.

Nine local government areas are represented in the catchment. Accurate population figures are difficult to ascertain, as these are gathered on administrative boundaries, not catchment boundaries. The population is currently estimated at between 50,000 to 60,000 people. Annual population growth has been rapid since the early 1960's, at more than 3 to 8 times the state average (ERMP Stage 2-1988, SWDA 1992). This rapid growth is expected to continue.

Most growth is the result of urban expansion in the City of Mandurah, and the development of rural residential holdings, particularly in the north of the catchment.

Despite this growth, the predominant land-use in the catchment is still agricultural. The catchment retains a high economic and social dependence upon agriculture, and produces between 60-100 million dollars worth of agricultural produce per year, much of it fresh food for the adjacent metropolitan areas.

The most extensive agricultural land-use is beef production. Dairying is also of major importance, particularly in the southern section of the catchment. Because of the proximity to Perth, and the Port of Fremantle, there are a significant number of intensive animal industries in the northern section of the catchment.

Of increasing importance in the northern section is horticulture, with over 150 commercial enterprises currently operating. These include large market gardens, production and retail nurseries and intensive floriculture enterprises.

There are currently major proposals to urbanise significant areas of the northern catchment. The state government has purchased a 4,000 hectare property on the Serpentine River (Amarillo), for the purpose of establishing a major urban area. Planning for the future of Perth suggests that as many as 60,000 to 80,000 extra people could be living in the region by 2010.

The proposals contained in this document for the use of bauxite residue, restricted as they are to existing land uses are not, on their own, expected to cause any major impacts on social or economic patterns in the catchment. While significant economic benefits exist in soil amending sandy farmland, these benefits will be offset by the declining profitability of broadacre agriculture.

3. The proposal

In its role as government agency responsible for the Peel-Harvey Catchment Management Program, the Western Australian Department of Agriculture proposes to enable the widespread use of bauxite residue on existing land uses in the Peel-Harvey coastal plain catchment.

The overall objective of this proposal is to decrease the amount of phosphorus that runs off the land and enters the Peel-Harvey estuary, while assisting landholders to increase their profitability in a sustainable manner.

A range of pollution control and soil improvement uses for bauxite residue have been identified by research and trials in Western Australia over the past 15 years. Results have been impressive and pressure to move beyond the research phase has increased to the point where use of bauxite residue is being proposed by land users and approving agencies. This has occurred in an informal way, and while publicity through the EPA's normal approval processes has been extensive it is believed that this Public Environmental Review (PER) will give the general community the chance to raise any concerns.

This report has been prepared to enable the EPA to assess the above proposal, in general terms, and to allow for informed public discussion of the proposal. Information outlined in this document demonstrates that residue use, within certain broad constraints, will have overall environmental and economic benefits in the coastal catchment of the Peel-Harvey estuary.

If this finding is accepted by the Minister for the Environment, after the EPA's assessment and after public discussion of the issues, the Department will commence negotiations with Alcoa of Australia Limited on the marketing and distribution of residue. It is anticipated that these negotiations will include the development of a mechanism to indemnify Alcoa from liabilities resulting from use of its residue beyond the stockpiling presently approved by government.

This document asserts that, based on examination of an extensive body of available information from laboratory, glasshouse and field trials, bauxite residue (as defined in Section 4 of this document) is suitable for use in a range of existing agricultural, horticultural and domestic situations. The range of research conducted in WA on environmental impacts of residue has concentrated on application at rates between 5 and 2000 t/ha. As outlined in Section 9.3, 1400 t/ha is the lowest application rate at which environmental impacts may become an issue. However, because our research into residue use on the coastal plain is only 15 years old, a conservative approach is adopted in this report, and soil amendment above 250t/ha is not recommended at this stage. This is also above the level at which soil amendment is currently economic for most land uses.

Use of residue at rates above 250t/ha, and as high as 1400t/ha may be appropriate in strategic situations, such as in effluent treatment ponds and compensating basins, and these should be assessed on their individual merits.

At applications below 100 t/ha the addition of gypsum is not considered necessary. At rates above this addition of gypsum is likely to be necessary. This recommendation is based on relatively recent research and will be kept under constant review.

Because these upper limits are set on such a conservative basis, it is anticipated that they will be reviewed and increased in years ahead, if the need arises. But it is now considered clear, that distribution of residue for soil amendment and nutrient control can expand, and bring the environmental and economic benefits outlined elsewhere in this document.

However, with these upper limits in mind the Department of Agriculture is adopting a lead agency role within government in seeking all the relevant government approvals for the more widespread use of bauxite residue, within the limits specified above, and in facilitating the development of a distribution structure acceptable to the agencies involved and to Alcoa of Australia Ltd.

The specific management commitments the Department of Agriculture has made, in order to carry out its role of facilitating more widespread use of bauxite residue, is outlined in Section 11. It is anticipated that, following assessment of this document by the EPA., bauxite residue use will be subject to the following recommendations, which are based on current knowledge and set conservatively within the rates previously tested.

Guidelines for Bauxite Residue Use

- Standard health and safety precautions should be taken, eg. maintaining dust skirts on spreading equipment, keeping loads covered when trucking, and ensuring that eye and dust protection is worn when handling bauxite residue.

- Single applications of red mud to pasture at below 100 t/ha are recommended to avoid overliming the soil or creating dust problems, and are probably most economic at a rate between 20 to 80 t/ha. At these rates gypsum addition is not required. Applications of over 100 t/ha need to be mixed into the soil to avoid creating dust, and gypsum addition needs to be considered.

- Bauxite residue used for soil amendment to aid phosphorus retention in domestic garden situations should be well mixed into the soil, at a maximum of 80 t/ha, or incorporated into a soil blend or compost to minimise the nuisance effect of staining. To avoid these nuisance effects the maximum recommended proportion of red mud in soil blends and composts is 30% by weight.

- With adequate mixing, red mud can be applied to horticultural soils to the maximum of 250 t/ha.

- Mixing will not need to be as thorough in rural areas because of the low rates used and the natural mixing by stock and rain.

- For use in infiltrating filters the proportion of residue should be carefully designed to allow adequate infiltration.

- Residue is a useful liming agent in well drained sandy soil, but site specific testing of pH and buffering capacity is required to avoid over-liming.

4. Bauxite residue

4.1. Bauxite residue production

Two companies in Western Australia process bauxite into alumina: Alcoa of Australia Ltd. and Worsley Alumina Pty. Ltd. Alcoa operates three mines in the Darling Range (Jarrahdale, Huntly and Willowdale), and three processing plants (Kwinana, Pinjarra and Wagerup). These plants together produce over 12 million tonnes of residue per year, both red mud and red sand. This is currently stockpiled in storage sites adjacent to the refineries, and within the Peel-Harvey catchment. Commencing in 1987 Alcoa has converted its residue storage from wet impoundment to a dry stacking operation. This makes recovery of residue for outside use both practical and low cost.

Since the early 1980's Alcoa has pursued the concept of using red mud for a range of beneficial uses in conjunction with the CSIRO, Murdoch University, Western Australian Department of Agriculture and other public and private institutions. All Western Australian research and field trials into the use of this residue have been conducted in conjunction with Alcoa.

Because of this involvement, and the proximity of the storage sites to the areas of greatest need (coastal plain catchments), this report only deals with bauxite residue produced by Alcoa's three refineries.

4.2. Physical and chemical characteristics

Bauxite residue is the by-product formed when alumina is extracted from crushed alumina rich gravels and ironstones (bauxite) with hot caustic soda (sodium hydroxide). With current processing technologies applied to Darling Range bauxites about 35% of the original bauxite is removed in the process. The resultant residue is washed to reclaim most of the caustic soda solution and is then stored in residue disposal areas. The residue reflects the mineralogy of the original bauxite ores.

Consequently, bauxite residue, as covered by this document, can be defined as material with the major constituents being approximately:

Constituent	Proportion
Iron oxide (Fe_2O_3)	25% to 40%
Silica (SiO_2)	20% to 30%
Aluminium oxide (Al_2O_3)	15% to 20%
Calcium oxide (CaO)	2% to 4%
Titanium oxide (TiO_2)	2% to 4%
Sodium oxide (Na_2O)	1.5% to 3%
Loss on ignition	10% to 11%

The trace materials that make up the remaining 3% are listed in the Appendix in tables comparing residue with naturally occurring soils. Red mud varies between refineries due to natural variations in the composition of the ores while the variation within the stockpiles of individual refineries is not as great.

Red mud is the fine fraction of bauxite reside with over 50% of the particles less than 10 microns in size. However these tend to be agglomerated and the material behaves like a silt. There is up to 15% fine sand in the red mud. Red sand is mainly fine to medium sand with less than 5% silt. There is some slight variation in texture between refineries.

In some situations gypsum (calcium sulphate, supplied by CSBP), is mixed with red mud to reduce the pH. The chemical composition of the minor elements in this gypsum source is listed in the Appendix.

4.3. Research background

The use of residue to improve the nutrient and water retention of the infertile and acid sandy soils of Western Australia was first reported in 1982 (Barrow, 1982). Following this, a number of trials were established in the Peel-Harvey catchment during the 1980's. Reviews of this work have been published by Tacey *et al* (1984) and Vlahos *et al*, (1989).

In 1976, the United States Environmental Protection Agency assessed the technology of the use of Bayer process muds, and recommended residue be investigated as an absorbent for use in pollution abatement. The Agency report cited an example of a wastewater treatment plant in England that had used bauxite residue in the 1930's to remove nutrients (Parekh and Goldberger, 1976). In this publication alone there are 267 referenced articles on the use of residue.

Western Australia is now a world leader in research into the use of bauxite residue, as evidenced by work sponsored by Alcoa:

- pioneering work on ceramic uses and soil amendment by CSIRO since the late 70's;
- at Murdoch University on nutrient uptake, microbiological purification and composting;
- at Curtin University on radiological implications of residue;
- at Chemistry Centre on the mechanisms involved in nutrient uptake; and
- conducted by the Western Australian Department of Agriculture on the agricultural and horticultural uses of residue.

Bauxite residue has been commercialised for use in septic leach drains by Ecomax Waste Management Systems Pty. Ltd. Their invention has been patented and is being installed in several shires in Western Australia after its acceptance by the WA Health Department. Interest in the system has been expressed from as far as Sydney. A patent on the use of residue for composting urban refuse has also been applied for by researchers at Murdoch University.

4.4. Current arrangements

Alcoa supplies residue to approved research and development programmes free of charge; Alcoa also helps fund a number of these programmes. CSBP has supplied gypsum free of charge for trials where gypsum blends were tested.

Alcoa has supplied residue to a small number of commercial customers at a cost per tonne which reflects the cost of preparation and handling. This includes supply for use in septic leach systems, in compensating basins, and for horticultural use. Most of this work has been for trials or demonstrations.

Residue has been used in a number of situations with the involvement or approval of government agencies. A number of soil amendment and effluent treatment trials have been developed and implemented in conjunction with the Department of Agriculture and the Water Authority. Officers of the Environmental Protection Authority have recommended the use of residue in a number of horticultural and sub-division proposals in the past eighteen months. A major horticultural development at Serpentine is using red mud to meet EPA requirements.

The Department of Planning and Urban Development, in its Statement of Planning Policy for the Peel-Harvey Coastal Plain Catchment, specifies the use of nutrient retentive soil amendments, such as red mud, in a number of situations. Modified leach drains utilising red mud amended with gypsum in conjunction with conventional septic tanks have received EPA, Water Authority and Health Department approvals, and are now commercially available in WA.

5. Soil amendment

5.1. Techniques for application

In early research in Western Australia, red mud and red mud amended with gypsum was applied at 200 to 2000 t/ha using elevating scrapers and heavy earthmoving equipment. In recent agricultural trials, however, red mud has been applied at between 5 and 80 t/ha using conventional agricultural spreading equipment (multispreaders), modified slightly to give even distribution and minimal dust (Summers and Smirk, 1992).

In horticultural trials red mud amended with gypsum has been applied at up to 250 t/ha and has been incorporated using rotary hoes.

Sterile artificial soil can be created by incorporating bauxite residue into potting mixes used in glasshouses and for growing plants for export horticulture.

5.2. Benefits

5.2.1. Reduction in phosphorus runoff

In Western Australia, the use of bauxite residue to retain nutrients was first suggested by Barrow (1982) following laboratory studies. Field trials confirmed that residue applied at 200 t/ha to sandy soils reduced phosphorus leaching from greater than 40 kg P/ha to less than 3 kg P/ha in a three-year trial (Vlahos *et al*, 1989).

This work paralleled trials in Germany where the application of 10 and 20 t/ha of red mud reduced phosphorus leaching to subsurface drains (Scheffer *et al*, 1986). Analysis of the drainage water showed a reduction of up to 70% in phosphate leaching within five years with 20 t/ha of red mud or a red mud/ferrous sulphate treatment. Fertiliser phosphates were retained in the enriched upper layer, adsorbed by the iron oxides of the red mud, but still available to plants (Scheffer *et al*, 1986).

In a large scale field trial of 30 ha in a sandy catchment near Harvey, application of 80 t/ha of red mud reduced phosphorus runoff by 70% when compared with the untreated catchment - from 13.8 kg P/ha reduced to 4.2 kg P/ha (Summers *et al*, in press).

The rates of residue application recommended in this document, combined with the standard rates of fertiliser application used in the Peel-Harvey catchment, have been estimated to last at least five years, through field trials in Germany (Scheffer *et al.* 1986). Similar results have been found in laboratory trials conducted in Western Australia (Summers *et al.* unpublished).

Any recommendations for the reapplication of red mud will be based on the monitoring of key field trials by the WA Department of Agriculture. These have already been in place for several years and are continuing.

5.2.2. *Water conservation and water drainage patterns*

Water is conserved following soil amendment with red mud. The addition of fine particles to the sands enhance water holding and reduce water repellence. This improvement in water holding capacity is achieved by the greater surface area of the bauxite residue available to hold onto the water. The greater surface area of the bauxite residue also reduces the ability of the hydrophobic materials to completely coat the soil and makes it more wettable.

However, the rates of red mud application proposed here are not expected to significantly affect overland flow of water during winter. Most of the catchment is inundated during the winter, which results in an existing high level of overland flow. The extent of inundation is not affected as much by the permeability of the soils as by the ability of drains to remove the surface water.

Reduced water repellence, increased pH and increased fertiliser retention, following soil amendment is expected to improve the efficiency of water use by pasture plants.

5.2.3. *Increases in production*

Pasture production improves following soil amendment with residue, within a range of tonnages applied. This is largely due to:
• Nutrients being retained in the topsoil and not leached before pasture has established.
• The acid soils being neutralised by the alkaline materials in red mud.
• Addition of trace and minor elements in red mud not present in sandy soils.
• The absorbent properties of red mud, which improve the water retention of the sandy soils.

