Summary Report

Bauxite Residue (Alkaloam®) Sustainability Assessment: Technical, Community Consultation, Benefit Cost and Risk Assessment

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Prepared for

Centre for Sustainable Resource Processing

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Table of Contents

Abbreviations

Abbreviation	Description
Alcoa	Alcoa World Alumina
APVMA	Australian Pesticides and Veterinary Medicines Authority
ASLP	Australian Standard Leaching Procedure
CEC	Cation exchange capacity
CSRM	Centre for Social Responsibility in Mining
CSRP	Cooperative Research Centre for Sustainable Resource Processing
DAFWA	Department of Agriculture and Food Western Australia
DEC	Department of Environment and Conservation
DOC	Clay dissolved organic content
DOW	Department of Water
EIL	Ecological Investigation Level
EPA	Environmental Protection Authority of Western Australia
FSANZ	Food Standards of Australia and New Zealand
GILS	Groundwater investigation levels
HIL	Health investigation level
Kd	Soil to water partitioning coefficient
Kow	Octanol to water partitioning coefficient
ML	Maximum limit
NGO	Non-Government Organisation
NORM	Naturally-occurring radioactive materials
OM	Organic matter
PCR	Progress and Compliance Report
PER	Public Environmental Review
TCLP	Toxic characteristic leaching procedure
UWPCA	Underground water pollution control area
URS	URS Australia Pty Ltd
WHC	Water holding capacity
WQIP	Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System - Phosphorus Management

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CSRM was commissioned to undertake the external community engagement for this project.

Summary Report

This report is a summary of the more detailed Final Report titled "Bauxite Residue (Alkaloam®) Sustainability Assessment: Technical, Community Consultation, Benefit-Cost and Risk Assessment". Readers should refer to that full report for the full context of the information summarised below.

1.1 Introduction

The Centre for Sustainable Resource Processing (CSRP) commissioned URS, in conjunction with the Centre for Social Responsibility in Mining (CSRM) from The University of Queensland, to perform a Sustainability Assessment (Benefit-Cost and Risk Analyses) on the use of Alkaloam® (also referred to as 'red-mud' and/or 'bauxite residue') on agricultural land. The key tasks of this review were to provide a risk and sustainability assessment of the use of bauxite residue (Alkaloam®) in the Peel-Harvey catchment by undertaking community consultation, a consolidated safety and technical review (of research and assessments previously conducted by others), and an indication of the potential benefits and costs with commercial use of bauxite residue.

This sustainability assessment undertaken by URS involved the development of a framework to provide the basis for an assessment of the environmental, social and economic values associated with the use of Alkaloam®. The framework aimed to provide an open and transparent set of criteria, that provided an long term assessment of effects and values.. The key objectives of the sustainability assessment as identified by CSRP were to assess:

- *the safety of Alkaloam®;*
- *the effectiveness of Alkaloam®;*
- *the value of Alkaloam®; and*
- *the current status of community acceptance of Alkaloam®, and how best to achieve endorsement should it be shown to be safe, effective and of value*.

The context of this review has been structured to assess stakeholder goals, objectives and values using economic, social and environmental criteria. Stakeholder values were assessed by CSRM for three primary groups: product users (Peel-Harvey farmers), the community but with specific attention to the local Peel-Harvey catchment community; and Alcoa as the primary source of Alkaloam®.

What is Alkaloam®?

Alkaloam® is the registered trademark for Alcoa-produced red mud, it differs slightly from conventional red mud in that it is carbonated through a reaction with carbon dioxide. The pH of Alkaloam® (pH<10.5) is therefore less than conventional red mud due to the carbonation process converting residual caustic soda to its corresponding carbonate salt. Alkaloam® is referred to as 'atmospherically carbonated red mud', however forced carbonation may also be used. The terms Alkaloam® and 'red mud' are used interchangeably depending on the research being discussed, but for the purposes of this review are considered to be virtually the same. The only difference is where red mud has been amended with gypsum giving slightly different characteristics, as discussed in later sections.

Alkaloam® research and development in WA

Alcoa has worked for several decades on residue management techniques and continues to support a diversity of research initiatives into potentially beneficial uses of residue. The earliest research into the use of red mud in Western Australia was in the 1980s, when Barrow (1982) investigated the improvements in nutrient and water retention of red mud amended soil. Research continued

1 Summary Report

throughout the 1980s and 1990s, and in 1993 the (then) Department of Agriculture Western Australia (DAWA[1]) submitted a proposal, as a Public Environmental Review (PER), for the use of Alkaloam® in the Peel-Harvey Coastal Plain Catchment. Approval was given by the Western Australian Environmental Protection Authority (EPA) for a project entitled 'Widespread use of bauxite residue, Peel-Harvey Coastal Plain Catchment' (EPA, 1993). The project was approved for a period of 5 years with a number of environmental conditions, including the development of a Code of Practice (COP).

In 1994 a trial of Alkaloam® application began in the Meredith drain sub-catchment of the Peel-Harvey. This comprised of a monitoring program that included monitoring remnant vegetation, impacts on wetlands, changes to surface run-off quantities, and the quality of ground and surface water. Approval lapsed in 1998 and DAWA applied for an extension of the project's approval which prompted a re-examination of the original approval conditions.

There was extensive consultation and negotiation between DAWA, the (then) Department of Environmental Protection (DEP), the (then) Water and Rivers Commission (WRC) and the EPA, and the approval was extended in 2000 (EPA, 2000) with several amendments to the conditions. The first commercial application of Alkaloam® was implemented in 2001 within the Peel-Harvey catchment, with Alkaloam® applied to 10 properties from Waroona to Serpentine.

In 2002, a Sydney Morning Herald article criticized the use of Alkaloam® and other industrially-sourced soil amendments (Ryle G, 2002). This resulted in considerable attention on the project - both positive from supportive landholders and negative. In 2002 Alcoa withdrew the availability of Alkaloam®. In 2006 the Department of Agriculture and Food Western Australia (DAFWA) submitted a Progress and Compliance Report to DEC and EPA requesting formal clearance of all outstanding conditions. At the time of writing the processing of this request for clearance by the EPA has not yet been finalised.

Potential value of Alkaloam® in the Peel-Harvey Catchment WA

The Peel-Harvey region/catchment is characterised by poor quality sandy soils and extensive waterways that feed into the Peel Inlet and Harvey Estuary. The application of red mud is proposed as a way to reduce phosphorus leaching, which can result in environmental impacts to waterways, and to improve agricultural productivity.

In 2008 the EPA released the "*Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System - Phosphorus Management (WQIP)*" (EPA, 2008). This report recommends the use of slow release phosphate fertiliser, and soil amendment materials such as bauxite residue to adsorb phosphorus and therefore reduce leaching into the Peel Inlet-Harvey Estuarine System. Rivers (1999) states that the ability of the soil conditioner bauxite residue to hold onto phosphorus (the phosphorus retention index (PRI)) is hundreds of times greater than that of naturally occurring soils.

[1] Now the Department of Agriculture and Food (DAFWA)

1.2 Community Consultation

The CSRM was contracted by CSRP to undertake a consultation and review process of Alkaloam® and its application in agricultural practice in the Peel-Harvey Catchment. The focus of the study was to ascertain current community perceptions of the risks and benefits of Alkaloam®, its source, applications, and opinions on the product's potential future commercialisation. Notwithstanding the focus on agricultural applications, the consultation sought the views and input from a cross-section of the Peel-Harvey community.

1.2.1 Community consultation methodology

The first stage of the community consultation comprised a literature review of reports, media, and other published data relevant to community perception and attitudes towards Alkaloam®. There is little public domain data that address the social impacts of Alkaloam® or that document the events leading up to the cessation of the farm trials in 2002. One of the priorities of the community consultation was that the research should reflect the views of a range of community stakeholders. A three step process was undertaken by CSRM to identify potential project participants:

- Step 1: Regional scanning and information on potential stakeholders gathered from key informants with knowledge of the region;
- Step 2: Snowball, or word-of-mouth identification; and
- Step 3: Project promotions via distribution of the Project Information Sheet and a Community Notice placed in the Harvey Reporter.