Red mud has been used throughout the world to amend soil (Table 1) for pasture production. The increases in production from rates of red mud below 100 t/ha are mainly due to the increase in pH of the soil, and the addition of iron and trace elements. Heavy applications (greater than 100 t/ha) of red mud improve the water holding capacity of sandy soils.

Table 1. Increases in production from red mud as soil amendment.

Country	Rate (t/ha)	Increase in Production	Reference
Germany	10 to 20	26 to 75%	Scheffer *et al* (1985) Scheffer *et al* (1986)
Suriname	2 to 8	60%	Simons (1983) Simons (1984)
Western Australia	10 to 80	24%	Summers *et al* (in press)
Western Australia	500	>100%	Ward (1986)
Western Australia	2000	50 to 116%	Summers *et al* (1987)

Improvements in production in floriculture have also been found (Ward, 1992 pers. comm.) where White Sim carnations grown in 250 t/ha red mud and gypsum increased the number of stems per square metre from 231 to 315 and the number of stems per plant from 6.4 to 8.8.

Research now being carried out by the Department of Agriculture includes:
- determining fertilizer requirements and residual effects of fertilizer on red mud sites.
- the use of red mud and bauxite process sand as a liming agent on heavy soils in irrigation areas.

- the effects of red mud on the uptake of elements in vegetables.

Reference sites for soil amendment are included in Appendix D.

5.3. Recommendations

5.3.1. Pasture and horticulture

The major practical limitation on the quantity of red mud applied as a soil amendment for nutrient retention and increased production is increased pH. The amount of red mud applied to a soil constrained by pH will depend on the initial pH and the amount of mixing. Most coastal plain sands are acidic, making the alkalinity of bauxite residue a benefit, not a limitation.

The optimum rate of application for pasture growth is around 20 t/ha. This coincides with the rate which gives a 50% reduction in phosphorus leaching in broadacre farming situations, which will achieve the nutrient target of the Peel-Harvey catchment management program. Therefore the recommended application rate for red mud on pasture is 20 t/ha. Higher application rates will depend upon economic factors, mixing facilities, nutrient status, the initial pH and the buffering capacity of the soil.

If too much red mud is applied, particularly without adequate mixing, the pH of the soil may become too high for ruminants such as cows and sheep. If soils are overlimed, either with red mud, agricultural lime, or similar alkaline materials, it may reduce the amount of copper available to ruminants in the first year. This must be kept in mind when considering higher rates of red mud. High soil pH makes elements such as molybdenum more available in the soil and it is taken up by plants. Because of the digestive processes in ruminants elements such as molybdenum may react with copper. This results in the copper being excreted and a copper deficiency occurring in the animal. This is usually overcome by providing extra copper to the animals or by rotating grazing and feeding onto untreated areas. Copper deficiency may only happen when red mud is applied at greater than 100 t/ha and only in the first year of application.

High rates, and inadequate mixing, may also cause dust problems. In horticultural situations it is possible to achieve a high level of mixing, through the soil preparation which is required anyway for each successive crop. This makes it possible to apply rates as high as 250 t/ha without causing dust problems. Several applications of about 50 t/ha may be needed to accurately determine the best rate for the particular crops involved.

5.3.2. Urban

For existing urban areas, 30% residue in soil blends, potting mixes and composts would be useful in retaining nutrients. Distribution of unmixed residue for existing urban use is not recommended because of concerns about misuse resulting in problems with alkalinity, salinity, dust and staining.

6. Effluent and waste management

6.1. Techniques

6.1.1. Intensive animal industries

6.1.1.1. Effluent ponds

Red mud has been used to line a piggery effluent pond by using earthmoving equipment to mix 70% native sand with 30% red mud amended with 10% gypsum, and building a liner of red mud 60 cm thick under and around the pond (Summers and Smirk, 1992).

Dairy effluent is now being safely stored on a number of sites using a ponding system which allows anaerobic digestion to occur. Sludge from these ponds is available for use by the landholder as fertiliser. Excess liquid is discharged onto filters made of red sand (Summers and Smirk, 1992)

Future uses could include processing of effluent from feedlots and abattoirs. Red sand may also be used as a substitute for red mud when amending soil to improve drainage and nutrient absorption around dairies.

6.1.1.2. *Disposal of effluent on amended soil*

If effluent is disposed onto amended soil, nutrients will be intercepted, thus reducing the area of application and increasing production. As yet, red mud has not been used for this purpose, although it has been explored for use with piggeries. Specific techniques will need to be developed.

Phosphorus from organic effluent is retained (as with phosphorus from inorganic fertilizers) when leached through red mud (amended with 10 % gypsum) amended soil (Ho *et al*, 1989).

6.1.2. ***Urban effluent disposal***

6.1.2.1. *Modified leach drain and aerobic treatment unit disposal*

Two designs incorporating bauxite residue are currently licensed for use in WA.

One drain design uses an impermeable plastic liner below the leach drain to stop rapid downward movement of effluent and to encourage horizontal filtering through a 90 cm layer of red mud, red sand and gypsum, which is covered with topsoil.

Another design uses an area of red mud amended soil to dispose of effluent that has been processed by a domestic aerobic treatment unit. The red mud amended area is about 30 cm thick and is spread over 90 to 150 m^2.

Both these designs are commercially available and have been approved by the EPA, the WA Health Department and WA Water Authority. Both systems cost about $6000.

6.1.2.2. *Municipal sewage disposal*

Red mud was used in the flocculation of sludge from municipal wastewaters on a commercial scale in England in the 1930's (Ellis, 1947) with removal of up to 80% of nutrients (Parekh and Goldberger, 1976).

A pilot scale field trial has been conducted at the WA Water Authority's Kwinana Groundwater recharge basin. The basin was packed with 20% red mud (amended with 5% gypsum) and mixed with sand from the site to 1 m deep (Ho *et al*, 1986).

Another major trial underway at the sewage treatment plant at Pinjarra consists of three consecutive digestion ponds. The effluent had been discharging from the ponds into a stream that flows to the Murray River and into the Peel-Harvey estuary. The annual discharge contains about two tonnes of phosphorus.

In the trial, the effluent stream is being diverted and pumped onto a 4 ha artificial basin. The basin is lined with red mud (amended with 5% gypsum) at 750 t/ha and rotary hoed to a depth of 25 cm. Slotted pipe below the basin drains the site to a measuring point. Grass will be grown on the basin to harvest the nutrients captured from the effluent by the red mud. The basin is divided into four cells which will be flooded in rotation for maximum pasture growth.

6.1.3. *Composting and mulching (urban refuse disposal)*

The manufacture of useable compost from municipal waste is limited only by the contamination of heavy metals. Contamination with heavy metals and other pollutants occurs before collection and is impossible to reverse. During the composting process a reduction in volume of up to 50% occurs and any contamination is concentrated. Organic acids are a by-product of the composting process and these acids act as carriers for heavy metals.

If an adsorbing and alkaline material such as red mud is added to the compost the mobility of the metals and other contaminants is reduced (Hofstede and Ho, 1991).

The use of red mud in urban refuse composting is being investigated in a joint venture between Alcoa of Australia Ltd., Perth City Council, Western Australian State Government and Murdoch University.

In the current work, red mud is mixed with municipal waste, at a rate of about 30% by weight, before the composting process.

6.2. Benefits

6.2.1. *Intensive animal industries*

Lining a piggery effluent pond with red mud ensures that leachate from the effluent is stripped of nutrients as it passes through the pond walls. This is particularly important in the first 12 - 18 months of pond life, after which the pond tends to be sealed by organic matter.

In one trial, the solids filtered from piggery effluent were separated by a filter screen, collected and sold as fertilizer and the liquid effluent passed to a treatment pond. Following biological treatment the pond effluent was collected in a tanker and spread onto paddocks. The effluent replaced artificial fertilizers on the property. Nitrogen and phosphorus levels from the piggery effluent were reduced by 92 and 96% respectively as the leachate passed through the pond walls in the first season of operation (Summers and Smirk, 1992).

A series of dairy effluent ponds have been designed and constructed for high water table areas which have clay soils and are often in irrigation areas. The high value of the land and the close proximity to drains makes compact treatment systems a necessity.

Ponds have been designed which are primarily for storage of fresh effluent, allowing evaporation of the liquid and subsequent use of effluent as a fertilizer. Red sand overflow channels have been constructed as a safety measure.

The dairy ponds were only commissioned in 1992 and the effectiveness of the red sand filter systems has not been measured because the ponds have not overflowed into these filters (Summers and Smirk, 1992).

Red mud removes microorganisms as well as phosphorus from effluent. It has been demonstrated that the concentrations of microorganisms *Escherichia coli, Salmonella adelaide* and poliovirus are reduced by eight orders of magnitude through a 65 cm column of 30% red mud and 70% Bassendean sand. The mechanisms that contributed to the removal included filtration, die-off and adsorption (Ho *et al.* 1986, 1987, 1991, 1992).

6.2.2. *On-site effluent disposal*

A domestic effluent treatment system has been tested by WAWA and removes up to 99% of phosphorus (15 ppm to < 0.1 ppm), up to 80% of nitrogen and 90% of BOD (250 to < 30). The aerobic treatment units have the added advantage of directly recycling the water onto the garden.

6.2.3. *Municipal sewage disposal*

At the Water Authority groundwater recharge basin trial in Kwinana, the removal of faecal coliforms and coliphage was several orders of magnitude greater than before the basin was amended with red mud (Ho *et al.* 1991). The bacterial counts in all the monitoring bore samples were within irrigation water quality standards (Ho *et al*, 1992). Phosphorus removal continued at about 50%. Nitrogen in the form of ammonium was removed, probably by adsorption onto the red mud, while nitrate nitrogen passed through. This removal of ammonium ions has also been found by other research (Robson, 1982).

The Pinjarra sewage treatment plant is expected to be operational by early 1993. Performance of the system to reduce nutrients and other contaminants will be monitored.

6.2.4. *Composting and mulching (urban refuse disposal)*

The benefits of composting with red mud are:

- Composting of municipal refuse without the problem of contaminants is an alternative to land fill.
- The final compost has greater stability and density.
- The half life of the organic fraction of the product is up to five times higher due to the formation of very stable clay organic complexes.
- Value adding of the product for sale by increasing the bulk of the product.
- Improved water retention, nutrient retention and buffering capacity.
- The large amount of CO_2 produced during decomposition is absorbed into the alkaline material in the red mud.
- Bauxite residue amendment dilutes and retains the heavy metals.
- Bauxite residue-compost has high adsorption capacity for fertilizers, increasing their efficiency and reducing run-off and ground and water pollution.
- Improved retention of ammonia from the composting process.

These benefits are documented elsewhere (Hofstede and Ho, 1992., Hofstede in prep.)

Reference sites for effluent and waste management are included in Appendix D.

6.3. Recommendations

On-site effluent disposal systems using red mud have been reviewed by the EPA, Health Department and the WA Water Authority and are subject to recommendations and requirements approved by those bodies and available from the Health Department. This process should continue.

Municipal effluent disposal systems are subject to individual assessment by the EPA and the WAWA. This process should continue. The Department of Agriculture is currently extending information on the diary effluent systems to farmers throughout the catchment. This process should continue.

6.3.1. *Composting and mulching (urban refuse disposal)*

The recommended maximum proportion of red mud in urban compost is 30% because above this level the composting process may be adversely affected.

7. Stormwater basins and drainage structures

7.1. Techniques

7.1.1. *Sumps and filters*

To reduce nutrient loss from agricultural properties runoff can be passed over and through red mud amended filters.

7.1.2. Subsurface drainage in clays

Poorly drained sites with heavy clay such as those around many dairies become boggy and respond well to subsurface drainage (Robillard, 1983). Subsurface drains reduce the export of nutrients by improving the contact of runoff with the soil and discourage surface runoff (Bengston *et al*, 1982, Schwab *et al*, 1980). Red sand has been suggested as a permeable and nutrient absorptive medium for lining subsurface drainage and for backfill into trenches for tile drains.

7.1.3. Stormwater basins

Lining of stormwater infiltration basins with 35% red mud (amended with gypsum) reduces nutrient loss from sub-divisions. The red mud is incorporated by rotary hoe to a depth of 0.3 m and lightly compacted (McAuliffe and Evangelisti, 1991).

7.2. Benefits

7.2.1. Sumps and filters

Treating sumps has the potential to retain phosphorus on the farm without the cost of treating the entire property.

Where subsurface drainage is used, soils are drier during winter and sustain better pasture growth which reduces phosphorus loss by encouraging uptake and acting as a vegetative filter. Also there is improved trafficability from subsurface drainage.

7.2.2. Stormwater basins

The red mud reduces the nutrient runoff, as well as reducing the BOD and suspended solids through filtration and removing many inorganic pollutants such as heavy metals.

Reference sites for stormwater and drainage structures are included in Appendix D.

7.3. Recommendations

The proportion of red mud for drainage structures and infiltration basins should be carefully designed to create a mixture which is suitably permeable for the purpose. Beyond about 30% the permeability is too low to allow adequate infiltration for many structures.

Where the infiltration basins are accessible to the public the red mud should be well mixed and covered with sand or dense vegetation to avoid dust and staining.

8. Construction material

8.1. Techniques

Red sand (residue sand) has drainage and compaction characteristics which make it a useful construction material for structural fill, such as house pads, and as a general landfill for a range of purposes. For example it has been suggested for use in the Kwinana region to reclaim disturbed areas such as limestone quarries. Residue sand has been used on one occasion as an alkaline backfill material to protect buried concrete drainage pipes in an highly acidic soil which was created by past waste disposal practices.

Red sand and red mud can be useful materials for road construction. Red sand can provide a strong sub-base layer and residue mud can be blended with limestone or other materials as a binder for roadbase and to improve adhesion of bitumen. Trials were carried out as early as 1980 in road base blends (Hartley and Thorpe, 1980, and Ludiera 1981). There has been renewed interest in recent years in those concepts and a Perth based construction materials company is currently working on the development of a binder using residue mud. They have had separate contact with the EPA.

These uses don't relate to the issue of nutrient control directly but in a number of cases the use of bauxite residue would provide incidental nutrient reduction.

8.2. Benefits

Red sand and red mud could be used to replace other sources of construction fill and road base which require the construction and expansion of quarries.

Shire Councils on the coastal plain are increasingly finding that sources of gravel for road building are diminishing, and gravel is often contaminated by the organism that produces dieback (*Phytophthora cinnamomi*). Red mud and red sand have the advantage that they are effectively sterilised by the caustic solutions used in alumina processing. Consequently, if used for roadbuilding there is no risk of dieback spread.

Reference sites for construction material are included in Appendix D.

8.3. Recommendations

The use of red mud for road base is subject to separate discussions between the EPA, the road materials construction companies and local government authorities. This process should continue.

The use of red sand for house pads or quarry backfill is under investigation and recommendations will follow those investigations.

9. Environmental impacts

The more widespread use of bauxite residue is being proposed primarily for its environmental benefits and to a lesser extent economic benefits. By seeking EPA approval for the more widespread use of residue, the Department of Agriculture is taking one step in a process aimed at achieving soil amendment of the bulk of the sandy soils of the Peel-Harvey catchment, and at treating point sources of effluent within the catchment. If achieved this will cause a major reduction in the amount of phosphate reaching the estuary without significantly affecting the economics of current land uses in the catchment.

These benefits need to be balanced against potential adverse environmental impacts which are associated with the following properties of bauxite residue:

• Because red mud and red sand are derived from the extraction of crushed bauxite by sodium hydroxide they are alkaline and saline.

• During processing, part of the alumina fraction is removed and there is a proportional increase in the concentration of naturally occurring trace materials such as heavy metals and radioactive elements.

This section outlines the impacts that may result from the increased use of bauxite residue and lists those constraints on the use of residue that are necessary to manage those impacts.

9.1. Nutrient loads

The Peel-Harvey Estuarine System has been recognised as being environmental degraded, largely as a result of high loads of phosphorus reaching the estuary from its catchment. A major program is currently underway, aimed at restoring the estuary to "health and resilience" (EPA, 1988).

The EPA has put in place a legal framework whereby the Department of Agriculture has a major role in catchment management. The overall aim is to achieve a reduction in phosphorus loads reaching the estuary, to a level that "shall not exceed 85 tonnes in more than four years out of ten" (Ministerial Conditions set 4/1/89). This level represents approximately half the annual load estimated by the EPA to have been reaching the estuary up till 1989.

At the time the Ministerial Conditions were set, there were few practical and effective means of reducing the phosphorus load to that extent. Bauxite residue is presented in this document as a major resource that can be used to improve the "health and resilience" of the Peel-Harvey Estuary, as well as reducing the nutrient loads reaching a number of smaller water bodies in the catchment.

Use of residue, as a soil amendment to reduce nutrient loads, has been discussed in previous publications (Hodgkin 1984, ERMP Stage 2, 1988). However, these were all at much higher rates of application than outlined in this document.

Hodgkin found that a "reduction in P loss in the Harvey catchment of 23% would be possible if the deep sands were treated and 57% if the Bassendean sands and Coolup (duplex soils) were treated". In the Stage 2 ERMP it was estimated that "The broad-scale amendment of cleared deep-grey sands in the catchment is estimated to be capable of reducing the phosphorus losses to the estuary by up to 25%".

It is now almost 5 years since that estimate was published, and considerable refinement of techniques and data has occurred. Soil amendment is now proven at economic rates, and phosphorus load reductions at those rates is well documented. Soil amendment has now been researched on a broader range of soil types, and in a greater number of "targeted" situations, such as sumps, filters and effluent ponds.

The research trials conducted since January 1990 have, in themselves, reduced phosphorus loads leaving the respective sites by over 4 tonnes.

Based on the information presented in this report, and in the publications referred to, it is estimated that 90,000 ha of deep grey sandy soils and 40,000 ha of sand over clay soils could be amended with bauxite residue. If this was to occur, this would give a 30% reduction in the phosphorus load estimated by the EPA to be reaching the estuary.

The actual area that does get amended will depend largely on the costs and availability of residue, and on farmer acceptance of soil amendment as a viable agricultural tool. Construction of sumps and filters in farming situations will be largely driven by the programs of various sub-catchment and landcare groups, a number of which are already undertaking drain improvement and associated activities.

Adoption of the practical and economical effluent containment systems that have been developed utilising residue has the potential to further reduce phosphorus loads from point sources by an estimated 5 to 10 tonnes. Systems utilising residue are the most practical and economic for most of these point sources. Therefore ready availability of residue is essential if improved management is to occur.

At the moment it is not possible to accurately estimate the scale at which residue will be used in the catchment, and the consequent environmental benefits. However, the Department of Agriculture is confident that use of residue will occur on a scale sufficient to reduce the amount of phosphorus entering waterways in the Peel-Harvey catchment by over 30 tonnes in the next decade.

Constraints: None for uses within the criteria set out in the proposal at the beginning of this document.

9.2. Transport and safety

Residue does not fall within the hazardous category for transport set down by the Department of Mines (1983, 1985). While residue is not hazardous by regulation, people handling residue should follow normal safety procedures for protection against particulates, ie, eye and respiratory protection. Caution should be taken to avoid any alkali that may not be properly mixed.

Any road spill of residue would only be hazardous in the sense that any bulk material (similar to a truck load of crushed gravel with 8% crushed limestone and 2% quicklime) is when spilled on a thoroughfare. Cleaning up the spill would be readily accomplished by commonly available equipment, such as a front end loader or bobcat and road broom.

As outlined in subsequent sections, the leachates from residue are not of sufficient toxicity to cause a hazard, beyond being a physical nuisance, even if a truckload of 20-40 tonnes was to be spilled into a sensitive site, such as a river foreshore or wetland.

Constraints: Normal safety procedures should be taken for protection against dust should be followed when handling and transporting bauxite residue.

9.2.1. Alkali content

Residue which is dry enough to be recovered for alternative uses, has a total soluble alkalinity of 25 to 35 g/L (70% solids). The alkalinity is mainly present as sodium carbonate with decreasing sodium hydroxide as it is exposed to air. In the fully carbonated state the pH of residue would be 10.8. When necessary for a particular end use, waste gypsum from CSBP can be added to the mud to further reduce the pH to 8.3 at which it is only mildly alkaline and not aggressive. Special care should be taken to avoid particles of unmixed or separated alkali getting into the eye. After spreading and rain this risk is neutralised.

Constraints: Normal safety precautions (as with lime or gypsum) should be observed. Wear goggles when handling fresh red mud.

9.3. Radiation

Bauxite contains naturally occurring radioactive minerals in trace amounts, as do many soils, rocks and minerals. When bauxite is processed, about a third of the material is removed as alumina, which is low in radioactivity. Subsequently, there is a proportional increase in concentration of radioactive materials in the residue.

Radiation studies were carried out on bauxite residue in 1982 and 1984 by Robert Stanford and Associates, and in 1989 by B.H. O'Connor. Based on O'Connor's work the assessment of bauxite residue is confined to gamma radiation effects because the contribution from other sources such as inhaled dust are likely to be negligible.

The radiation standard set down by the State Radiological Council is such that the public is not to be exposed to an increase in radiation of 1 mSv/year above natural background radiation (incremental dose).

The recommended rates of application covered in this document affect background radiation at levels that are too low to effectively differentiate them from background radiation on the Swan Coastal sandplain. This applies even when these dose rates are calculated for continuous exposure. An increase in dose of 1 mSv per year for continuous exposure (100% occupancy) would require the application of 1400 t/ha of red mud (O'Connor *et al*, 1991). The soils of the sandplain have a background level of 0.5 mSv/year (Toussaint, 1985). For red mud applied at 1400 t/ha the background level would increase to 1.5 mSv/year.

By way of comparison, the background levels of some suburbs in the Darling Scarp are between 2 and 3.5 mSv/year assuming 100% occupancy. Inside brick houses in Perth the level varies between 1 and 2 mSv/year (Toussaint, pers. comm.).

The following assessments are based on a report by O'Connor *et al*, 1991:

9.3.1. On-site effluent disposal

A leach drain amended with red mud (amended with gypsum) for on-site effluent disposal gives an annual incremental dose equivalent to < 0.1 mSv/year within the immediate confines of the system, assuming an occupancy limit of 10% (ie no-one lives on the drain for more than 10% of their life, or 2.4 hours per day).

9.3.2. Road construction

Even with the application of pure red mud for road construction (which is not advisable for engineering reasons) the highest conceivable dose is 1.39 μGy/hour, which is below the maximum limit of 1.63 μGy/hour for roads.

9.3.3. Transport

Materials are defined as radioactive within the meaning of the Australian Code of Practice for the Safe Transport of Radioactive Substances (1990) if the specific activity exceeds 70 Bq/g. The upper level of activity of red mud is 26 Bq/g and is exempt from the provisions of the code (O'Connor, 1991). In addition the combined concentrations of uranium and thorium (approx 300 ppm) do not exceed the notification limit of 500 ppm currently being considered by the Mines Radiation Board.

Constraints: Residue should not be used at levels above 1400 tonnes/ha in any area subject to 100% occupancy. Uses below this level are unconstrained.

9.4. Salts and trace elements

Bauxite, like soils in the Darling Range, naturally contains many trace metals which if mobilised could pose environmental risks. However, most of these elements are tightly bound in mineral compounds and require exceptional circumstances to be released, such as being immersed in concentrated acid. They will not leach under the circumstances likely following soil amendment.

In fact the absorbent qualities of residue for heavy metals can be of benefit. Red mud has been described as a good absorbent for arsenic from industrial wastewaters (Parekh and Goldberger, 1976) and is being used to absorb heavy metals in municipal compost (Hofstede and Ho, 1991).

9.4.1. Uptake by plants

9.4.1.1. Pasture plants

None of the elements arsenic, fluoride, chromium, nickel, cadmium, and lead accumulated to any significant extent in pasture plants grown in red mud (amended with gypsum) at 280 to 1680 t/ha in Western Australia (Ward, 1983, 1986). The uptake of heavy metals by plants from red mud has also been examined in tropical crop species in Suriname and the elements nickel, cadmium and lead were all below US EPA (1976) health standards.

9.4.1.2. *Vegetables*

The uptake of trace metals by vegetables is being studied by Ian McPharlin and Wendy Robertson of the WA Department of Agriculture. Table 3 shows their preliminary results on carrots, which demonstrate that red mud/gypsum does not raise the metal content greatly. In the case of nickel, lead and cadmium the levels actually fell because of red mud/gypsum.

Table 3. Average heavy metal contents of carrot leaves and roots (mg/kg fresh weight) grown in soil treated with up to 250 t/ha red mud/gypsum (Mud), compared with carrots grown without red mud (No mud).

Element	Leaves No mud	Leaves Mud	Roots No mud	Roots Mud	MRL
Cr	0.09	0.12†	0.02	0.02	
Ni	0.11	0.07*	0.04	0.025	
Pb	0.10	0.11	0.02	0.01*	2.0
Cd	0.02	0.005*	0.02	<0.01	0.05

MRL = maximum residue limit * significant decrease ($P < 0.05$)
† significant increase ($P < 0.05$).

Constraints: None within the rates of bauxite residue which have been tested (250 t/ha).

9.4.2. *Uptake by animals*

As documented elsewhere, the maximum recommended rate of residue application (unmixed) on pasture is 100t/ha. Naturally occurring soils derived from bauxite are commonly grazed along the Darling Scarp. When red mud is applied at 20 to 100 t/ha it represents 3 to 14% of the top 5 cm of soil. The slight increase in concentration of trace elements is caused by the removal of about a third of the bauxite as alumina. This increase is insignificant when compared with the dilution of red mud into amended soil.

A comparison of elements in naturally occurring soil and red mud (which can be seen in the tables in the appendix) shows that red mud, even undiluted, is within the range of most elements. When red mud is diluted in soil the final concentrations for all elements is similar to or less than naturally occurring soils. Stock grazing pasture on soils amended with red mud will ingest similar amounts of elements to stock grazing on naturally occurring soil.

The amount of soil a grazing animal consumes varies with the farming system used. The worst case of ingestion of soil occurs when sheep are forced to graze short pastures, where extreme cases have been recorded of up to 50% of the diet being soil. Cattle may take up to 10% of their diet (1 to 2 kg/day) if the pasture is short or muddy (Awad *et al*, 1989). A comparison of the maximum levels of trace elements which grazing animals can tolerate in their diet and the levels of these elements in red mud (which can be seen in the Appendix) shows that even if the animals had a diet of pure red mud these levels would not be reached.

Constraints: None for uses within the criteria set out in the proposal at the beginning of this document.

9.4.3. *Leachates and water quality*

Sodium sulphate is the major salt that leaches from red mud amended with gypsum (gypsum is calcium sulphate). Under current agricultural practices gypsum is commonly applied at 2 to 4 t/ha (equivalent to 20 to 40 t/ha red mud with 10% gypsum) as a soil conditioner and there is no restriction on its use in sensitive areas. Gypsum is not necessary when the red mud is applied at rates less than 100 t/ha, hence there will be no major source of sulphate in broadacre applications.

In a trial using Western Australian red mud and gypsum at 850 t/ha the concentration of the elements iron, aluminium, and cadmium in leachate was negligible. The salts leached to groundwater in one year were equivalent to 20 years of leaching by rainfall on an untreated soil, and would pose no significant impact when applied to the sandy agricultural soil in the catchment of an estuary. Fluoride from the waste gypsum was leached rapidly and reduced to background levels (< 1 mg/L) within one winter rainfall (Ho *et al*, 1989).

Another trial examined the potential pollutants: cadmium, aluminium, iron, arsenic, fluoride and sulphate, plus electrical conductivity, and pH, in leachates for Western Australian red mud applied to sandy soils at between 5 and 80 t/ha. The red mud was both without gypsum and with gypsum added (10%), and the leachate was within background levels or below maximum limits for drinking water, except fluoride when gypsum was applied. The concentration of fluoride that leached from the gypsum-amended red mud dropped to drinking water standard within seven months rainfall (Summers *et al*, 1992). The use of the drinking water standard is a very stringent comparison because there will be dilution with existing groundwater. Many manures and fertilizers produce leachates that will not meet drinking water standards.

The levels of cadmium and fluoride in leachate from Western Australian red mud and gypsum applied to sandy soils at between 500 to 2000 t/ha was below detectable levels and within the drinking water range respectively (Vlahos *et al*, 1989).

When red mud (amended with gypsum) was applied at 250 t/ha the leachate showed no detectable increase in radioactivity. The leachate from both the untreated and the treated soil was < 40 mBq/L (McPharlin *et al*, unpublished paper).

No discernible impact on water quality is expected as the scale of application increases. The loss of salts from amended soils has been found to be minor, and rapidly diminishing with time from the date of application. That is, the level of salts are insignificant in comparison with annual precipitation and existing levels in soils and groundwater (Summers *et al.* in press).

Constraints: None for uses within the criteria set out in the proposal at the beginning of this document. If bauxite residue is to be used on underground water pollution control areas, the Water Authority require the use to be referred to them.

9.5. Possible contamination from fungus or other soil borne disease.

In the process of extracting alumina, bauxite is crushed and then treated with concentrated, hot caustic soda, a process which effectively sterilises the residue. Apart from eliminating the possibility of the residue containing fungus or other harmful soil borne diseases, this sterility has a number of benefits. Nursery trials on native plants have shown red mud is a useful additive to sterile potting mixes. The use of red mud, especially in road construction, will reduce the transport of the disease dieback (*Phytopthora cinnamomi*). It is becoming increasingly difficult to find uncontaminated gravel to construct roads.