The field research for the community consultation phase of this project was undertaken between 22 September and 11 November 2008, and consisted of a series of one-on-one semi-structured interviews with a cross-section of stakeholders. Interviews were conducted by senior CSRM researchers. In total, 30 one-on-one qualitative interviews were undertaken with 33 participants. In reporting participant responses, all data have been de-identified except for the participant category of representation.

Community consultation summary

Substantial support for the future commercialisation of Alkaloam® was expressed by many of the participants consulted for this project, but there are several technical and social issues that participants raised. These issues are summarised and addressed by the authors in sections 1.6.1 1.6.2 and 1.7.4 below.

1.3 Review of Product Safety and Technical Assessments

1.3.1 Background and scope of review

The technical and safety review examines scientific literature in the public domain regarding the use of Alkaloam® in WA and related literature on red mud and brown mud[2] internationally. In addition, some unpublished data were obtained directly from Alcoa. The research conducted in Western Australia (predominately by DAFWA) is a central focus of this review, and appears to represent some of the most comprehensive research on the application of Alkaloam® type materials in agriculture. In addition, this review has examined documentation on specific tests conducted by Alcoa on Alkaloam® and examines the monitoring programme conducted by DAFWA.

Whilst the original PER proposed that application rates of up to 250t/ha would be suitable for broadacre agriculture, an application rate of 20 t/ha was used for a trial period, because it was considered the most cost-effective application rate. This review is focused on the proposed Alkaloam® application rate of **up to 20 t/ha** (as a one-off application or in increments up to 20 t/ha). Assuming this rate is applied, the purpose of the technical review into Alkaloam® is to:

- review the science of Alkaloam® application to agricultural land;
- evaluate the robustness and coverage of past assessments, and identify gaps in evidence or research; and
- examine the number of times Alkaloam® can be re-applied.

1.3.2 Framework for Technical Assessment

In principle, the application of any material to agricultural land requires consideration of several factors across the three media – land, water and air. There is currently no Australian standard or accepted framework for assessing the application of fertilisers and materials such as Alkaloam® to land.

The potential exposure pathways of Alkaloam® amendment, are utilised to form the framework for this review, as no standard framework currently exists for assessing a fertiliser or soil amendment (apart from some related guidelines on sewage sludge applications or water quality standards etc).

The primary transport pathways of potential contaminants applied to soil include (Sorvari *et al*., 2006):

- leaching to groundwater and runoff to surface water;
- absorption to plant roots; and
- particle transport via air and then deposition.

Subsequent contaminant transport can occur via secondary pathways. Those considered in this review are from:

- groundwater and air to a water body;
- surface water to sediment;
- soil water to plant roots;
- irrigation water to plants;
- soil to animals; and
- drinking water to humans, and animals.

[2] In some operations red mud is further processed to produce aluminium oxides. The waste product from this process is called "brown mud."

1 Summary Report

For each exposure pathway certain tests/experiments can be performed to assess the potential risk. Some exposure pathways are only relevant if there is a risk upstream, e.g. if the levels of contaminants present in plants are within acceptable limits, then there is minimal risk (downstream) associated with the consumption of plants by animals, and therefore no need for further consideration. If the contaminant concentration is below the relevant guideline threshold, then there is minimal risk and therefore no need for further analysis.

1.3.3 Alkaloam® use in agriculture

Bauxite residue has a fairly long international history of being utilised, with the first reported case for agriculture being in Arkansas, USA, in 1955, where it was used as a replacement for crushed limestone (Whittaker *et al*., 1955: quoted in Summers *et al*., 1996). The earliest research on the use of red mud in Western Australia was in the 1980s, when Barrow (1982) investigated the improvements in nutrient and water retention of red mud amended soil.

The most recent research on red mud was in Western Australia where several benefits were demonstrated. The research was predominately led by the DAFWA and also sought to address and analyse many of the potential exposure pathways. Much of this research was based in the Meredith catchment, a sub-catchment of the Peel-Harvey catchment, situated about 150 km south of Perth with a total area of about 4,360 ha (Department of Agriculture, 1993).

1.3.4 Alkaloam® composition

Alkaloam® differs from conventional red mud in that it is carbonated through a reaction with carbon dioxide. The pH of Alkaloam® (pH<10.5) is therefore less than conventional red mud due to the carbonation process converting residual caustic to its corresponding carbonate salt. It is a fine material of mainly silt size particles (<150 µm) consisting predominately of silica with large proportions of iron and aluminium oxides (Summers et al, 1996a).

A comparison was conducted of the heavy metal concentrations present in Alkaloam® amended soil (assuming Alkaloam® is mixed with the top 10cm of soil) to that of background soil, against several criteria (including the ANZECC (1992) criteria for assessment of contaminated sites, and remediation criteria levels for other countries, i.e.Canada, UK and US). The results showed that for the application rate of 20 t/ha, the concentration levels of all heavy metals fall within normal background soil levels, and are under levels of concern (i.e. within environmental investigation or remediation levels) (Summers, 2001).

1.3.5 Review of Potential Exposure Pathways

Alkaloam® research has covered the concerns and exposure pathways of relevance, and appears comprehensive. The level of research is beyond that typically performed for products applied to agricultural land. This is despite the research being performed in an *ad hoc* fashion over some 20 years. The findings and recommendations from this review are summarised below by the primary (direct) exposure pathways.

Soil to surface water

The monitoring of surface water was one of the requirements of the original PER approval for the application of Alkaloam® in the Peel-Harvey Coastal Plain (EPA, 1993). The remit was to monitor

1 Summary Report

"changes to surface water run-off flow patterns and volumes, and the effects of these changes on wetlands and drainage water quality". There is no evidence in the literature to suggest that Alkaloam® application presents a risk to surface water (DAFWA, 2006). The monitoring program has indicated that run-off following Alkaloam® application has reduced and less discharge has entered the monitored drains. This should lead to increased groundwater recharge and availability of water for plants. The surface water monitoring programme has been well implemented and reported in the Performance and Compliance report, in accordance with the requirements of the EPA in its response to the PER (DAFWA, 1993; DAFWA, 2006).

Soil to groundwater

The quality of leachate from the application of Alkaloam® has been tested by laboratory column tests, field lysimeter tests and through monitoring of Alkaloam® application in the field (MPL, 1997; Summers *et al*, 1996; Scheffer *et al.* 1986; Ho *et al*. 1989; McPharlin, 1994; Carter *et al.*, 2009b; Vlahos *et al*., 1989; Alcoa, 2009. A variety of laboratory methods were used including the Toxic Characteristic Leaching Procedure (TCLP) as per USEPA 1311 method, the Australian Standard Leaching Procedure (ASLP) (Australian Standards Committee CH/35, 1997), lysimeter column tests, and the recently developed European method CEN/TS14429.

The leaching tests confirm that Alkaloam® amended soil is within acceptable limits based on water quality guidelines, landfill guidelines and soil investigation levels. It is recommended that the CEN/TS 14429 tests are repeated using the soil intended for amendment, if applications of Alkaloam® exceed 80 t/ha in total (as a one-off application or in increments up to a total of 80 t/ha).

The groundwater monitoring programme has monitored 9 bores since 1995 and a further 12 since 2001 (DAFWA, 2006). The programme has not been performed to the same standard as the surface water monitoring programme. However, the leaching tests performed indicate that recommended concentrations of elements would not be exceeded after Alkaloam® addition. If additional groundwater monitoring is required by the EPA, the results would be more useful and informative if performed both before and after application.

Soil to plants

A range of research has been conducted since 1983 on Alkaloam® amended soil at rates of up to 1,680 t/ha (Ward *et al.* 1983 &1986; Smith 1998; Robertson *et al.*,1994; Cooper *et al.* 1995; Summers *et al*. 1996). A variety of plants were investigated including clover, capeweed, lettuce, cabbage, carrots, onions, potatoes, cauliflower and Chinese cabbage. The research has covered heavy metals and radionuclides and has shown that uptake of elements by plants is well within guideline levels. There were no detrimental effects to cultivated or remnant vegetation in applications up to 1680 t/ha. In some cases, uptake of heavy metals (particularly Cd) was even reduced.

Soil to animals

The animals that have the greatest potential for contact with Alkaloam® are domestic livestock grazing on Alkaloam® amended land. Cattle and sheep grazing on pasture growing in Alkaloam® amended soil and the Alcoa residue area "maintained good health and grew well" (Smith, 1998) and "no obvious health problems in the cattle were identified" (Allen, 1997). Analysis showed that levels of minerals, heavy metals and vitamins were generally within normal levels (apart from cadmium, which as discussed above is high due to the use of superphosphate fertiliser in WA).

1 Summary Report

In addition to the animal studies, the analysis of Alkaloam® amended soil (at 20 t/ha) shows that soil constituents are below the maximum tolerable levels for animal feed, recommended in the standards (Summers, 2001).

Further periodic monitoring and sampling of livestock is recommended, in order to address potential community concerns. An additional level of robustness to the research would be met if soil involved in the studies was analysed before and after Alkaloam® addition. This should also contribute to maintaining the regions reputation.

There has been no testing on wildlife, but this is not considered a 'gap' *per se*, as testing of livestock has been conducted. The reported good health of the livestock grazing directly on Alkaloam® amended pasture indicates that further analysis on wildlife is not needed. In addition, the Code of Practice mandates a buffer zone between native vegetation or riparian areas and amended farm land.

Soil to soil organisms

There is no evidence in the literature to suggest that Alkaloam® is detrimental to the health of the soil and its organisms. The levels of elements in Alkaloam® are within regulatory guideline limits and most are similar to naturally occurring soils (although concentrations of Fe and Al are slightly elevated, which gives Alkaloam® its beneficial effects). Application of Alkaloam® is targeted at sandy, acidic soils and therefore the rise in pH provided by Alkaloam® would be expected to favour most organisms. Without specific studies on soil organisms, the overall health of the soil has to be judged by the health of plants and the ease of growing a variety of species in Alkaloam® amended soil. The growth rate of plants grown in Alkaloam® amended soil is improved compared to control sites (Summers, 2001) and strongly suggests that the soil is in good health.

Radiation

The Bayer process extracts aluminium hydroxide from bauxite. In Western Australian bauxite, extractable aluminium hydroxide[3] is present at levels of around 30 per cent (measured as Al_2O_3), and therefore the residue fraction (from which Alkaloam® is derived) has slightly elevated concentrations of the remaining elements. Alkaloam® contains minor amounts of radioactive uranium (15-23mg/kg) and thorium (220-250 mg/kg) (Alcoa, 2009) which remain from the original bauxite source. The corresponding head-of-chain activities for Alkaloam® are 0.19 – 0.25 Bq/g for uranium and 0.90 – 1.02 Bq/g for thorium, respectively (Alcoa, 2009).

For potential exposure to the public, estimating the potential impacts of Alkaloam® use against the 1 mSv/year public limit involves modelling the combined contributions of exposures to (1) gamma radiation from the Alkaloam®, (2) inhalation of radon progeny deriving from radon gas emitted by Alkaloam®, and (3) inhalation of dust which contains Alkaloam® particles.

Research has shown that there is a linear relationship between the amount of Alkaloam® applied and the resultant gamma radiation emission (Summers *et al*, 1993). The research showed that the 1 mSv/yr effective dose would only be reached at very high rates of over 1,500 t/ha of red-mud-gypsum (RMG)[4] application and with 100 per cent occupancy (meaning that the person would have to

[3] Total aluminium hydroxide is higher than this; extractable aluminium hydroxide is that which is extracted in the Bayer process.
[4] At very high application rates red mud was mixed with gypsum (called red-mud-gypsum or RMG) to reduce the pH and increase the leaching of salt (Barrow 1982; Ward 1983). Without gypsum, pasture either failed to grow (because levels of application were much higher than the 20 t/ha now recommended) (Barrow 1983) or suffered a slight yield reduction (Ward, 1983).

live on the treated land for every hour of an entire year). Therefore, at the suggested application rate of 20 t/ha, over 75 repeat applications would be required to reach a level of potential concern for humans. Based on Alcoa's extensive radiological evaluations of bauxite residue storage (Alcoa, 2009), the impacts from radon progeny and dust inhalation will also be very small at this application rate to the extent that the combined above-background dose will be much less than 1 mSv/year. The risk from radiation or radionuclides from Alkaloam® application at the suggested rate of 20 t/ha, is therefore considered to be low.

Human health - air/dust and soil to organism

The main considerations for human health are:

- potential consumption of vegetables or animals in contact with Alkaloam® (secondary exposure),
- radiation;
- direct contact through handling of Alkaloam®; and
- dust emanating from the material.

Radiation has been discussed above and has been shown in the literature to be a low risk. Potential consumption of vegetables or animals are secondary exposure pathways. Therefore the fact that contaminant levels are within guideline levels in vegetables and animals, grown or grazed on Alkaloam® amended land, indicates no secondary risk present to their consumption.

The Code of Practice provides guidance on the handling of Alkaloam®, and provides a range of recommendations such as not applying Alkaloam® during times of high wind and using skirts on spreaders to confine dust if moisture content of Alkaloam® is low. Alkaloam® penetrates into the top soil with further watering or rain. Therefore any dust created during dry times would be a mixture of soil and Alkaloam®, rather than Alkaloam® by itself.

Several studies have addressed potential dust and respiratory issues. This includes a survey of 89% of 2,964 employees at three Western Australian refineries, which concluded that working in a WA refinery had no major adverse effects on respiratory health (Musk *et al*. 2000). A comparison of an Alkaloam® amended farm with a control farm that had not received Alkaloam® found no significant or potentially hazardous effects from the dust (MPL, 1998).

A Screening Health Risk Assessment (SHRA) of the particulate emissions from Alcoa's Pinjarra Refinery Residue Storage Area (RSA) was undertaken to investigate the potential health risks arising from these emissions (ENVIRON, 2008). This report found that:

- *"the potential for emissions from red mud to cause acute health effects is primarily driven by the nature of the material (contains particulate matter of 10 micrometers or less) rather than the composition of the material (individual metals in the particulates), but represents no cause for concern;*
- *the potential for emissions from red mud to cause chronic non-carcinogenic health effects represents no cause for concern; and*
- *the potential for emissions from red mud to contribute to the incidence of cancer is below the USEPA de minimis threshold of one in a million (i.e. 1×10^6)"* (ENVIRON, 2008).

Overall, the research to date indicates that dust from Alkaloam® application does not represent a health hazard to workers or surrounding communities. Further research on farm dust could strengthen these results, but is not regarded as essential, given the results of research conducted to date.

1.3.6 Performance and Beneficial Effects

The body of Alkaloam® research reviewed has shown that its application can provide the following benefits:

- **High Sorptive Capacity -** Alkaloam® has a high sorptive capacity and an ability to adsorb a range of elements including phosphorus and heavy metals.
- **Phosphorus retention** - Column test and field trials have shown that Alkaloam® can greatly improve the phosphorus retention of certain soils. Alkaloam® can reduce phosphorus run-off by up to 50 per cent when applied at 20 t/ha. On a catchment scale Alkaloam® can potentially reduce phosphorus run-off by 30%, from 140 t/y to 98 t/y. This is a substantial advancement towards the EPA target of 75 tonnes per year.
- **Increase in pH of soil -** Alkaloam® performs well as a liming agent with an alkalinity equivalent to 11% calcium carbonate ($CaCO_3$). At the suggested application rate of Alkaloam® at 20 t/ha,a beneficial increase in pH of the soil and soil leachate, of between 0.5 and 1 unit, has been shown.
- **Increase in plant growth** - There is adequate research and evidence to support claims that Alkaloam® increases plant growth, primarily through: increased phosphorus retention in the soil, and increased uptake of phosphorus by plants; and increased pH of the soil. At the suggested application rates of 20 t/ha pasture production could be improved by ~ 21% and dry matter yield of clover herbage by up to 48%.
- **Improved water holding capacity** - Alkaloam® applied on severely water repellent sand, at applications of 200 t/ha made the soil slightly water repellent and at 500 t/ha the soil became completely wettable. Therefore at Alkaloam® application rates of 20 t/ha, the water holding capacity of these sandy soils may not be significantly altered. The water holding capacity of the soil would be greatly improved, with repeat applications that result in levels of Alkaloam® of 500 t/ha.