Constraints: None for uses within the criteria set out in the proposal at the beginning of this document.

9.6. Marine and freshwater impacts

Soluble salts, such as those that leach from residue, are common in aquatic systems.

Pure residue has been disposed of in marine environments in many countries. The main effect on marine and freshwater life has been through the physical effects of smothering and accumulation of particles on gills (Sigmond *et al*, 1980). This level of damage does not occur in any of the uses outlined in this report.

The application of residue to soil is not expected to result in runoff at levels likely to cause any impacts on aquatic organisms. This is discussed further in 10.7.

Constraints: None for uses within the criteria set out in the proposal at the beginning of this document.

9.7. Impacts on flora, fauna and ecosystems

The uses of residue proposed here are restricted to application on land that has been largely cleared of its original vegetation. Dispersal by dust is not expected to occur (see Section 9.9). Because the amended soils are sandy the residue does not move horizontally. This is due to a combination of the tendency of water to percolate downwards, and the fact that the paddocks are very level and runoff is slow and carries few particulates. Hence, flora and fauna adjacent to the areas of application will not be exposed to residue.

The biological communities which are likely to be exposed are downstream areas, which come into contact with salts from amended areas. Field trials and laboratory trials have shown that leachates from red mud treated soils have concentrations (Summers *et al.* in press) less than those commonly found in groundwater and runoff. The leachates are discussed in further detail in Section 9.4 3.

As discussed there, the only concern would be if gypsum amended residue were used. However, sulphates from gypsum are not expected to be added to residue for broad acre sites because it is not needed and it is too expensive.

The major impact of red mud will be to return the water based ecosystems of the Peel Harvey Estuary and its catchment to a more natural regime by reducing the phosphorus loadings that fuel eutrophication. In short, this proposal's main environmental impact is a beneficial one.

Constraints: Only cleared areas should be amended. Areas of remnant vegetation on farmland should be avoided. Gypsum need not be added to residue applied to broadacre situations.

9.8. Landscape and recreation values

Residue application does not adversely impact on landscape or recreational values. The levels of residue proposed in this report for broad acre application here are difficult to visually detect in the year after application, even when standing on the amended areas. The major effect of red mud is its reduction in flow of nutrients which feed algal blooms in the Peel-Harvey estuary, which will result in improved landscape and recreation values.

Trials are underway in the use of red mud in tree planting programmes where soil acidity and poor moisture retention are a factor in seedling mortality. This may result in increased tree and shrub cover in the catchment.

Trials are also underway in the use of residue to assist in the establishment of perennial pastures, which is often hampered by acid subsoils. If this work is successful, it may lead to greener paddocks in the summer, which will help return the hydrological regimes in the catchment to a level closer to that which existed before widespread clearing occurred.

Constraints: None for uses within the criteria set out in the proposal at the beginning of this document.

9.9. Nuisance effects - dust and staining

During trials in 1991, using ordinary superphosphate spreaders to distribute red mud, a visible dust plume was created. The dust can be avoided by surrounding the outlet of the spreader with a skirt.

Below application rates of approx. 50 t/ha. the normal vegetative cover is sufficient to virtually eliminate the possibility of significant dust levels occurring. Above 50 t/ha. the residue should be mixed into the surface, to reduce the possibility of dust blowing from the amended land. In bare soil situations, cover crops should be applied.

Because of its red pigment qualities, red mud can cause nuisance staining of carpets and furniture if brought inside on shoes etc. Similar problems exist with naturally occurring clayey soils and manures. The problem can be reduced by mixing soil when bauxite residue is applied.

Constraints: Measures to reduce major dust nuisance need to be taken during broadacre application. This is readily achievable. Special precautions are needed when applying residue in urban or rural residential situations. These involve ensuring residue is mixed into soil or similar immediately upon delivery.

9.10. Impact of haulage of red mud on roads

The Peel-Harvey ERMP suggested the use of red mud as a soil amendment at the rate of 200 t/ha, which was expected to cause significant wear and tear on roads in the catchment.

In fact, residue application, as outlined in this document, will be very infrequent as the effects of red mud are expected to last over five years. The average application rate of red mud on grazing land is expected to be about 20 t/ha which, when spread over five years, is similar to the amount of hay cut per hectare on the low lying sandy soils. Although not all the hay is transported around the catchment this comparison does bring the magnitude of transport involved with shifting residue into context.

Nevertheless, as much as 250,000 tonnes of residue may be trucked around the catchment in any one year, with the bulk of movement probably occurring in the autumn. Due to the location of the residue stockpiles, in relation to the soils that benefit most from amendment, it is anticipated that most truck movement will be on roads controlled by local government authorities.

The environmental benefits and the savings from the use of residue in the construction of roads are expected to broadly outweigh the increased costs of wear on roads. The Department accepts that no agency or local government authority should be expected to carry any unfair maintenance burden that may result from increased residue haulage. However the scale of residue use will largely be determined after assessment of this report by the EPA, and will need regular assessment and monitoring.

Following approval of this report by the EPA, the Department of Agriculture will negotiate with the Main Roads Department and local government authorities an appropriate mechanism to ensure that residue transport does not cause undue problems for them.

Constraints: Haulage of residue can only proceed with the agreement of the Main Roads Department and local government authorities.

10. Public participation and consultation

Involvement of the local community has been a feature of the soil amendment program virtually since its inception. There has also been considerable media coverage.

Early in the 1980s a number of large field trials were conducted to demonstrate heavy applications of residue as a possible alternative to its disposal in stockpiles. There were field days, publications and press releases with the involvement of farmers, Alcoa of Australia, and the Western Australian Department of Agriculture. Residue application was outlined in the Peel-Harvey ERMP (Stage 2). However, the rates of application proposed (above 200 t/ha) were considered too expensive and impractical.

A meeting of representatives from a number of landholder groups, Alcoa, and Agriculture Department researchers was held at the Community Catchment Centre in December 1990, largely because of interest in soil amendment amongst landholders.

Since that time a number of trials have been set up in response to requests from groups and individuals throughout the catchment, and many of these trials have been detailed in this document. There have also been more than 24 articles in local, state, interstate and international newspapers and magazines. There have been many talks, some radio and television interviews, and seminars to landholder groups and local government authorities to explain the use of residue and the results of trials.

Additionally, requests for residue have been received from landholders at a rate of about two per week. This is not including referrals from the EPA, who have approved or specified residue use in a number of developments assessed by them.

In summary, community and landholder involvement has been an integral part of the development of the soil amendment and effluent treatment programmes.

Following review of this document by the EPA, and setting of conditions for the more widespread use of residue, the Department of Agriculture will be responsible for maintaining a high level of landholder and general community awareness of residue use.

This will be achieved by:
- programs for amendment of large areas to be arranged through landholder groups, such as Land Conservation District Committees and general catchment and landcare groups.
- publication of farmnotes specifying guidelines for residue use.
- publication of a question and answer sheet for the general public on residue and its benefits.
- offers being made to discuss the program with all local government authorities and landholder groups in the catchment.
- continued promotion through the media.
- continued scientific research and publications.

11. Operational management issues

As residue is not defined as a dangerous material for transport, there are no contingency plans for accidents. Spilled loads would be a physical nuisance only, which could be easily remedied by use of conventional and readily available equipment, such as front end loaders. However, persons handling residue should take precautions such as eye and respiratory protection to avoid dust and unmixed particles of alkali.

Potential industrial contaminants are listed in Section 9.4. In bauxite residue, as defined in this document, these contaminants will not cause adverse environmental impacts.

12. Management commitments

Following public discussion of this document, and assessment by the EPA of the points contained within it, the West Australian Department of Agriculture will accept commitments binding it to:

1. Commencing negotiations with Alcoa of Australia Limited which, if successful, will produce a Code of Practice and management structure enabling the widespread use of bauxite residue for nutrient control in the Peel-Harvey coastal plain catchment.

2. Maintaining, in conjunction with other agencies and institutions, and to the satisfaction of the EPA, a program of strategic monitoring of residue use and its benefits and impacts, under the program established through the Codes of Practice.

3. Providing the EPA and the general public with regular reports outlining the use and distribution of bauxite residue, under the program developed above and produce a major review of the program for EPA assessment within ten years.

None of the above commitments should be read as impinging on any separate arrangements Alcoa of Australia Limited may choose to make between itself, other interested parties, and other government agencies, regarding the sale, use and distribution of bauxite residue.

13. References

Included are references in the text as well as background information inlcuding a brief abstract where relevant.

Awad, A. S., Ross, A. D. and Lawrie, R. A. (1989). Guidelines for the use of sewage sludge on agricultural land. NSW Agriculture and Fisheries.

Australia and New Zealand Environment and Conservation Council, National Health and Medical Research Council. (1992). Australian and New Zealand guidelines for the assessment and management of contaminated sites. January 1992.

Baker, D. B. (1986) Impacts of cropland runoff on nutrient and pesticide in river systems, in The offsite costs of soil erosion. Ed. Waddell T. E.Washigton D. C. USA Conservation Foundationp 63-80.

Barrow, N. J. (1982). Possibility of using caustic residue from bauxite for improving the chemical and physical properties of sandy soils. Australian Journal Agricultural Research, 33:275-285.

> *The cation exchange capacity of red mud increased with pH, the adsorption of phosphate decreased, and the adsorption of cadmium increased. A pH of just above eight seemed to provide a good combination of desirable properties. This could be achieved by exposing the red mud to air and mixing it with gypsum - also available as a waste product. Carbon dioxide was absorbed by the alkali in the red mud, and then precipitated by the gypsum as calcium carbonate. This released sodium sulphate which could be leached from the mud. Medic species could be grown, provided that phosphate, potassium and manganese were supplied. Residual sodium sulfate from incomplete leaching seemed to limit growth of the other species.*
>
> *There seems to be a good potential to use the amended red mud to improve the water holding properties and the chemical properties of sandy soils of the WA coastal plain.*

Bayer, G. and Chardron, E. (1974). Red mud flocculation for waste treatment. Ger. Offen. 2:242 811 9pp, March 14 1974.

Bengston, R. L., Carter, C. E., Morris, H. F., Kowalczuk, J. G. (1982). Subsurface drainage improves water quality. Proceedings of the Specialty Conference on Environmentally Sound Water and Soil Management [edited by Kruse, E.G., Burdick, C.R., Yousef, Y.A.]. 1982, 106-112, 9 ref., 5 tab. New York, USA, American Society of Civil Engineers.

> *A subsurface drainage-runoff-erosion experiment on clay loam alluvial soil near Baton Rouge, Louisiana, was conducted in 1980 and 1981. The experiment consisted of four plots, two of which were subsurface drained. From June 1, 1980, to December 31, 1981, surface runoff was reduced 17%, soil erosion 17.3%, phosphorus loss 48%, and potassium loss 22% by subsurface drainage.*

Binnie and Partners. (1988). Public environmental report for proposed upgrades of existing North Dandalup abattoir. Public report to EPA, April 1988.

> *Gives P capacity of red mud: at 2000 t/ha 90-99% of P applied at 275 - 1170 kg P/ha. The experiments suggest that the red mud can absorb 2.5 to 3.0 kg P per tonne red mud before the red mud is saturated.*

Modification of sand with neutralised red mud was shown to increase P adsorption to about 90% and reduce hydraulic conductivity by about 50cm/day (M. Kayaalp, pers. comm.).

Birch, P. B. (1982). Phosphorus export from coastal plain drainage into the Peel-Harvey estuarine system of Western Australia. Australian Journal Marine and Freshwater Research, 33:23-32.

Bowman, Bishaw, and Gorham, Consultants. (Undated-estimate early 1991). New design for a low profile septic tank leach drain incorporating high performance leachate renovation.

Specifications in internal report. The document describes a new system for disposing sewage effluent (septic tank effluent) on-site. It is suitable for domestic scale or could be used for larger scale application.

The design incorporates red mud into a standard leach drain to give a long life to removal of phosphorus. Can be used in areas of high water table. Nitrogen removal may be possible with refinement. Low profile practical and economical.

Uses an impermeable plastic liner below the leach drain to stop rapid downward percolation and encourage horizontal diffusion through a red mud layer.

Includes explanatory information for the Ecomax-1 septic system.

Considine M. L. (1985). Industrial wastes with potential. Ecos, 45 Spring, 1985.

Deeney, A. C. (1989). Geology and groundwater resources of the superficial formation of the coastal plain between Pinjarra and Bunbury. Hydrology Report No. 1988/5 GSWA File No. 323/80. Geol. Survey of WA, Perth.

Dethlefsen, V. and Rosenthal, H. (1973). Problems with dumping of red mud in shallow waters. A critical review of selected literature. Aquaculture, 2, 267-280.

German aluminium producers wanted to dump their wastes directly into the North Sea. Several experiments were carried out to assess the effects on marine organisms. Red mud dumped directly, and in high concentrations, proved to be harmful with the most predominant effect being agglutination of gill tissues and through the physical and mechanical properties of red mud in high concentrations. The dumping project was refused. There were no objections to the dumping of red mud into less confined waters.

Department of Conservation and Environment: report No. 9 - The Peel-Harvey Estuarine System Study (1976-1980). December 1990.

Department of Conservation and Environment: Bulletin 160. February 1984. Potential for Management of the Peel-Harvey Estuary. Proceedings of the Peel-Harvey Study Symposium, University of WA, 28-29 November 1983.

Department of Conservation and Environment, Perth, Western Australia: Bulletin 170 Management of Peel Inlet and Harvey Estuary. Report of research findings and options for management. May 1984.

DCE. (1985). Management of the estuary: Proceedings of a Symposium at the University of Western Australia, February 1985. Department of Conservation and Environment, Bulletin 195, July 1985.

Department of the Environment. (1989). Code of practice for agricultural use of sewage sludge. Her Majesty's Stationery Office, London.

Department of Mines. (1983). Explosives and Dangerous Goods Act 1961-1984. Dangerous Goods (Road Transport) Regulations 1983.

Department of Mines (1985). Transport of dangerous goods: understanding the Dangerous Goods (Road Transport) Regulations 1983.

Department of Planning and Urban Development: Draft Peel Regional Plan. October 1990.

Department of Planning and Urban Development: Statement of Planning Policy for the Peel-Harvey Coastal Plain. 1991.

Environment Canada. (1991). Review and recommendations for Canadian interim environmental quality criteria for contaminated sites. Scientific Series No. 197. Inland Waters Directorate, Water Quality Bransh, Ottawa, Ontario.

EPA. (1988). Proposed upgrading of existing North Dandalup abattoir. Clover Meats. Department of Conservation and Environment, Bulletin 349, September 1988.