1.3.7 Reapplication and potential heavy metal accumulation

The potential for accumulation of contaminants in soil is based on both the levels of elements in the background soil and the concentration in the applied fertiliser or soil amendment, in this case Alkaloam®.

In a separate analysis, URS compared Alkaloam® application for six WA soils (based on data supplied by Alcoa) against a range of standards (see main report for a full explanation). The number of times Alkaloam® can be applied was calculated by comparison against a range of thresholds (maximum concentrations) provided in the standards. The analysis assumes that the Alkaloam® becomes incorporated (e.g. through being washed in) or is mixed with the top 10cm of soil. The analysis simply assesses how many times the soil can be amended with Alkaloam® before maximum concentrations, specified in the standards are reached. Therefore the number of times Alkaloam® can be applied is independent (in this simple analysis) of time and whether reapplication is performed yearly or every five years.

Based on this analysis Alkaloam® can be applied up to 40 times (at the 20 t/ha application rate) for certain soils (equivalent to 800 t/ha). In many cases the acceptable value will be higher once some of the unknown concentrations of the soils have been analysed to a low enough level. The simple analysis performed by URS for a range of soils, against available standards, has not indicated any concerns, but applications over 80 t/ha should be supported by leachate tests (using the CEN/TS 14429 method).

1.3.8 Summary

In summary, the Alkaloam® research and literature has covered the exposure pathways of relevance and concludes that Alkaloam® can be applied to broadacre agricultural land for applications up to a total of 80 t/ha (as a one-off application or in increments up to 80 t/ha). Comparison against a range of criteria suggests that Alkaloam® could be applied at levels of up to 800 t/ha for some soils, but this needs to be supported by leachate analysis.

1.4 Alkaloam® Project Administration and Approval Processes

A barrier to the commercialisation of Alkaloam® and other similar products that may be beneficially reused in Western Australia, is the lack of a transparent environmental approval framework for proponents to undertake.

Specifically, there is no formal framework for assessing and approving soil amendments or fertilisers for application to agricultural land in Western Australia. New South Wales has specific guidelines for a limited number of substances that have achieved exemption from the legislation “Protection of the Environment Operations (Waste) Amendment (Residue Wastes) Regulation 2005 (New South Wales) (although the reuse of residues from metal processing is currently still prohibited).

In other states, such as WA, the acceptability of using by-products as a soil amendment is assessed on a case-by-case basis, which can often be an arduous and inconsistent process. A proponent must apply to the DEC through a PER and clearly demonstrate the product to be beneficial and not harmful to the environment, human health or agriculture.

In the case of Alkaloam®, the approval process was exclusively related to the use of Alkaloam® on agricultural land in the Peel-Harvey region. The process to achieve that was long and often without agreed targets from the perspective of both the proponent and the regulator. The process is therefore inefficient.

1.4.1 Assessment framework recommendation

Western Australia requires a framework that clearly authorises the use of industrial by-products where the safety and benefits have been demonstrated. This has been highlighted in recent research (Harris, 2007; Bossilkov and Lund, 2008). The approval process must contain three elements:

1. **Assessment criteria** – the approval process needs to clearly state how the product is to be considered and assessed. This could be based on:
    a. an Exposure Pathways approach (addressing potential environmental and health impacts);
    b. contaminants thresholds; and
    c. leaching risk /behaviour under proposed and potential conditions.
2. **Approved testing procedures–** an approved list of tests depending on the material and proposed use, e.g. to assess the leaching characteristics, should the proponent use the Australian Standard Leaching Procedure or the European CEN/TS14429 test?
3. **Review and approval process**– options include:
    a. exemption from the need for approval (for example in the case of Victoria where materials with ‘direct beneficial reuse’ do not require EPA approval);
    b. procedures based on material and/or specific end use;
    c. streamlined approvals process, such as waste exemption, prior notice and permits; and
    d. a hybrid approach - different levels of approval process depending on the anticipated ‘risk’, which would typically be dependent on end use (i.e. a ‘waste exemption’ for low risk and or a ‘permit’ for the higher risk uses). Waste classification categories can be created that define a range of contaminant thresholds for particular uses.

Approval processes may also stipulate a requirement for the development of management strategies to ensure the appropriate and controlled use of the substance. There may also be a requirement for:

1 Summary Report

- **Quality assurance systems** – to ensure procedures are in place to manage the quality of the material;
- **Specifications and Standards** – development of suitable standards if the material does not meet any existing specification or standards.
- **Transport and storage guidelines – which are** currently covered by the Code of Practice for Alkaloam®.

For application to land there is a need for a mechanism to assess and approve application rates of the soil conditioner. The limits of the maximum average and absolute average of chemical constituents can be provided, in addition to the test methods that must be used to determine these levels.

1.5 Benefits of Using Alkaloam®

The benefits associated with the use of Alkaloam® as a soil amendment on agricultural land in the Peel-Harvey catchment were classified into:

- Agricultural benefits, which will occur with productivity improvements and cost savings from reduced fertiliser usage. These benefits will tend to flow directly to the farmers who apply Alkaloam® on their farms;
- Environmental benefits, which will be generated as a result of reduced phosphate runoff from agricultural land with a consequent reduction in eutrophication and lower frequency of algal blooms and associated fish kills. Reduced frequency of algal blooms will also reduce waterway cleanup costs and reduce the frequency of impacts on recreation value and impacts of odour upon urban areas. If eutrophication can be reduced sufficiently, then in time, agency costs associated with research, monitoring and regulation might also be reduced; and
- Stockpile cost savings, which will be realised as a result of reduced residue storage requirements. Lower storage costs of bauxite residue will potentially provide some reduction in Alcoa's operation costs and will also reduce the area of land required for storage of bauxite residue if significant volumes of red mud can be diverted from stockpiles. However, only sustained releases of red mud over a long period of time could impact the overall operational costs, if it defers or avoids the requirement to construct residue storage areas. In the short term there is likely to be additional costs with commercialising Alkaloam® – new stockpiles will need to be established for external access, potentially with loading and access infrastructure.

The potential value of Alkaloam® was assessed within a benefit-cost analysis framework by estimating value to agriculture, the environment, and stockpile costs savings. The destailed assumptions used in this analysis are discussed in the full report. Overall the potential net value of Alkaloam®, if used as an agricultural soil amendment in the Peel-Harvey catchment is estimated to in the region of $70 million over 25 years. This comprises some $39 million in agricultural benefits, $24 million in environmental benefits, and $6 million in saved residue storage costs.

The benefit: cost ratio of agricultural values was shown to be 1.75, and the internal rate of return was 59 per cent. These numbers suggest a strong financial incentive for farmers to use Alkaloam® on their low PRI or sand soils. These returns exclude any additional environmental advantages to the community, and any liming effect benefits.

The adoption of Alkaloam® will be contingent on high financial incentives generated by productivity improvements. These incentives are based on a 20 per cent productivity increase and application costs at budgeted levels of around $15-16 per tonne. In practice, any decline in productivity gain or increase in application cost will result in little incentive for farmers to use the product.

The marginal benefit of using Alkaloam® as a phosphate export abatement mechanism suggests an environmental value of $24 million. This estimate excludes the value of environmental amenity, recreational and tourism value, and any human health costs that may be associated with a degraded ecosystem. As such the $24 million estimate should be considered as a lower-bound approximation of environmental value.

The projected savings in residue storage costs come from delayed construction of new residue storage areas, but are unlikely to have effect within the next 15 years. The estimated use of

Alkaloam® in the Peel Harvey area over 25 years is about 6.6 million tonnes or 1.5 per cent of residue produced.

This assessment indicates the use of Alkaloam® as an agricultural soil amendment in the Peel-Harvey catchment will produce a net benefit to the community. It should provide productivity benefits to farmers, provide a cost effective approach to reduce exports of phosphorus from agricultural soils and reduce environmental impacts, and to some extent it will reduce the area required and cost of bauxite residue storage.

1.6 Addressing comments arising from Community Consultation

This section summarises and addresses comments raised during the Community Consultation phase of this project. They are responded to using evidence provided in this report.

1.6.1 Stakeholder comments summary

- **Alkaloam® is not effective on clay** – this is true, agricultural soils with a low phosphorus retention index (PRI) are those that will receive the greatest productivity improvements from Alkaloam®.
- **Don't see any agricultural benefits from using Alkaloam® just a way of reducing the stockpile** - Laboratory, field and catchment-scale trials have repeatedly shown use of Alkaloam® to increase pasture productivity by up to 25 per cent. This study estimates the value to agriculture in the Peel Harvey area to be some $40m over 25 years. The estimated use of Alkaloam® is only 1.5% of residue produced and represents a small saving in storage costs to Alcoa.
- **Radiation** - Research showed that the 1 mSv/yr effective dose would only be reached at very high rates of over 1,500 tonnes of Alkaloam® per hectare and with 100 per cent occupancy (meaning that the person would have to live on the treated land for every hour of an entire year). Therefore, at the suggested application rate of 20 t/ha, over 75 repeat applications would be required to reach a level of potential concern. The risk of radionuclide bioaccumulation by livestock through soil ingestion is small but there appears to have been no research in WA or internationally regarding this. Based on the research the from radiation or radionuclides from Alkaloam® application at the suggested rate of 20 t/ha is considered to be very low.
- **Heavy metals** – The leaching ability of Alkaloam® has been tested using a variety of methods. The leachate tests have covered heavy metals of concern to groundwater. Leachate tests confirm Alkaloam® amended soil to be within acceptable limits based on water quality guidelines, landfill guidelines and soil investigation levels. The research and literature suggests that Alkaloam® could be reapplied up to 40 times for some soils (equivalent to 800 t/ha). Applications over 80 t/ha (as a one-off application or in increments up to 80 t/ha) should be supported by leachate tests using the intended soil type. Alkaloam® amendment raises the pH of acidic soils to a level where leaching of metals is less likely
- **Caustic soda and leaching into water system** – The pH of Alkaloam® is less than conventional red mud (pH<10.5) due to the carbonation process converting residual caustic to its corresponding carbonate salt. The effects of accumulation in water course sediments (and potential effects on meiofauna) has not been specifically researched, but the results of the research have not highlighted this as a concern. In addition, the risk has been mitigated by the Code of Practice which states: Alkaloam® should not be applied directly to, or within 50 metres of open water or wetland dependent vegetation of Conservation Category Wetlands, as defined by the Water and Rivers

Commission. Alkaloam® shall not be applied directly to, or within 50 metres of wetlands listed on the Environmental Protection (Swan Coastal Plain lakes) Policy 1992. Further to these safeguards, the composition of Alkaloam® and the proposed application rates indicate that there is no need for any further research. There is no evidence in the literature to suggest that Alkaloam® presents a risk to surface water at the suggested application rate of 20 t/ha.

- **Effects of Alkaloam® on farm productivity** – There is adequate research and evidence to support claims that Alkaloam® increases plant growth. The net value from improved agricultural productivity in the Peel Harvey area, with the application of Alkaloam®, has been estimated to be worth some $40 million over 25 years.
- **Potential health risks to animals** – Quantities of heavy metals found in Alkaloam® are similar to many soils including those naturally occurring within the Peel-Harvey catchment. When applied at the suggested 20 t/ha rate, concentrations are well below the maximum tolerable levels for domesticated animals, detailed in the standards. Cattle and sheep grazing on pasture growing in Alkaloam® amended soil and the Alcoa residue area "maintained good health and grew well" (Smith, 1998) and "no obvious health problems in the cattle were identified" (Allen, 1997). Analysis showed that levels of minerals, heavy metals and vitamins were generally within normal levels (apart from cadmium, which as discussed above is high due to the use of superphosphate fertiliser in WA). Further periodic monitoring and sampling of livestock is recommended, in order to address potential community concerns. An additional level of robustness to the research would be met if soil involved in the studies was analysed before and after Alkaloam® addition..
- **Potential health risks to people** – Radiation has been shown to be a considerably low risk. Potential consumption of vegetables and animals are secondary exposure pathways. Therefore contaminant levels that are within acceptable limits in vegetables and animals, grown or grazed on Alkaloam® amended land, indicates no secondary risk present to their consumption. The potential concerns about Alkaloam® dust are the effects on farmers and workers that apply Alkaloam®, and the surrounding communities. The Code of Practice gives a range of recommendations such as not applying Alkaloam® during times of high wind and using skirts on spreaders to confine dust if moisture content of Alkaloam® is low. Alkaloam® penetrates into the top soil with further watering or rain. The research to date indicates that dust from Alkaloam® application does not represent a health hazard to workers or surrounding communities. Further research on farm dust could strengthen these results, but are not regarded as essential.
- **Alkaloam® dust as a nuisance issue -** It is noted that about half the respondents of the community consultation raised dust as a nuisance issue. The Code of Practice acknowledges that Alkaloam's high visibility and capacity to stain are likely to be a concern to the general public. The Code recommends a number of practices to minimise dust problems. These include:
  - Avoiding handling and application of Alkaloam during strong winds and storms.
  - Ensuring application to paddocks and temporary stockpiling of Alkaloam is undertaken at a sufficient distance from residences, other buildings and public amenities so as to not cause a dust nuisance.
  - Informing neighbours who may be affected by dust, of application times so that appropriate measures can be taken to reduce any possible dust problems.
  - Use of covers or sprinklers on temporary stockpiles should paddock application or stockpile cleanup be delayed.
  - Gearing the spreader for a slower spinner speed to prevent excessive pulverising of Alkaloam, thus reducing dust production.

1 Summary Report

- Putting skirts on spreaders to confine dust if the moisture content of Alkaloam falls to the point that dust production occurs.
- If excessive dust is generated to the extent that it is likely to cause concern to neighbours and/or the general public, and complaint or objection is likely to arise, spreading should stop or the application be modified to reduce dust levels significantly. This is the responsibility of the landowner or manager and the contractor.

- **Potential damage to the region's reputation as a 'clean' food production area – not taint the milk produced** - Cattle and sheep grazing on pasture growing in Alkaloam® amended soil and the Alcoa residue area "maintained good health and grew well" (Smith, 1998) and "no obvious health problems in the cattle were identified" (Allen, 1997). Analysis showed that levels of minerals, heavy metals and vitamins were generally within normal levels (apart from cadmium, which as discussed above is high due to the use of superphosphate fertiliser in WA). In addition to the animal studies, the analysis of Alkaloam® amended soil (at 20 t/ha) shows that soil constituents are below the maximum tolerable levels for animal feed, recommended in the standards (Summers, 2001). Further periodic monitoring and sampling of livestock is recommended, in order to address potential community concerns. An additional level of robustness to the research would be met if soil involved in the studies was analysed before and after Alkaloam® addition. This should also contribute to maintaining the regions reputation...
- **Propensity of Alkaloam® to harden into lumps, particularly in summer when Alkaloam® was not spread efficiently and effectively** - The Code of Practice shows the general requirements for distribution and application of Alkaloam®, and describes the requirements for cartage contractors. Adherence to this Code should address this issue.
- **Potential damage to local roads arising from the transport of Alkaloam® from the refinery to farms, and any risk of dust blowing off the back of the trucks** - The Code of Practice shows the general requirements for distribution and application of Alkaloam®, and describes the requirements for cartage contractors. Adherence to this Code should address this issue.
- **Inappropriate use of Alkaloam® as a potential risk - overuse, or over application, of Alkaloam® as a potential environmental and economic risk for the region** - The Code of Practice shows the general requirements for distribution and application of Alkaloam®, and describes the requirements for cartage contractors. Adherence to this Code should address this issue.
- **Risks of a product like Alkaloam® may only be understood in the longer term** - This may be true for some issues. This is why this report has made recommendations for some additional research, however, research has been ongoing for 20 years and in that time the literature reports that no specific issues have arisen from the earlier amendments.
- **Better to be 'safe than sorry' with respect to the use of Alkaloam®** – This report has attempted a thorough evaluation of technical and safety issues. In summary, the literature review shows that there is no evidence to suggest that Alkaloam® is unsafe. It also concludes that it is of value for agricultural use in the Peel Harvey area. Some issues have been identified for additional research to confirm assertions of safety. Like all products, at some point, the level of community benefit has to be compared against known levels of risk.
- **Price would be an important consideration in the commercialisation of Alkaloam®** - This is also true. This analysis suggests strong returns to agriculture, assuming distributions costs of around $15 per tonne. Ultimately it will be each farmer's commercial decision whether to use Alkaloam® or not. Like all farm management decisions they will assess expected benefits against costs for their particular mix of soils and landuses.