EPA (1988) Peel Inlet and Harvey Estuary management stategy environmental review and management programme Stage 2, Report and Recommendations of the Environmental Protection Authority Part I. Bulletin 363, November 1988.

EPA. (1992), Draft Environmental Protection (Peel-Harvey Estuarine System) Policy - March 1992

Glenister, D. (1990). Particle size distribution of red mud residue.

The particle size distribution for the red mud and red sand is given, also the distribution of both parts of the residue is given as mixed. The red mud fines are nearly all in the silt fraction.

Glenister, D. J. (1984). The application of bauxite residue to reduce phosphate loss in the Peel-Harvey catchment. Alcoa report.

In 1983 the estimated cost of preparing red mud soil amendment was \$4 to \$5 per dry tonne of residue. These costs could not be supported by the alumina industry.

The process of mixing bauxite residue into the topsoil may stabilise residual phosphorus present in the top 150 to 200 mm of soil as well as intercepting newly applied phosphorus.

Glenister, D. J. (1986). The application of bauxite residue to reduce phosphate loss from sandy soils - an update. Colloquium on Peel-Harvey Estuary, 15 December, 1986.

Over the past ten years Alcoa has investigated the application of bauxite residue to sandy soils as a means of improving agricultural production and reducing the leaching of phosphorus to groundwater. Laboratory research by Murdoch University and CSIRO and field trials set up and monitored with assistance of the Department of

Conservation and Environment, Department of Agriculture and Botany Department of the University of Western Australia have confirmed increased pasture yield and reduced phosphorus leaching.

Monitoring of the paired catchment "farm scale" trial at Serpentine was continued during 1985-86. Two years of post-treatment data is now available and monitoring will continue until 1988. Pasture production on the amended Gavin sands is 90% higher than the unamended plot while no significant increase was recorded in the Joel areas. Significantly lower levels of phosphorus in the groundwater beneath the amended plot and lower phosphorus in surface run-off from it was measured.

Glenister, D. (1985). The application of bauxite residue to reduce phosphate loss in the Peel-Harvey catchment. Management of the estuary: Proceedings of a Symposium at the University of Western Australia, February 1985 Department of Conservation and Environment, Bulletin 195, July 1985, p 85-92.

Bauxite residue following neutralisation by gypsum or ferrous sulphate can be mixed with sandy soils to improve moisture and fertilizer retention.

500 t/ha red mud reduces leaching by two orders of magnitude. Theoretically much lower rates should be sufficient to retain applied phosphorus.

Red mud may stabilise P present in the soil surface.

Red mud should be available in a five year time frame.

Suggests the use of red mud as a pre-requisite for future uses of land, present uses may not be able to afford it.

Hartley Thorpe. (1980). Alcoa of Australia Ltd. Pinjarra Refinery, red mud stabilised limestone road base trial. A report to Alcoa by Hartley Thorpe Consulting Chartered Engineers, West Perth.

Ho, G. E. (1989). Overcoming the salinity and sodicity of red mud for rehabilitation and reuse. 43rd Purdue Industrial Waste Conference Proceedings, 641-649.

Theoretically only 0.5% gypsum is needed to neutralise red mud's high pH. 4% gave about the maximum neutralisation. The gypsum increased the leaching of salt.

Copperas waste from the titanium industry is also discussed as a neutralising agent for red mud.

Ho, G. E., Gibbs, R., Mathew, K., and Newman, P. W. G. (1987). Red mud research at Murdoch University. Bacterial removal from infiltrating effluent in sand and red mud columns. Report to Water Authority of Western Australia and Water Research Foundation of Australia, February 1987.

The removal of Salmonella adelaide, indicator bacteria (E. coli, faecal coliform and faecal streptococci) and bacterial viruses from secondary effluent by Spearwood and Bassendean sands and their mixture with red mud and gypsum was determined in 15cm diameter 70 cm soil columns.

Significantly higher removal of all the microbes tested occurred in the amended sands. The higher removal was likely caused by the

reduction in infiltration rate (hence higher residence times) filtration and adsorption.

Tests using poliovirus and rotavirus are recommended to ascertain the removal of these human viruses in red mud/gypsum amended sands.

Ho, G. E., Gibbs, R., Mathew, K., and Parker, W. F. (1992). Groundwater recharge of sewage effluent through amended sand. Water Research. 25(3) 285-293.

The performance of a groundwater recharge basin at the Kwinana Groundwater Recharge Site in Western Australia was monitored between 1983 and 1986. A primary aim of the monitoring programme was to study the improvement in the removal of faecal coliforms and nutrients (nitrogen and phosphorus) by amending the sand of the recharge basin with gypsum neutralised red mud (fine bauxite refining residue).

The study consisted of five operating stages. Stage 1 was a baseline study using unamended sand. Stages 2-5 were after sand amendment with red mud. Continuous flooding and flooding drying regimes were studied with primary and secondary effluents.

Phosphorus removal was maintained at a high level (over 80%) in all of the stages after the sand amendment. Faecal coliform removal was generally excellent, except at the beginning of each stage when primary effluent was used, and only a thousand-fold reduction was achieved. Removal improved with time and most monitored bore samples contained no faecal coliforms/100mL. With one exception the groundwater met water quality criteria for irrigation.

Nitrogen removal of approximately 45% was obtained with primary effluent using a cycle of flooding and drying (Stage 3). Continuous primary effluent (Stage 5) did not improve denitrification. No nitrogen removal was observed with a mixture of two-thirds secondary effluent and one-third primary effluent.

Ho, G. E., Mathew, K., and Newman, P. W. G. (1989). Leachate quality from gypsum neutralised red mud applied to sandy soils. Water, Air and Soil Pollution, 47(1-2):1-18.

Mixtures of fine bauxite refining residue (red mud), waste gypsum and sand that are proposed to be used in a catchment nutrient management programme, were watered simulating rainfall over a period of two years and the quality of the leachate determined. The major salts released were sodium sulfate, a product of alkalinity neutralisation by gypsum, and excess gypsum released at its solubility concentration.

At an application rate of 850t/ha of red mud the additional salts to the groundwater amounted to 20 times that with no red mud application (from rainfall), and posing no significant impact when applied to the sandy agricultural soils in the catchment of an estuary (40 kg salt / tonne of red mud). The leaching of Al, Fe and Cd from the red mud gypsum was minimal, while the retention of superphosphate was considerably enhanced (99%). Fluoride from the waste gypsum was leached rapidly and reduced to background (less than 1mg/L) within one winter rainfall. Most of the F came from the Gypsum. Cd was less than 0.02mg/L after the first two waterings.

Ho, G. E., Mathew, K. and Gibbs, R. (1992). Nitrogen and phosphorus removal from sewage effluent in amended sand columns. Water Research, 26(3) 295-300.

Column experiments were conducted to examine the removal of phosphorus and nitrogen from sewage effluent by passage through sand amended with bauxite refining residue (red mud). Red mud was neutralised with 5% gypsum. The study was conducted in two parts. In part 1 the removal of nitrogen and phosphorus in mixtures of 30, 20, and 10% red mud in sand was compared. Cycles of 10 days flooding with secondary effluent and 18 days drying were used. An average of 24% nitrogen removal was obtained with 30% red mud, 9% removal with 20% red mud and very little removal with 10% red mud. An average of 91% phosphorus removal was obtained with 30% red mud, 63% removal with 20% red mud and 50% removal with 10% red mud. The decrease in phosphorus and nitrogen removal with decreasing red mud content was caused by a decrease in adsorption capacity of the soil and an increase in the infiltration rate. In part 2 the use of primary and secondary effluents was compared. Phosphorus removal was excellent using both effluents in columns packed with 30% red mud. Nitrogen removal continued to be poor using secondary effluent (16%) but was significantly greater using primary effluent (74%).

Ho, G. E., Mathew, K., Gibbs, R. and Newman, P. W. G. (1985). Red mud research report: recharge column experiment. Environmental Science Department Murdoch University Report. Unpublished report November 1985 (1982-1985).

An average of 24% nitrogen removal over eight cycles was obtained with 30% red mud gypsum, 8% removal with 20% red mud gypsum and very little with 10%. The latter was due to the low adsorption capacity of the soil and the high infiltration rate through it.

An average of 91% phosphorus removal was obtained with the 30% red mud gypsum, 63% removal with 20% red mud gypsum and 50% removal with 10% red mud gypsum. A lower adsorption capacity and a higher rate of infiltration were again the reason for the higher phosphorus leakage in the latter case.

The use of primary effluent is recommended in future experiments to reduce the infiltration rate and to supply more organic carbon to enhance the rate of nitrogen removal by denitrification.

Ho, G. E., Mathew, K., Gibbs, R. and Newman, P. W. G. (1986). Phosphorus retention and leaching in red mud amended sand columns. Red mud research report, Environmental Science, Murdoch University, February 1986. Report to Alcoa and Water Authority of Western Australia.

The Spearwood sand was leached with distilled water and the leachate produced contained an average concentration of 2 mg P/L. When leached with the alkaline leachate from red mud and gypsum the concentration of P from the Spearwood sand increased to an average of 7mg/L.

The second experiment investigates the adsorption of P from solution by RMG, and the subsequent leaching of the adsorbed P by distilled water. Breakthrough of P occurred after 20 pore volumes when 10% of the ultimate P adsorption capacity was reached, with the remainder of the capacity reached slowly, up to 750 pore volume. The ultimate capacity is between the capacities obtained from batch experimentation with contact times of one hour and one day.

Subsequent leaching with distilled only released 14% of the adsorbed P.

From the results of the columns experiments we can deduce that P in pans and monitoring bores at the Kwinana recharge site after application of red mud and gypsum must have come from P leaching from sand beneath the basin and not from the red mud.

Ho, G. E., Mathew, K., Gibbs, R. and Newman, P. W. G. (1986). Red mud research report: groundwater recharge study at Kwinana. Research report to Alcoa and Water Authority, February 1986.

A pilot scale study at Kwinana groundwater recharge basin to determine the removal of bacteria and nutrients from sewage effluent when Spearwood sand in the basin was amended by red mud.

A 30% red mud gypsum mix (5% gypsum by weight) incorporated into 1 metre of sand in the basin resulted in too low an infiltration rate (<0.1 m/day). Faecal coliforms and coliphage were completely removed during infiltration. About 50% removal of phosphorus was observed, most ammonium was nitrified, but no denitrification was apparent under flooding and drying regime of operation.

The basin was repacked with a lower 20% red mud gypsum content and gave satisfactory infiltration rates (1.0 to 0.2 m/day) even under continuous flooding over 100 days. The removal of faecal coliforms and coliphage was several orders of magnitude greater than before the basin was amended by red mud and gypsum. The bacterial counts in all the bore samples were within drinking water quality standards. Phosphorus removal continued at about 50%. Ammonium was nitrified even under continuous flooding of the basin, expected to enhance anaerobic conditions and furthermore no denitrification was observable.

It is recommended that the basin be operated with primary effluent to increase the organic carbon that would enhance denitrification.

Ho, G. E., Newman, P. W. G., Mathew, K. and de Potter, H. (1985). Neutralisation of bauxite processing residues with copperas. CHEMECA.

Ho, G., Gibbs, R., Mathew, K., and Newman, P. (1986). Bacteria and virus removal from infiltrating effluent in sand and red mud columns. Report to WA Water Authority and Water Research Foundation

The bauxite residue and gypsum mix (5% by weight) was incorporated into soil columns (30%) and removed the three organisms with a seven to eight orders of magnitude drop in numbers from the original solution.

Filtration die-off and adsorption by the soil all appear to play a role in the organism removal. The results also show that E. coli. can be used as an indicator for bacteria contamination, though S. adelaide was less efficiently removed than E. coli. Poliovirus was, on the other hand, better removed than E. coli.

Ho, G., Gibbs, R., and Mathew, K. (1991). Bacteria and virus removal from secondary effluent in sand and red mud columns. Water Science Technology, 23, 262-270.

Column experiments were conducted to determine the improvement in the removal of Escherichia coli, Salmonella adelaide and poliovirus-1 through sands amended with bauxite refining residue. The residue *(red mud) was neutralised using 5% gypsum and incorporated to form 30% of the amended sands. In 65 cm long soil columns the removal of the three organisms in the amended sand columns was excellent with over seven orders of magnitude reduction in concentration. Removal in unamended sands was poor. From breakthrough curves in unamended sand columns filtration, die-off and adsorption all appear to play a role in organism removal. The results also show that E. coli can be used as an indicator for contamination, though S. adelaide was less efficiently removed than E. coli. Poliovirus was on the other hand better removed than E. coli.*

Ho, G., Robson, B., de Potter, H., Robertson, W., Wong, J., Mehlika. (1988). Inventory of red mud research reports from Murdoch University. A two page sheet by Goen Ho. All the research carried out at Murdoch University up to April 21 1988.

Hodgkin, E. P. (1984). Potential for management of the Peel-Harvey estuary: Peel-Harvey symposium. Proceedings of the Peel-Harvey Study Symposium held at the University of Western Australia, 29-29 November 1983, compiled by Hodgkin, E. P., Department of Conservation and Environment Bulletin No 160, March 1984.

Bauxite residue soil amendment- application rates of 1000-2000 t/ha has been suggested but rates as low as 200 t/ha may reduce P leaching. Up to a ten-fold increase in pasture productivity may occur on deep sands. A reduction in P loss in the Harvey catchment of 23% would be possible if the deep sands were treated and 57% if the Bassendean sands and Coolup (duplex soils) were treated. Costs would be $4/t for 40km cartage to load spread and cart a rate of 200t/ha this would cost $800/ha. Transport costs account for 50% of the total cost - the pumping of slurry of approximately 45% solids may be cheaper.

Hofstede, H. and Ho, G. (1991). The effect of addition of bauxite refining residue (red mud) on the behaviour of heavy metals in compost. In Heavy Metals in the Environment, Edited by Vernet, J. P. Elsevier, Amsterdam.

Hofstede, H. and Ho, G. (1992) Red mud for production of novel clay compost from organic waste. International Bauxite Tailing Workshop W.A. Nov 1992, 356-365.

Jardine, E. St. A. (1977). Prospects for disposal of red mud from Jamaica alumina refineries. Joint Conference of Clay Minerals Society and ICSOBA, Kingston, 1977, 32p.

Kayaalp, M., Ho, G., Mathew, K. and Newman, P. (1988). Phosphorus movement through sands modified by red mud. Water, March, p26-29,45.

Phosphorus retention of red mud was found to be 1.68 g of phosphorus per kilogram of red mud and gypsum mix (10% gypsum) in column experiments where the P concentration was 9.5mg/L on a continuous flow of 50 cm/day for 750 pore volumes. Batch tests indicate no P was desorbed however in flow experiments 14% of P desorbed. During flooding and drying episodes 91% of P removal occurred through 30% red mud gypsum with Bassendean sand, 63% of P removal through 20% RMG, and 10% RMG continued to absorb phosphorus even after the calculated capacity had been exhausted at 50% of P input.