- **There is a lack of understanding in the community about Alkaloam®** – This project is one effort to help address this concern.
- **Community engagement practices would be needed to connect with the community and reverse any remaining negative public perceptions** about Alkaloam® – Again this report and its release is part of an effort to address that concern. Further efforts will be contingent on decisions to re-release or commercialise Alkaloam®
- **Perceived lack of government policy frameworks in respect to land management and resource practice** – This issue is beyond the scope of this project but the Peel-Harvey Water Quality Improvement Plan provides useful context regarding the value and use of Alkaloam® as a land management option.

1.6.2 Stakeholder expectations

- **That all agencies and stakeholders associated with Alkaloam® conduct themselves with the highest standards of transparency of process, evaluation and implementation** – There is no reason to suggest why this has not, or will not, be the case.
- **That the declared benefits of Alkaloam®, such as increased crop yields, are fully understood with key stakeholders taking into account the range of soil types and potential applications** – There is a great range of literature available to describe this, including this report. There may be advantage in providing concise summaries and field information days if considered appropriate.
- **That the product is demonstrated as acceptable for human and animal health, and that any residual safety concerns are addressed to the satisfaction of the community** – This is a key objective of this report.
- **That the off-farm benefits and the role of Alkaloam® in promoting and sustaining the health and well-being of the broader catchment are demonstrated** - These results indicate such, and are supported by the Peel-Harvey Water Quality Improvement Plan.
- **That the potential long-term consequences of Alkaloam® – both positive and negative – be considered and evaluated on an ongoing basis.** Agreed, and for some technical issues, this forms the reason for some of the recommendations for further research.

1.7 Alkaloam® Sustainability Assessment

A summary of the sustainability assessment is presented against four areas:

- the safety of Alkaloam®;
- the effectiveness of Alkaloam®;
- the value of Alkaloam®; and
- the current status of community acceptance of Alkaloam®, and how best to achieve acceptance should it be shown to be safe, effective and of value.

Each of these goals is evaluated against a number of criteria, for which the current status of knowledge or management or process is assessed. If there are any identified gaps in knowledge or management or process they are described, and then the implications for possible adoption of Alkaloam® as a soil amendment in the Peel-Harvey Catchment are discussed.

1.7.1 Safety of Alkaloam®

Soil to surface water

- **Status -** There is no evidence in the literature to suggest that Alkaloam® application presents any risk to surface water. The monitoring programme has indicated that run-off following Alkaloam® application has reduced and less discharge has entered the monitored drains. This should lead to increased groundwater recharge and availability of water for plants. The surface water monitoring program has been well implemented and reported in the Performance and Compliance report, in accordance with the requirements requested by the EPA in its response to the PER.
- **Knowledge or process gaps -** No identified gaps.
- **Implications for adoption -** No further implications. Surface water monitoring should be performed in accordance with the requirements stipulated by the EPA.

Soil to groundwater

- **Status -** Leachate tests confirm Alkaloam® amended soil to be within acceptable limits based on water quality guidelines, landfill guidelines and soil investigation levels. The groundwater monitoring programme has not been performed to the same standard as the surface water programme. However, the leachate tests performed indicate that recommended concentrations of elements would not be exceeded.
- **Knowledge or process gaps -** The results of the ground water monitoring would be more useful and informative if the tests could be performed again with bore monitoring both before and after application. If this is undertaken for a selection of future amendments, two years of data before application would provide a sound level of robustness.
- **Implications for adoption –** It is recommended that the CEN/TS 14429 tests are repeated using the intended soil, if applications exceed an accumulative total of 80 t/ha are implemented or more than four applications of 20t/ha are proposed.

Soil to plants

- **Status -** A range of research has been conducted on Alkaloam® amended soil at rates up to 1,680 t/ha. The research has covered heavy metals and radionuclides and has shown that uptake of elements by plants is well within regulatory and guideline levels. There were no noted detrimental effects to either cultivated, or remnant vegetation.

- **Knowledge or process gaps -** No identified gaps.
- **Implications for adoption –** No further implications.

Soil to animals

- **Status -** Cattle and sheep grazing on pasture growing in Alkaloam® amended soil and the Alcoa residue area "maintained good health and grew well" (Smith, 1998) and "no obvious health problems in the cattle were identified" (Allen, 1997). Analysis showed that levels of minerals, heavy metals and vitamins were generally within normal levels (apart from cadmium, which as discussed above is high due to the use of superphosphate fertiliser in WA). In addition to the animal studies, the analysis of Alkaloam® amended soil (at 20 t/ha) shows that soil constituents are below the maximum tolerable levels for animal feed, recommended in the standards (Summers, 2001).
- **Knowledge or process gaps -** Further periodic monitoring and sampling of livestock is recommended, in order to address potential community concerns. An additional level of robustness to the research would be met if soil involved in the studies was analysed before and after Alkaloam® addition. This should also contribute to maintaining the regions reputation..There has been no testing on wildlife. This is not considered a 'gap' *per se*, as testing of livestock has been conducted. The reported good health of the livestock grazing directly on Alkaloam® amended pasture indicates that further analysis on wildlife is not needed. In addition, the Code of Practice mandates a buffer zone between native vegetation or riparian areas and amended farm land.
- **Implications for adoption -** Further periodic monitoring and sampling of livestock is recommended, to demonstrate satisfactory animal health.

Soil to soil organisms

- **Status -** There is no evidence in the literature to suggest that Alkaloam® is detrimental to the health of the soil and its organisms. The improved growth and health of plants on Alkaloam® amended soil support this view.
- **Knowledge or process gaps -** No gaps identified.
- **Implications for adoption -** No further implications.

Air/dust to organism (human health)

- **Status -** The research indicates that dust from Alkaloam® application does not represent a health hazard to workers or surrounding communities.
- **Knowledge or process gaps -** No gaps identified.
- **Implications for adoption -** No further implications.

1.7.2 Alkaloam® is effective

High Sorptive Capacity

- **Status -** The ability of Alkaloam® to adsorb heavy metals has been well documented.
- **Knowledge or process gaps -** No identified gaps.
- **Implications for adoption -** Alkaloam® has a high sorptive capacity and an ability to adsorb a range of elements including phosphorus and heavy metals.

Phosphorus retention

- **Status -** Column test and field trials have shown that Alkaloam® can greatly improve the phosphorus retention of certain soils. There is sufficient research and evidence to support the claim that Alkaloam® will greatly aid phosphorus retention on amended land.
- **Knowledge or process gaps -** No identified gaps.
- **Implications for adoption -** Alkaloam® can reduce phosphorus run-off by up to 50 per cent when applied at 20 t/ha. On a catchment scale Alkaloam® can potentially reduce phosphorus run-off by 30%, from 140 t/y to 98 t/y. This is a substantial advancement towards the EPA target of 75 tonnes per year.

Increase in pH of soil

- **Status -** Alkaloam® performs well as a liming agent with an alkalinity equivalent to 11% calcium carbonate ($CaCO_3$).
- **Knowledge or process gaps -** No identified gaps.
- **Implications for adoption -** At the suggested application rate of Alkaloam® at 20 t/ha a beneficial increase in pH of the soil and soil leachate of between 0.5 and 1 unit has been shown.

Increase in plant growth

- **Status -** There is adequate research and evidence to support claims that Alkaloam® increases plant growth, primarily through: increased phosphorus retention in the soil, and increased uptake of phosphorus by plants; and increased pH of the soil.
- **Knowledge or process gaps -** No identified gaps.
- **Implications for adoption -** At the suggested application rates of 20 t/ha pasture production could be improved by ~ 21% and dry matter yield of clover herbage by up to 48%.

Improved water holding capacity

- **Status -** Alkaloam® applied on severely water repellent sand at applications of 200 t/ha made the soil slightly water repellent and at 500 t/ha the soil became completely wettable. Therefore at Alkaloam® application rates of 20 t/ha, the water holding capacity of these sandy soils may not be significantly altered.
- **Knowledge or process gaps -** No identified gaps.
- **Implications for adoption -** At suggested rates of 20 t/ha the water holding capacity of the soil will not be significantly altered. The water holding capacity of the soil would be greatly improved with repeat applications that result in levels of Alkaloam® of 500 t/ha.

1.7.3 Alkaloam® has value

Value to agriculture

- **Status -** Benefits to farmers applying Alkaloam® to low PRI soils at 20 t/ha every five years in the Peel-Harvey catchment were estimated to be positive. Net agricultural benefits of $39 million were shown with a benefit cost ratio of 1.75, and the internal rate of return was 59%. These numbers suggest a strong financial incentive for farmers to use Alkaloam® on their low PRI or sandy soils. These returns exclude any additional environmental advantages to the community.

- **Knowledge or process gaps -** The result is shown to be sensitive to assumed application cost and productivity increases. Productivity increases have been long tested by research and field trials and should be robust (i.e. reliably achievable) with widespread adoption. Supply and application costs do not seem to be as robustly developed. There is a need to validate supply chain costs.
- **Implications for adoption -** The adoption of Alkaloam® will be contingent on strong financial incentives generated by productivity incentives. These incentives will be based on at least a 20% productivity increase and the maintenance of application costs at budgeted levels around $15-16 per tonne in the paddock. Any decline in productivity gain or increase in application cost will result in little incentive for farmers to use the product, unless the environmental value from the use can be used to offset supply and application costs.

Value to the environment

- **Status -** Environmental benefits were estimated by using the marginal benefit of phosphorus export abatement as a measure of value. They are indicated to be at least $24m.
- **Knowledge or process gaps -** This assessment did not estimate the value of environmental amenity, recreational and tourism value, and any human health costs that may be improved with improved ecosystem health in the Peel-Harvey catchment. These values might be useful in better understanding a level of cross funding from environmental management budgets to enable higher levels of Alkaloam® use should it be seen as appropriate.
- **Implications for adoption -** Alkaloam® provides one of the most cost effective options to reduce phosphorus exports. Its use should provide environmental benefits that complement agricultural benefits. Adoption may be enhanced by using the level of marginal environmental benefit to assist with farmer adoption of Alkaloam®.

Stockpile cost savings

- **Status -** The analysis showed the saving to Alcoa from reduced residue storage costs to be $6 million over 25 years, given 6.6 million tonnes or 1.5% of residue produced is used in the Peel Harvey area as a soil amendment.
- **Knowledge or process gaps -** It is unclear from available data what is included in the estimated cost of applying Alkaloam®. The key assumption in stockpile cost calculation is that Alkaloam® is provided by Alcoa at a rate that is cost-neutral to Alcoa. The cost of supplying, carting and spreading of Alkaloam® needs to be validated to ensure the total cost aligns with the estimate used in this study (as per Agricultural benefit knowledge gap).
- **Implications for adoption -** The returns to agriculture are sensitive to the cost of application. Results indicate only a small margin for a third party to supply some 200,000 tonnes annually to the Peel-Harvey catchment.

1.7.4 Alkaloam® endorsement by regulators and the community

Government agencies support Alkaloam® in the Peel Harvey project area

- **Status –** In 1993 the (then) DAWA submitted a proposal, as a PER, for the use of Alkaloam® in the Peel-Harvey Coastal Plain Catchment. Approval was given by the EPA for a project entitled ‘Widespread use of bauxite residue, Peel-Harvey Coastal Plain Catchment’. The project was approved for a period of 5 years with a number of environmental conditions, including the development of a Code of Practice (COP). Approval lapsed in 1998 and DAWA applied for an extension of the project's approval which was extended in 2000 with several amendments to the conditions. In 2002 a Sydney Morning Herald article criticized the use of Alkaloam® and other industrially-sourced soil amendments. This resulted in considerable attention on the project - both positive from supportive landholders and negative. In 2002 Alcoa withdrew the availability of Alkaloam®. In 2006 the Progress and Compliance Report was submitted to DEC and EPA requesting formal clearance of all outstanding conditions;, but at the time of writing the processing of this request has not yet been finalised..

- **Knowledge or process gaps –** DAFWA are seeking clearance of outstanding EPA project approval conditions.
- **Implications for adoption** – Once Progress and Compliance Report conditions are cleared by the DEC and EPA there are no obstacles to the release of Alkaloam® in the Peel-Harvey catchment It will become an issue of community endorsement and an operational decision for Alcoa.

Peel Harvey stakeholders and State community endorse and trust Alkaloam®

- **Status -** There exist a wide variety of perceptions and misconceptions about the safety and value of Alkaloam®. Community views of Alkaloam® are inextricably linked with the reputation of Alcoa. Concerns were raised regarding Alcoa's reputation in terms of a lack of transparency and insufficient engagement processes.
- **Knowledge or process gaps -** Public perceptions of Alkaloam® and Alcoa need to be addressed for the commercialisation of Alkaloam® to be a success. A comprehensive community engagement strategy regarding Alkaloam® which ties in with a broader Alcoa engagement strategy is required. A variety of dissemination and engagement processes need to be adopted, including opportunities for the community to feedback on this current review. Information about the product uses and benefits needs to be readily available to interested stakeholders. Marketing and community engagement are needed to connect with the community and reverse deep seated public perceptions.
- **Implications for adoption -** Any strategy to re-release or commercialise Alkaloam® should be accompanied by a program of best-practice community and participatory engagement. This should, in the first instance at least, be inclusive of all key organisational actors and incorporate a representative cross-section of community interests. Provision of a comprehensive and appropriately targeted education program utilising a range of engagement and information dissemination mechanisms will need to be implemented to address inaccurate perceptions and knowledge gaps.

  — **Implement a program of best-practice community and participatory engagement**: Ensure regional Indigenous groups are factored into any engagement plans, taking into account the range of interest groups and their priorities.

  — **Ensure transparency of future research dissemination**: Put in place precautionary steps to ensure current and future processes in respect of Alkaloam® are suitably disseminated with appropriate opportunities for community to review, engage and provide feedback, particularly in instances where community members have made a contribution to the data collection process.

  — **Education**: For the product to be successful and achieve market share, both on-farm and off-farm, a comprehensive and appropriately targeted education program that utilises a range of engagement and information dissemination mechanisms will need to be implemented. These education programs must directly tackle the key issues of concern identified by stakeholders.

1 Summary Report

Government agencies approve and endorse the use of Alkaloam® as a product

- **Status -** Currently Alkaloam® is approved as a project for defined uses in a defined area; it does not have approval as a generic product. Western Australia requires a framework that clearly authorises the use of industrial by-products where the safety and benefits have been demonstrated.
- **Knowledge or process gaps –** The approval process must contain three elements: assessment criteria; approved testing procedures; and review and approval process. Approval process may also stipulate a requirement for the development of management strategies to ensure the appropriate and controlled use of the substance. There may also be a requirement for: quality assurance systems; specifications and standards; and transport and storage (currently covered by the Code of Practice). For application to land there is a need for a mechanism to assess and approve application rates of the soil conditioner. As in the regulation for New South Wales the limits of the maximum average and absolute average of chemical constituents can be provided, in addition to the test methods that must be used to determine these levels.
- **Implications for adoption –** Without an approval process with the capability to approve and endorse by-products such as Alkaloam® as products with defined uses, approval processes will continue to be somewhat arbitrary in their timelines and requirements. This will be a barrier to efforts to turn residue into by-products of value.

1.8 Summary and Recommendations

The assessment methodology extends the scope of previous environmental assessments of Alkaloam® which have been compliance driven to meet the requirement of the Environmental Protection Act. The inclusion of social and economic considerations in conjunction with an environmental assessment may lie outside the EPA's jurisdiction in terms of any recommendations to the Minister. However, social perception issues and economic benefit are encompassed in the sustainability assessment to provide a more complete evaluation of the potential issues and opportunities associated with any by-product reuse.