Initially previously applied phosphorus would be leached because of the alkaline leachate from the overlying red mud displacing the phosphorus.

In general P removal by renovated soils seems high.

Kinhill Engineers (1988): Peel Inlet and Harvey Estuary Management Strategy Environmental Review and Management Programme Stage 2. Department of Marine and Harbours, Department of Agriculture. Report and Recommendations of the Environmental Protection Authority. Part I and II. EPA Bulletin 363, November 1988.

Knight R.: The role of perennial plants in reducing the movement of phosphorus from pastures to waterways in Western Australia. Department of Agriculture, November 1990.

Lester, J. N. (1987). Heavy metals in wastewater and sludge treatment processes. Volume 1, Sources, Analysis, and Legislation. CRC Press Inc. Boca Raton. Florida.

Ludera, V. (1981) Road base course stabilisation using Alcoa red mud. Alcoa report, Sept. 1981.

McAuliffe, T. F. and Evangelisti. (1991). State of the art innovations in stormwater quality control basins. Local Government Engineers Association of W. A. Eighth State Conference Perth 1991, Technical Papers, Volume 2.

Two technical reports on cost-effective options for improving water quality control performance of stormwater basins. Both crushed limestone and bauxite residue are examined and compared for their nutrient stripping potential when incorporated in infiltration basins.

The PRI for different mixes of red mud and sand were compared. The proportion of P adsorbed was found and compared with limestone.

McPharlin, I. R., Jeffery, R. C., Toussaint, L. F. and Cooper, M. (1992) P, N, and radionuclide retention and leaching in a Joel sand amended with red mud/gypsum. To be submitted to A. J. S. R.

The leaching of P, N, and radionuclides (232Th, 226Ra, 228Ra, 40K) from Joel sands amended with red mud/gypsum (RMG) at 9 rates (0, 2, 4, 6, 8, 16, 32, 64, 128 and 256 t/ha) was measured using columns. Intense leaching conditions (34 mm/day for 12 days) and a high rate of applied phosphorus (P 320 kg/ha as superphosphate) and nitrogen (680 kg/ha as ammonium nitrate) were used to simulate irrigated vegetable production on the Swan Coastal Plain. At the highest rate of RMG (256 t/ha) leaching of fertiliser P and ammonium-nitrate was reduced 85% and 50% respectively compared with 0 t/ha after 12 days. Nitrate-N leaching was not affected by addition of RMG. P retention in the soil increased with rate of RMG to > 50 µg P/g soil (bicarbonate extractable P) at 256 t/ha. This indicates that soil testing of residual P could be used to reduce P inputs to vegetable crops on RMG amended soils.

The increase in 232Th specific activity in Joel sand amended with RMG was well below safety limits even at the highest rate. Neither 40K not 226Ra were detectable in RMG amended sands up to 256 t RMG/ha. There was no evidence of leaching of 226Ra or 228Ra at any rate of RMG. These results suggest that the use of RMG amendment on horticultural properties on the Swan Coastal Plain could be possible and needs to be evaluated further.

National Health and Medical Research Council. (1987). MRL Standard. Standard for maximum residue limits of pesticides, agricultural chemicals, feed additives, veterinary medicines and noxious substances in food. Australian Government Publishing Service, Canberra.

O'Connor, B. H., Fox, D. R., Glenister, D. J., Chesson, B. J., Summers, K. J. and Smirk, D. D. (1991) Radiological evaluation of proposed end-uses of solid residue from bauxite processing. Report to the Radiological Council of Western Australia.

Parekh B. K. and Goldberger W. M. (1976). An assessment of technology for possible utilization of Bayer process muds. US Environmental Protection Authority Series EPA 600/2-76-301, December 1976.

A possible use of red mud is as a coagulant for the treatment and sedimentation of municipal wastewaters and for sludge flocculation. This was done on a commercial scale in England before the war (Ellis, 1947). The process involves treatment of the red mud with concentrated acids, the drying at modest temperatures and crushing to give a granular product.

Either sulphuric or hydrochloric acids can be used to convert the iron and aluminium salts to sulphates or chlorides. This ferric chloride or alum can be produced which are well known for their coagulating properties. In addition to these effects, it has also been reported that the red mud materials are effective in removing phosphorus from municipal wastes with 70 to 80% effectiveness.

Patel, C. B., Jain, V. K. and Pandey, G. S. (1986). Micropollutants in red mud waste of aluminium plant. International Journal Environmental Analytical Chemistry. 25, 269-274.

Chemical analysis of a number of red mud samples collected at different points in red mud ponds, at different periods, have been carried out, and the concentrations of the micropollutants determined to assess their probable impacts on the soils and water of the adjoining areas.

Peel-Harvey Catchment Support Group: Sustainable land and water use in the Peel-Harvey Coastal Catchment - Draft catchment management plan. January 1991.

Robertson, W. J. (1990).The germination of carrot seeds (cv. 'western red') in a virgin Joel sand mixed with red mud/gypsum. Unpublished report Western Australian Department of Agriculture.

Carrot seeds were sown with 0, 250, and 1000 t/ha red mud amended with 5 % gypsum.

EC(25) of 308 mS/m before sowing and > 120 mS/m after 12 days of leaching at 100 t/ha with a pH increase from 6.2 to 8.3 there was no significant difference in germination.

Robertson, W. J., Jeffery, R. C. and McPharlin, I. R. (1990). Gypsum-amended 'red mud' increases phosphorus retention of sandy soils without reducing yield of causing contamination of carrots. A paper was presented at the Bauxite Tailings Workshop, November 1992, Perth.

The leaching of phosphorus (P) from sandy soils on the Swan Coastal Plain causes eutrophication of local waterways. Carrots were grown on soil amended with gypsum neutralised red mud (RMG) applied at rates ranging from 0 to 240 t RMG/ha in order to reduce P leaching. Applying RMG at rates of > 60 t/ha increased bicarbonate extractable P 2.5 times compared with 0 t/ha. The phosphorus *retention index was increased from 1 at 0 t/ha to 10 at 250 t RMG/ha. Retention of fertilizer P in the top 15 cm of the soil increased from 14% of applied P (160 kg P/ha) at 0 t RMG/ha to 100% at > 60 t RMG/ha. Uptake of P during the first half of growth was reduced by the presence or RMG, P retention, P uptake and pH/Ca supply are discussed. Neither radiation nor heavy metals appear to pose health problems for carrots grown on RMG at these rates. Target-P levels which hold sufficient P for maximum yield of carrots were achieved. RMG amendment of poorly buffered grey sands increases P retention ability to allow soil testing to be used in fertiliser management.*

Robillard, P. D.,Walter, M. F. and Hirazumi, M. (1983). Phosphorus control alternatives for dairy barnyards. Technical paper No 83-2546, American Society of Agricultural Engineers, St Joseph Michigan.

The control of water from the property is the main interest of the paper. The diversion of roof runoff in the deep aquifer below the impermeable layer was successful and the drainage of wastes from the area by tile drain was also successful and enhanced the trafficability of the area.

Robson, B. J. (1982). Use of Bayer process solid residue (red mud and process sand) for the renovation of wastewater - in particular the removal of ammonium. Masters (MSc) thesis in Environmental Engineering, School of Environmental and Life Sciences, Murdoch University WA, August 1982.

Previously soil has been used to remove ammonium ions from wastewater. This relies on the cation adsorption capacity of the soil.

In Perth WA the local soil has very little adsorption capacity. This work investigates the potential of alumina refinery residues (red mud and process sand) to be used for removal of ammonium from wastewater.

A mix of 32% red mud and 68% process sand has been shown to give the required percolation rate and to satisfactorily remove ammonia from the simulated wastewater. The resultant effluent has a high pH and sodium content rendering the treated effluent suitable for use only with industrial process or to prevent saline intrusion.

A major portion of the adsorption takes place very quickly, but is dependant upon ammonia concentration.

The effluent after passing through the red mud not amended with gypsum has too high a pH and is too saline for either agricultural or domestic purposes.

Scheffer, B., Bartels, R. and Blankenburg (1985). Practical application of red sludge and melanterite ($FeSO_4$) on bog peat soils. Zeitschrift fur Kulturtechnik und Flurbereinigung, 148, 527-535.

A new way is shown to dispose the industrial by-products red sludge and melanterite by agricultural application. The ferrous products absorb the moveable phosphates in the acid bog peat soil, so that they are still available for plants, but will not or only a little leach. In a field trial the amount of leached phosphorus could be reduced by about 80%. The agricultural use of red sludge and melanterite is thereby at the same time a contribution to reduce the pollution of surface waters.

Scheffer, B., Kuntze, H. and Bartels, R. (1986). Application of bauxite residues (red sludge) and industrial ferrous sulphate (green salt) on acid bog peat soils to reduce the leaching of phosphates. Anwendung von Rotschlamm und Grunsalz auf sauren Hochmoorboden zur Reduzierung des Phosphataustrages. Zeitschrift fur Kulturtechnik und Flurbereinigung. 1986, 27: 2, 76-82; 7 ref., 2 fig., 5 tab.

Results of pot trials have shown a better retention of phosphates by iron in bog peat soils after application of a by-product of bauxite manufacture (this contains 29% Fe2O3, and is known as red sludge). These retained phosphates were still available to plants. Phosphate and iron leaching were also measured in a field trial over several years under the following treatments: control; 10 t ha-1 red sludge; 20 t ha-1 red sludge; 10 t ha-1 red sludge + 10 t ha-1 industrial ferrous sulphate. Analysis of the drainage water showed a reduction in phosphate leaching losses within five years of up to 70% under the higher rate of red sludge or the red sludge/ferrous sulphate treatment. Fertilizer phosphates remained in the enriched upper layer, adsorbed by the iron oxides of the red sludge. Analysis of the drain water showed no leaching of iron from the red sludge during the test period of five years. Red Mud

Schwab, G. O., Fausey, N. R. and Kopeak, D. E. (1980). Sediment and chemical content of agricultural drainage water. Transactions of the American Society of Agricultural Engineers, 1446-1449.

1.0 metre deep subsurface drains, 0.5m deep subsurface drains, and surface drainage lost 1.2, 0.8 and 2.2 kg of phosphorus respectively. The soil was a silty clay loam.

Shioa, S. J. and Akashi, K. (1977). Phosphate removal from aqueous solution from activated red mud. Journal of the Water and Pollution Control Federation, Vol 49, February, 280-285.

Red mud was activated by hydrochloric acid. It is an excellent adsorbant for phosphorus.
The effect of adsorption of P by activated red mud was not affected by red mud over the range of zero to boiling celsius.
The composition of raw red mud was:
Al_2O_3 *20.5%*
Fe_2O_3 *34.2%*
SiO_2 *17.2%*
Na_2O *9.4%*
TiO_2 *3.3%*
Loss on ignition was 12%.

Sigmond, G., Csutkay, J., Horvath, G., Kacso, M., Molnar, A., Szabo, A. and Vargo, L. (1980). Study on the disposal of bauxite residues - final report United Nations Industrial Development Organization, October 1980 Budapest Hungary.

Several alumina plants have discharged into what appears to be fresh water rivers and this has resulted in unacceptable problems with fish kills. Kaiser plant in Germany, Batton Rouge into Mississippi (USA) and Revere plant in Maggotty River (Jamaica).

The main problem with red mud in water is its poor settling properties.

The pH of the liquid is effectively neutralised by the precipitation of the hydroxide and carbonate ions in the water. Disposal into the sea is in use by several countries. France, Japan, Italy, Britain.

Toxicity is caused by smothering of fish gills.

Simons, A.P. (1983). Red mud (bauxite residue) as a potential liming alternative for acid sandy soils in Suriname. Surinaamse Landbouw Surinam Agric. Paramibo: Departement van Landbouw, 31(3):80-86.

Simons, A. P. (1984). Red mud (bauxite residue) as a potential liming alternative for acid sandy soils in Suriname. Surinaamse Landbouw Surinam Agric. Paramibo: Departement van Landbouw, 32(3):100-113.

Sinclair Knight and Partners. (1990). Review of industrial wastewater treatment technologies. Environmental Protection Authority Report, December 1990.

Waste minimisation, established and non-proprietary methods of waste treatment, proprietary methods, process under development.

There are five paragraphs on biological control of phosphorus and several references referred to including reed bed use and red mud. This reference is very general for most processes and is a first stop for investigation of processes.

Stanford, R. (1982). Studies on radioactivity. Report to the Health Department of WA on the radioactivity of caustic bauxite residue.

Vegetables were grown on reclaimed red mud lakes.

There was no consistent evidence of elevated concentrations of K^{40} in a range of vegetables (compared with control) grown on sand (2m) overlying a lake of red mud, however there were elevated concentration of K^{40} in broad beans (7.09 versus 1.41 p Ci/g) and cauliflowers (2.2 versus 1 to 1.5). In the broad beans the concentration could have been explained by weight loss during ashing. No such reason could explain the high concentration in cauliflowers.

There was no significant increase in uranium concentrations in broccoli, cauliflower, carrots or tomatoes grown on the red mud lake compared with the control. There was an increase in uranium in peas and beans but this was probably due to weight loss during ashing.

Summers, R.N., Guise, N.R. and Smirk, D.D. (In Press). Bauxite residue (red mud) increases phosphorus retention in sandy soil catchments in Western Australia. Submitted to Fertilizer Research, 1992.

The Peel-Harvey estuary on the Swan Coastal Plain, Western Australia has become eutrophic partly because of the leaching of fertiliser phosphorus from sandy soils. The acid, coarse textured sandy soils are predominantly quartz, have a low iron and aluminium content and do not retain phosphorus. Red mud, derived from bauxite, is a by-product of the alumina industry and has the ability to retain phosphorus. Retention of phosphorus is enhanced when the red mud is neutralised with gypsum. Red mud has been suggested as a soil amendment to reduce phosphorus leaching.

To investigate the reduction in the leaching of phosphorus from soils amended with red mud, weirs were constructed at the outlets from a pair of catchments to quantify the amount of phosphorus in the streamflow. Both catchments were deep grey Bassendean sand. One of the catchments was treated with 80 t/ha of red mud which had been neutralised with waste gypsum from the phosphate industry. The red

mud was applied to the soil surface using conventional fertiliser spreading equipment. The other catchment was untreated.

The red mud reduced phosphorus loss by 70% from 13.8 kg/ha on the untreated catchment, to 4.2 kg/ha on the treated catchment. Both catchments were treated with 20.4 kg/ha of phosphorus as superphosphate. The catchment treated with red mud also received a further 41.5 kg/ha of phosphorus from the phosphogypsum that was used to neutralise the red mud.

Our results show that red mud reduces phosphorus leaching and is potentially a nutrient management option in sandy soils. Red mud has the potential to reduce the impact of agriculture on the estuarine environment and has implications for the continued expansion and intensification of agriculture in the Peel-Harvey catchment.

Summers, R.N., Guise, N.R. and Smirk, D.D. Unpublished. Bauxite residue (red mud) improves pasture growth. To be submitted to Fertilizer Research -1993.

Red mud is a good replacement for conventional crushed limestone and can be top dressed without disturbing the existing pasture with cultivation. Red mud was applied at rates of 10, 20, 40 and 80 t/ha with and without 10 % gypsum ($CaSO_4$) in the red mud. Application of 40 t/ha increased hay cut by 24 % and pH by 1.0 unit from 3.5. In previous trials at application rates in excess of 500 t/ha gypsum was mixed into red mud to reduce salinity and pH. However, amending the red mud at rates below 80 t/ha with gypsum proved unnecessary.

When red mud is applied to acid infertile sands it should be applied with manganese because the rise in pH rapidly induces deficiency in plants. Care should be taken to monitor other nutrients which have availability affected by pH such as copper, zinc and molybdenum.

Summers, R.N., Smirk, D.D. and Karafilis, D. Unpublished. Phosphorus retention and leachates of bauxite residue (red mud). To be submitted to Fertilizer Research -1993.

This study aimed to assess the longevity of phosphorus retention of red mud and find the best application rate of red mud to retain phosphorus. The need for gypsum to maintain the phosphorus retention of red mud was examined. Also the composition of leachates relative to drinking water standards and background levels was measured.

Monthly rainfall was simulated and leachate was collected from lysimeters filled with bleached grey sand amended with 5 to 80 t/ha red mud, with and without gypsum. Leachates from over 12 months simulated rainfall were tested for the potential pollutants: Cd, Al, Fe, As, F, SO_4, electrical conductivity, pH and P. The rainfall simulation was continued for four years and P was monitored during this period.

All of the parameters tested were within background levels or below maximum limits for drinking water, except fluorine when gypsum was applied. The concentration of fluorine that leached from the gypsum amended red mud dropped to drinking water standard within 7 months rainfall. In general gypsum was a hindrance to water quality by raising the level of major contaminants.

The best application rate of red mud to reduce phosphorus leaching is about 10 t/ha without gypsum. The improved nutrient retention from red mud continues for at least 4 years.

Summers, R. N. and Smirk, D. D. (1992). Using bauxite residue to conserve agricultural nutrients in sandy soils. International Bauxite Tailings Workshop, November 1992 Perth.

Bauxite residue (red mud or red sand) can absorb large quantities of phosphorus. This paper will discuss large scale field trials which are investigating the commercial use of bauxite residue to increase pasture production and reduce the leaching of phosphorus.

To assess the reduction in the leaching of phosphorus applied as superphosphate fertilizer a pair of adjacent catchments were monitored. A surface application of 80 t/ha of red mud with gypsum was applied to one catchment with the other left untreated. The red mud reduced phosphorus loss by 70%, from 13.8 kg/ha on the untreated control catchment to 4.2 kg/ha on the treated catchment.

Red mud was applied at rates from 10 to 80 t/ha in trial strips on a clover hay paddock. The rates were replicated with and without gypsum incorporated into the red mud and found no improvement with the incorporation of gypsum. An increase in dry matter production of up to 24 % was produced by the red mud. The pH of the soil increased with application rate of red mud.

Soil columns were treated with red mud equivalent to 5 to 80 t/ha (with and without gypsum), and monthly rainfall of five years was simulated over five months and the leachate was collected. To assess the suitability for red mud to be applied on groundwater recharge areas the leachate was analysed for the potential pollutants Cd, Al, Fe, As, F, SO_4, electrical conductivity and pH. All of these were within background levels or below maximum limits for drinking water. The concentration of fluoride that leached from the gypsum amended red mud dropped to drinking water standard within 7 months. These analyses did not take into account the dilution effect of the groundwater on the leachate which would result in concentrations well below drinking water standards.

Amended soil filters were constructed to remove nutrients from effluent created by intensive animal industries. Preliminary results show nitrogen and phosphorus losses were reduced by 92 and 96 % respectively.

Summers, K. J., Vlahos, S. and Bell, D. T. (1986). Amendment of coastal farmland with bauxite residue - water quality and pasture responses (report for 1986). Internal report to Alcoa. 2 years monitoring of a broad acre trial. Residue was applied at 1890t/ha to the Gavin and 700 t/ha to the Joel soils within one of the catchments studies.

Residue ameliorated soils showed significant reductions in phosphorus leaching to the groundwater. Following amendment, phosphorus storage in the groundwater was one-third the level of the control catchment. Under existing soil conditions phosphorus in native soils was readily leached generally resulting in low total and available levels. This was most evident for the upland Gavin soils which had significant increases in phosphorus levels following amendment. Available (Bic) P levels in the amended soils were equal

to or higher than in native soils indicating phosphorus was not irreversibly bound but readily available to pasture plants.

High sulphate concentrations were encountered in the groundwater beneath the amended catchment. Total sulfate storage in the groundwater showed reductions by the end of the second year and thus were not considered to pose any long term environmental problem.

Surface runoff from the amended catchment appeared to be greater than from the untreated catchment. Soil hydraulic conductivity indicated intense rainfalls of 3 to 4 mm per minute would be required to produce runoff. Neither soil erosion or particulate material in surface water were observed. Although surface water flow increased from the amended catchment, phosphorus loss was significantly reduced.

Pasture crop yield on amended Gavin soils showed a 90% increase over control areas in the second year. Although reductions in production on amended lowland Joel soils occurred in the first year, yields were at least equal to that achieved in control soils in the second year and showed signs of further improvement.

Summers, K. J., Vlahos, S. and Bell, D. T. (1988). Amendment of sandy coastal soils with red mud residue - water quality and pasture response 1984-1987. ALCOA Environmental Technical Series No 6.

Four year trial of a broad acre trial using red mud/gypsum as a soil amendment for the sandy soils of the Swan Coastal Plain. Two adjacent catchments both with Joel flats and Gavin dunes of the Bassendean association. One catchment was treated with 1900 and 700 t/ha red mud.

Treatment of the soil reduced P loss significantly, P loss from runoff was 1/16 less. P losses to ground water were a third of control. Even after three years of leaching the treated soil had the capacity to adsorb phosphorus.

Pasture growth on the deep Gavin sands increased from 50 to 110%. Joel sand reduced production by 50% in the first year probably due to salt. But returned to normal in 12 months and continued to improve beyond the yield of the control.

Major benefit appears to improve water holding capacity and the pH increased from 4 to 7.5.

Summers, K. J., Vlahos, S., and Bell, D. T. (1989). The characteristics of leachates derived from a sandy soil ameliorated with red mud neutralised with acidic copperas waste. Environmental Department Technical Series No 5.

The experiment examined the leachates from sandy agricultural soil amended with bauxite processing residue (red mud) neutralised with acidic copperas waste from the titania processing industry. The soil was treated with 0, 200, 500, 1000 and 2000 t/ha red mud.

SWDA (1992) Peel - the Developing Region. South West Development Authority November 1992.

Tacey, W. H. (1986). Prospects for reducing phosphate loss and improving productivity on sandy farmland using neutralised bauxite residue. Colloquium on Peel-Harvey estuary 15 December, 1986

Loss of phosphorus on Gavin sand treated with red mud (1000t/ha) was 4% as opposed to 40% on control.

Water repellence was lowered and could act to reduce the patchy germination of pastures.

Gives the costs to treat all of the sandy soils.

Tacey, W. H., Ward, S. C., Summers, K. J. and Barrow, N. J. (1984). Soil improvement with bauxite residue. Journal of Agriculture (WA), 25:92-93.

In experimental plots, from 200 to 2000t/ha of gypsum-treated residue were incorporated into Gavin and Joel sands. Up to 270 kg/ha of phosphorus - 15 times the normal application - was spread on micro plots and the leached solution was collected.

Bill Bowden from the WA Dept of Agric. is quoted as calculating the application of 20 tonnes of residue per hectare could be enough to reduce phosphorus loss and pollution.

Toussaint, L. F. (1985). Background radiation in Western Australia. Radiation Protection in Australia. Vol 3 (4) 151-155.

The background level for radiation on the coastal sandplain was 0.5 mSv/year and the background level for radiation in the Darling Scarp was 3.5 mSv/year.

Vlahos, S., Summers, K. J., Bell, D. T. and Gilkes, R. J. (1989). Reducing phosphorus leaching from sandy soils with red mud bauxite processing residues. Australian Journal of Soil Research, 27:651-62.

This study used field lysimeters to investigate the reduction in the leaching of phosphorus (P) applied as superphosphate fertilizer from a sandy Swan Coastal Plain soil treated with bauxite processing residue (red mud) neutralised with either waste gypsum from the phosphate industry or ferrous sulphate (copperas) from the titanium dioxide industry. Addition of 500 t/ha red mud gypsum or 200 t/ha red mud/copperas were found to reduce the leaching of P to below 3 kg/ha for application rates of 270 and 80kg P/ha, respectively.

Water retention from these excessively well drained soils was increased by 14 and 50 % by the addition of 200 and 2000 t/ha red mud respectively. The pH of the leachate for all rates of red mud/copperas application increased from approximately 4 to range between 7 and 7.5. the concentration of Na and SO_4 were about 8 and 17 g/L, respectively, in the initial leachates collected from the 2000t/ha red mud treatment but declined to approximately 0.4 and 2.0 g/L after 3 years of leaching. The Ca leaching appeared to be initially controlled by the solubility of the excess $CaSO_4$ remaining after the red mud neutralised, with concentrations ranging between 0.3 and 0.5 g/L. The Na, SO_4 and Ca concentrations in the leachates from the 500 t/ha red mud/copperas treated soil decreased to acceptable levels after 2 years. High total soluble salt (TSS) levels associated with high levels of residues application may affect pasture production in the years immediately following soil amendment.

Ward, S. C. (1983). Growth and fertiliser requirements of annual legumes on a sandy soil amended with fine residue from bauxite refining. Reclamation and Revegetation Research. 1983, 2: 3, 177-190; 16 ref., 6 fig., 2 tab.

Annual legume pastures yielded from 5.02 to 6.66 t ha-1 dry matter five months after sowing on plots receiving a range of application levels of red mud up to 1680 t ha-1. In most cases, the red mud was mixed with about 5-8% gypsum. The highest levels of mud decreased yields slightly. Adding gypsum increased the yield. Sodium salts were quickly leached by rain from sand amended with 1680 t ha-1 red mud. Only normal agricultural rates of potassium fertiliser and 0-20 kg ha-1 of phosphorus were required for maximum yield. At high levels of red mud, foliar analyses indicated low manganese concentrations and an excessive uptake of molybdenum added as fertiliser. There was no accumulation of heavy metals, or fluoride, in plants growing on the amended sands. Increased waterholding capacities in the amended sands did not improve growth because of poor drainage in the trial area. There may be more potential for the use of red mud as a soil amendment on more freely drained sands.

Ward, S. C. (1984). Agricultural use of bauxite refinery residue pasture growth in residue amended sand. Report to ALCOA Australia, January 1984.

Residue treated with gypsum significantly increased yields of legume pasture on Bassendean sands in the year of application. Bassendean association Gavin sands show the maximum increase in yields. Yields of 3 to 4 t/ha dry matter should be able to be maintained on red mud amended Gavin sands compared with the usual 0.5 t/ha on unamended sands. On Karrakata sand the beneficial effect was not evident until the second growing season after amendment. The highest yields were at the highest application rates of red mud and gypsum.

Amendment of a Gavin sand with red mud and gypsum significantly reduced water repellence and increased water holding capacity. Medic species, particularly Medicago polymorpha varieties are best suited to red mud gypsum amended soils.

Ward, S. C. (1986). The use of fine bauxite residue from bauxite refining as a soil amendment. PhD. thesis, School of environmental science, Murdoch University, Murdoch Western Australia.

Weaver, D. M. and Ritchie, G. S. P. (1987). The effectiveness of lime-based amendments and bauxite residues at removing phosphorus from piggery effluent. Environmental Pollution, 46, 163-175.

Piggery effluent may contribute to the eutrophication of waterways, if it is not treated before disposal because of high levels of phosphorus. Limes and red mud were used to remove P from piggery effluent - 41 mg/L total P. Lime based amendments were more effective than the red muds when compared to the same ratio of treatment to wastewater.

Based on laboratory measurements the costs of treating effluent increased rapidly as the final concentration decreased to less than 4 mg /L. Kiln dust was the cheapest method down to 2mg/L. Hydrated lime was able to clarify and flocculate down to 1mg/L. Red mud could be used to remove P when the pH was lowered to 6-6.5 and used at a liquid to solid ratio of <20:1.

Typical analysis of red mud from Kwinana was 20% Al_2O_3, 27% SiO_2, 31% Fe_2O_3, 4.5% CaO, 3% TiO_2, 7ppm (μg/g) bicarbonate extractable P and has a loss on ignition of 11.5% (Robson 1982).

Red mud could only achieve 0.8kgP/T red mud only after acid treatment.

World Health Organization (1984) Guidelines for drinking-water quality. Vol 1 recommendations. WHO Geneva.

Appendix A.

Table 1. Environmental levels of elements in soil compared with those found in pure red mud and the contribution of red mud to these elements in soil amended with red mud. The maximum concentrations of elements in red mud are the highest levels found in samples from the three refineries. The contribution of red mud to these elements in soil is based upon applications of 100 t/ha to derive the maximum concentration and 20 t/ha to derive the mean concentration in the top 5 cm of soil. The concentrations of these elements when applied at horticultural rates of up to 250 t/ha will actually be lower because of the improved mixing in horticulture. The levels in gypsum and the contribution gypsum would make at the application rate of 100 t/ha of red mud. The references numbered here are included at the end of this appendix.

	Background - soil (mg/kg)	Environ'l investigation - soil (mg/kg)	Assessment criteria agric'l soil (mg/kg)	Remediation criteria resident'l/ park soil (mg/kg)	Remediation criteria commerc'l/ industrial soil (mg/kg)	Maximum permissible conc'n in soil pH 5.0<5.5 (mg/kg)	Limits of conc'n in soil (mg/kg)	Limits of conc'n in soil (mg/kg)	Red mud max. (mg/kg)	Red mud mean (mg/kg)	Red mud amended soil max. (mg/kg)	Red mud amended soil mean (mg/kg)	Gypsum (mg/kg)	Soil and gypsum amended red mud (mg/kg)
Reference	1(Aust & NZ)	1(Aust & NZ)	6 (Canada)	6 (Canada)	6 (Canada)	7 (UK)	8 (Germany)	8 (UK)	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.
Antimony Sb	4-44	20 (2)	NS	NS	NS	NS	5	NS	0.4	0.3	0.06	0.009	<2	<0.014
Arsenic As	0.2-30 (3)	20 (2)	10	30	50	50	20	10	36	29	5.04	0.87	2	0.014
Barium Ba	20-200	DB	200	500	2000	NS	NS	NS	390	121	54.6	3.63	63	0.441
Beryllium Be	NS	NS	5	4	10	NS	10	NS	1.0	0.7	0.14	0.021	<1	<0.007
Cadmium Cd	0.04-2	3 (2)	1	5	20	3	5	3.5	9	4.5	1.26	0.135	0.5	0.0035
Chromium Cr	0.5-110	50 (2)	100	600	800	600	100	600	750	314	105	9.42	<10	<0.07
Cobalt Co	2-170	NS	20	50	300	NS	50	NS	220	22	30.8	0.66	<5	<0.035
Copper Cu	1-190	60 (2)	80	100	500	130	100	280	45	27	6.3	0.81	NS	NS
Lead Pb	<2-200	300	50	500	1000	300	100	550	20	10	2.8	0.3	17	0.119
Manganese Mn	4-12,600	500 (2)	NS	NS	NS	NS	NS	NS	200	165	28	4.95	32	0.224
Mercury Hg	0.001-0.1	1 (4)	0.2	2	10	1.5	5	1	<0.05	<0.05	<0.07	<0.0015	0.03	0.00021
Molybdenum Mo	<1-20	DB	4	10	40	4	5	4	3.5	1.9	0.49	0.057	<2	<0.014
Nickel Ni	2-400	60 (2)	40	100	500	80	50	70	<5	<5	<0.7	<0.15	<1	<0.007
Selenium Se	NS	NS	1	3	10	5	10	3	<10	<10	<1.4	<0.3	NS	NS
Tin Sn	1-25	50	NS	NS	NS	NS	50	NS	25	8.7	3.5	0.261	<100	<0.7
Zinc Zn	2-180	200	120	500	1500	330	300	280	50	32	7	0.96	13	0.091
Boron B	1-75	DB				NS	25	3.25	<20	<20	<2.8	<0.6	<10	<0.07
Fluorine	NS	DB	200	400	2000	500	NS	NS	1210	1130	169	33.9	6000	42

NS- Not stated.

DB- Author recommends the use of the Dutch B level. This level is conservative and has been set principally for the protection of groundwater.

Appendix B

Table 2. Maximum tolerable levels of minerals in diets (mg/kg) of domestic animals (9) compared with red mud as with table 1.

Element	Cattle (mg/kg dry weight)	Sheep (mg/kg dry weight)	Horse (mg/kg dry weight)	Red mud max. (mg/kg)	Red mud mean (mg/kg)	Red mud amended soil max. (mg/kg)	Red mud amended soil mean (mg/kg)
Arsenic							
Inorganic	50	50	50	36	29	5.04	0.87
Organic	100	100	100	NS	NS		
Cadmium	0.5	0.5	0.5	9	4.5	1.26	0.135
Chromium							
chloride	1000	1000	1000	750	314	105	9.42
oxide	3000	3000	1000				
Copper	100	25	800	45	27	6.3	0.81
Lead	30	30	30	20	10	2.8	0.3
Mercury	2	2	2	<0.05	<0.05	<0.07	<0.0015
Nickel	50	50	50	<5	<5	<0.7	<0.15
Selenium	2	2	2	<10	<10	<1.4	<0.3
Zinc	500	300	500	50	32	7	0.96

Appendix C

1 Australian and New Zealand Environment and Conservation Council - National Health and Medical Research Council (1992). Australian and New Zealand guidelines for the assessment and managment of contaminated sites (January 1992).

2. Environment Canada (1988). The development of soil clean up criteria in Canada Volume 1. Methods and strategies currently used to develop clean up criteria for contaminated sites. Decommissioning Committee September 1988.

3. Department of Agriculture and Rural Affairs, Victoria (1990) Submission to draft Australian guidelines for the assessment and management of contaminated sites 1990.

4. Richardson, G. M. (1985) Inventory of cleanup criteria and methods to select criteria, Prepared for the committee on industrial site decommissioning, Environment Canada 1985.

5. Awad, A. S., Ross, A. D. and Lawrie, R. A. (1989). Guidelines for the use of sewage sludge on agricultural land. NSW Agriculture and Fisheries, December 1989.

6. Environment Canada (1991). Review and recommendations for Canadian interim environmental quality criteria for contaminated sites. Scientifc Series No. 197 Inland Waters Directorate, Water Quality Branch, Ottawa, Ontario 1991.

7. Department of the Environment (1989). Code of practice for agricultural use of sewage sludge. Her Majesty's Stationery Office, London.

8. Kirk, P. W. W. (1987). Pollution Control Legislation, Ch 3 in Heavy Metals in Wastewater and Sludge Treatment Processes Ed. Lester, J. N. CRC Press Boca Raton, Florida.

9. National Research Council (1980). Mineral tolerance of domestic animals. National Academy of Sciences, Washigton DC.

10 Jacobs, L. C. (1990). Potential hazards when using organic materials as fertilizers for crop production. Food and Fertilizer Technology Center, Extension Bulletin No. 313.

Appendix D

Soil amendment reference sites

Alexander Rd, Harvey - S. Henning and Q. Treasure. Trial of 80 t/ha and 5 t/ha of red mud on a catchment to assess the improvement in phosphorus retention. (32 ha).

Alexander Rd, Harvey - O. Eastcott. Trial of rates between 10 and 500 t/ha to assess the improvement in plant yield.

Lakes Road, Murray - C. Kielman. Trial of 40 t/ha of red mud on a catchment to assess the improvement in phosphorus retention. Also a previous trial from 1982 is on this property, which used 2000 t/ha gypsum amended red mud, .

Yangetti Rd, Serpentine - A. Wigg. Trial of 20 t/ha of red mud on a catchment to assess the improvement in phosphorus retention.

Pinjarra Rd, Murray - J. Tuckey. Trial of rates between 5 and 40 t/ha of red mud to assess the improvement in plant yield, longevity of the improvement and changes in the residual effect of superphosphate.

Yangetti Rd, Serpentine - C. Kentish. Trial of rates between 5 and 40 t/ha of red mud to assess the improvement in plant yield, longevity of the improvement and changes in the residual effect of superphosphate.

Yangetti Rd, Serpentine - Horti International. Trial of 60 t/ha of red mud and gypsum on a horticultural property to assess the improvement in phosphorus retention. Also a rate trial up to 120 t/ha of red mud and gypsum to determine the residual effect of fertilizer phosphorus.

Thomas Rd, Anketel. Trial of rates between 60 and 240 t/ha of red mud and gypsum to assess improvement in phosphorus retention and yield of vegetable crops.

Dog Hill Rd, Baldivis - Westralian Carnations. Trial of 250 t/ha of red mud and gypsum on carnations.

Wagerup Alcoa Farmlands - K. Powers. Trial of 10 to 40 t/ha of red mud and 20 to 100 t/ha process sand to assess the liming effect.

Heron Point Rd, West Coolup - R. Walmsley. Trial of 200 to 1000 t/ha red mud on pasture from 1982.

Intensive animal industries reference sites

Abernethy Rd, Mundijong - P. Kargotich. Dairy effluent pond for the processing of effluent from a 600 cow dairy. The anaerobic pond discharges into a separate aerobic, permeable pond, lined with red sand.

Harvey - C. Maughan. Dairy effluent pond for the processing of effluent from a 100 cow dairy. The anaerobic pond discharges onto a red sand filter.

Cookernup - R. Blackburn. Dairy effluent pond for the processing of effluent from a 100 cow dairy. The anaerobic pond discharges onto a red sand filter.

Harvey - G. Maughan. Dairy effluent pond for the processing of effluent from a 100 cow dairy. The anaerobic pond discharges onto a red sand filter.

S.W. Highway Coolup - H. Dilley. Dairy effluent pond for the processing of effluent from a 100 cow dairy. The anaerobic pond discharges onto a red sand filter.

Harvey - Moore G. Piggery effluent pond lined with red mud for the processing of effluent from a piggery.

On-site effluent disposal reference sites

Amended leach drain

There are a number of single units in place, including installations at Busselton, Osborne Park, Rockingham, Forrestdale and Innaloo. A multiple unit has been installed at a 14 unit retirement village in Byford.

Aerobic treatment unit disposal.

Single units in place include installations at Melville, Mundaring, Stirling, and Lake Carine (subsurface disposal into red mud amended soils). An

industrial unit has been installed in a bakery at Byford.

Municipal sewage disposal

Kwinana - WAWA recharge basin
Pinjarra - WAWA Pinjarra sewage treatment plant

Drainage structure reference sites

Williamson Road, Coolup - P. Stacey. Red sand lined basins strip nutrients when flooded and have fodder crops using the nutrients in summer.

Thompson Road, Mealup - A. McCormack. Red mud (amended with gypsum) lined basin floods and strips nutrients in winter.

Subsurface drainage using red sand filters has not been tried yet.

Stormwater basins

Leda Development, Shire of Kwinana. Design engineers, McAuliffe and Evangelisti. Monitored by WAWA.

Construction material reference sites

Alcoa refineries - residue operations. Red sand is widely used to construct drainage layers, embankments and foundation pads in the normal course of operations.

Kwinana refinery - Alcoa - residue sand for construction of a landscaped screening and railway safety embankment adjacent to Cockburn Rd.

Tonkin Park, Bassendean. Residue sand backfill for concrete drainage piping.

Alexander Rd. Harvey Shire - C. Lockwood, Shire Engineer. Secondary road trial pavements using red mud, red sand and limestone blends.

Appendix E

USE OF BAUXITE RESIDUE (RED MUD) IN THE PEEL-HARVEY COASTAL PLAIN CATCHMENT
PUBLIC ENVIRONMENTAL REVIEW
GUIDELINES

Overview

In Western Australia all environmental reviews are about protecting the environment. The fundamental requirement is for the proponent to describe what they propose to do, to discuss the potential environmental impacts of the proposal, and then to describe how those environmental impacts are going to be managed so that the environment is protected.

If the proponent can demonstrate that the environment will be protected then the proposal will be found environmentally acceptable; if the proponent cannot show that the environment would be protected then the Environmental Protection Authority (EPA) would recommend against the proposal.

Throughout the process it is the aim of the EPA to advise and assist the proponent to improve or modify the proposal in such a way that the environment is protected. Nonetheless, the environmental review in Western Australia is proponent driven, and it is up to the proponent to
identify the potential environmental impacts and design and implement proposals which protect the environment.

For this proposal, protecting the environment means that the natural and social values associated with the Peel-Harvey Coastal Plain catchment are protected. Where they cannot be protected, proposals to mitigate the impacts are required.

Purpose of a PER

The primary function of a PER is to provide the basis for the EPA to provide advice to Government on protecting the environment. An additional function is to communicate clearly with the public so that EPA can obtain informed public comment. As such, environmental impact assessment is quite deliberately a public process. The PER should set out the series of decisions taken to develop this proposal at this place and time and why.

Objectives of the review

The Public Environmental Review should have the following objectives:

- to place this project in the context of the regional environment and the progressive development of resources in the region, including the cumulative impact of this development;
- to explain the issues and decisions which led to the choice of this project at this place at this time;
- to set out the environmental impacts that the project may have; and
- for each impact, to describe any environmental management steps the proponent believes would avoid, mitigate or ameliorate that impact.

The Public Environmental Review should focus on the major issues for the area and anticipate the questions that members of the public will raise. Data describing the environment should be directly related to the discussion of the potential impacts of the proposal. Both should then relate directly to the actions proposed to manage those impacts.

Key issues

The critical issue for the proposal is likely to be the cumulative impacts of the use of bauxite residue (red mud) in the Peel Harvey Coastal catchment. It is important therefore that the PER shows a detailed understanding of the environmental and social values of both the sub-catchments and the catchment, and whether these values are represented elsewhere. The values of specific sites which have been or are likely to be disturbed should also be examined in detail. Any proposals the proponent has with respect to the potential locations for red mud use should be indicated clearly.

The key issues for this project should be clearly identified and the content of succeeding sections determined by their relevance to these issues.

In this case the key issues should include:

- The reasons for the use of red mud and the alternatives or combination of alternatives considered for the control of nutrients;
- Properties of bauxite residue;
- Leachate:
  - caustic;
  - sulphate;
  - heavy metals;
  - aluminium and other impurities;
  - radioactive;
- Impacts on groundwater including water quality;
- Impacts on adjacent or downstream drains, streams, estuarine or freshwater lakes/wetlands, including siltation, turbidity and other relevant water quality issues;
- Impacts on the marine environment, including water quality and fisheries;
- Impacts on soils:
  - permeability;
  - residual effects of fertilizer;
  - nutrient retention saturation particularly phosphorus;
  - possible contamination with fungi and other soil borne diseases;
- Impacts on flora, fauna and ecosystems:
  - significant flora, fauna and biological communities, likely to be affected;
  - inter-relationships of the biota and environment, including impacts on susceptible native vegetation and animals of trace materials,contaminants and/or organisms;
- Impact on landscape and recreation values;
- Impact on surface water drainage patterns particularly overland flow;

- Principles for use:
  - life expectancy of soil amended PRI;
  - replacement strategies as part of different management systems;
  - use in conjunction with existing government policies and regulations;

- Operational management issues:
  - control over use/safeguards against misuse;
  - dust and noise control during transport and application, and dust control in situ;
  - transport and safety issues (including caustic and radiation properties);
  - topsoil management and final land use (including staining);
  - contingency plans for accidents;
  - liability;
  - potential industrial contaminants and quality control;

- Monitoring:
  - to confirm predictions about leachate movement or lack of it;
  - of toxic substances;
  - of PRI run down rates;
  - the success in reducing phosphorus loss from land uses where this method is being used;

plus any other key issues which may be raised during the preparation of the report.

Public participation and consultation

A description should be provided of the public participation and consultation activities undertaken by the proponent in preparing the PER. It should describe the activities undertaken, the dates, the groups and individuals involved and the objectives of the activities. Cross reference should be made with the description of environmental management for the proposal which should clearly indicate how community concerns have been addressed. Where these concerns are dealt with via other departments or procedures, outside the EPA process, these can be noted and referenced here.

Detailed list of environmental commitments

The commitments being made by the proponent to protect the environment should be clearly defined and separately listed. Where an environmental problem has the potential to occur, there should be a commitment to rectify it. All actionable and auditable commitments made in the body of the document should be numbered and summarised in this list and should take the form of:

a who will do the work;

b what the work is;

c when the work will be carried out; and

d to whose satisfaction the work will be carried out.