The Alkaloam® research and literature has covered the exposure pathways of relevance and concludes that Alkaloam® can be applied to broadacre agricultural land for applications up to a total of 80 t/ha (as a one-off application or in increments up to 80 t/ha). Comparison against a range of criteria suggests that Alkaloam® could be applied at levels up to 800 t/ha for some soils, but this needs to be supported by leachate analysis for applications greater than 80 t/ha.

This assessment indicates the use of Alkaloam® as an agricultural soil amendment in the Peel-Harvey catchment will produce a net economic benefit to the community, valued at $70 million over 25 years. It should provide productivity benefits to farmers, provide a cost effective approach to reduce exports of phosphorus from agricultural soils and reduce environmental impacts. Use in the Peel Harvey area only will only provide a minimal reduction in the area required for, and cost of, bauxite residue storage.

If Alkaloam® is to be re-released or commercialised, there are a number of issues to be considered for achieving regulator and community endorsement. They are listed below as a set of recommendations.

1.8.1 Further research

1. The groundwater monitoring results from farmland applications of Alkaloam® have not shown any cause for concern, with relevant quality criteria being met. As such, the groundwater monitoring program in place is considered appropriate for farmlands in the Peel Harvey Catchment. The results of the ground water monitoring would be informative with bore monitoring both before and after application. If this is undertaken for a selection of future amendments, two years of data before application would provide a sound level of robustness (this period of monitoring would not entail unreasonable costs but would help overcome any discrepancies due to seasonal variations).
2. The testing and cost benefit analysis supports the repeat application of Alkaloam® at up to 20t/ha over appropriate soil types within the Peel Harvey Catchment. If more than four applications of 20t/ha are proposed (i.e. a total of 80 t/ha, regardless of the timeframe), further assessment of accumulation of trace elements and leachate may be warranted.
3. There is no evidence in the literature to suggest Alkaloam® is detrimental to health of livestock. . Further periodic monitoring and sampling of livestock is recommended, in order to address potential community concerns. The livestock should be tested for levels of trace elements within the tissue and organs An additional level of robustness to the research would be met if soil involved in the studies was analysed before and after Alkaloam® addition.
4. The economic analysis was shown to be sensitive to assumed application cost and productivity increases. Productivity increases have been long tested by research and field trials and should be robust (i.e. reliably achievable) with widespread adoption. Supply and application costs do not seem to be as robustly developed. The cost of supplying, carting and spreading of Alkaloam®

should be validated to confirm that Alkaloam® can be supplied at a cost that provides the indicated agricultural benefits.

5. This economic analysis did not include the value of environmental amenity, recreational and tourism value, and any human health costs that may be improved with enhanced ecosystem health in the Peel-Harvey catchment. These values might be useful in determining any appropriate cross funding from environmental management budgets to enable adoption of Alkaloam® should it be considered appropriate.

1.8.2 Endorsement

Public perceptions of Alkaloam® and Alcoa need to be addressed for the re-release or commercialisation of Alkaloam® to be a success. Provision of a comprehensive and appropriately targeted education program utilising a range of engagement and information dissemination mechanisms will need to be implemented to address inaccurate perceptions and knowledge gaps.

6. Implement a program to communicate the risks and benefits of Alkaloam® (which includes this project). This should be inclusive of key organisational actors and incorporate a cross-section of community interests. Ensure regional Indigenous groups are factored into any engagement plans, taking into account the range of interest groups and their priorities.
7. To achieve transparency of research dissemination there is a need to provide opportunities for community to review, engage, and provide feedback, particularly in instances where community members have made a contribution to the data process.
8. A comprehensive and appropriately targeted education program has been developed and is required by the Code of Practice to be in place for the release of Alkaloam®. The ongoing running of these education programs will need to continue under any commercialisation process.
9. In general Alkaloam® is of most use on acidic sandy soils that are typical of the Peel-Harvey catchment area. A summary document that explains the types of soils that lend themselves to the use of Alkaloam®, and those where there will be less benefit from soil amendment, would be beneficial for inclusion into future farmer education programs.

1.8.3 Approval processes

10. The current approval mechanism for the use of Alkaloam® in the Peel Harvey catchment has been under Part 4 of the Environment Protection Act, via a PER process. DAFWA believes that all the Ministerial Conditions which accompany this approval have been met and has provided a project closure report to the DEC. It is recommended that this process be concluded as a priority to provide clarity to potential commercialisation processes.
11. Western Australia requires a framework that clearly authorises the use of industrial by-products where the safety and benefits have been demonstrated. It is recommended that an approval process be developed that contains three elements: assessment criteria; approved testing procedures; and transparent review and approval process. Approval process may also stipulate a requirement for the development of management strategies to ensure the appropriate and controlled use of the substance. There may also be a requirement for: quality assurance systems; specifications and standards; and product transport and storage. For application to land there is a need for a mechanism to assess and approve application rates.

References

Community Consultation

Department of Housing and Works, 2007. Keralup Masterplan. Department of Housing and Works, Government of Western Australia, September 2007.

Harris, S. 2007. Regulatory and Policy Issues of Regional synergies in the Kwinana Industrial Area: A Scoping Study. Perth. Centre of Excellence in Cleaner Production, Curtin University of Technology.

Johnson, Catherine. 2008. Ribbons of Blue: Saltwatch 2008 Report, Kwinana-Peel Region. South West Catchments Council

PDC, 2006. Peel Economic Perspective: An update on the economy of Western Australia's Peel Region. Peel Development Commission, Department of Local Government and Regional Development, Government of Western Australia.

PDC, 2008. Peel Development Commission Annual Report 2007-2008. , Department of Local Government and Regional Development, Government of Western Australia.

Summers, R.N. et al. 2002. The use of Bauxite Residue to control diffuse phosphorus pollution in Western Australia – a win-win-win outcome. Proceedings of the 6th International Alumina Quality Workshop.

Safety and Technical Review

Akay G,Keskinler B, Cakici A and Danis U, 1998. 'Phosphate removal from water by red mud using crossflow microfiltration'. Water Research, Volume 32, Number 3, 1 March 1998 , pp. 717-726(10)

Akhurst, D.J., Jones, G.B., Clark, M. & McConchie, D., 2006, 'Phosphate Removal from Aqueous Solutions using Neutralised Bauxite Refinery Residues (Bauxsol (TM))', Environmental Chemistry, Vol. 3 (1), pp. 65-74.

Alcoa, 1982, 'Point Comfort Roundup', unpublished, 19 February.

Allen J, 1997, 'Investigation of Mineral Profiles and Health of Cattle Grazing Pastures Top-dressed with Alkaloam in the Meredith Region of the Peel-Harvey Coastal Plain Catchment', Agriculture Western Australia, South Perth, W.A.

Amritphale, S. S., Anshul, A., Chandra N, & Ramakrishnan, N., 2007, 'A Novel Process for Making Radiopaque Materials using Bauxite: Red mud', Journal of the European Ceramic Society, Vol. 27 (4), pp. 1945-1951 [7 page(s) (article)] (50 ref.).

Anderson, S., Hensley, P., & Smirk, D.,n.d., 'The Chemical Characteristics of Leachate from Blended Bauxite Refining Residue', Journal of Geotechnical Engineering, SE Asia Region, Vol. 23 (2), pp. 171-197.

ANZECC, 1992. 'Australian and New Zealand guidelines for the assessment and management of contaminated sites', January 1992.

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2008. Code of Practice for the Safe Transport of Radioactive Material . Australian Radiation Protection and Nuclear Safety Agency – Radiation Health Series No 2.

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2008. Management of Naturally Occurring Radioactive Material (NORM). Radiation Protection Series Publication No. 15.

Awad, AS, Ross, AD, and Lawrie RA, 1989. Guidelines for the use of sewage sludge on agricultural land. NSW Agriculture and Fisheries, December 1989.

Ballance, 2009. 'Trace elements in the soil'. Website (last visited: 14 July 2009): http://www.ballance.co.nz/Education/Fertilisers_in_the_soil/Trace_elements_in_the_soil.asp?PageID=4068&ID=9&CatID=2056&Level=1

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

Bennet-Chambers M, Davies P and Knott B, 1999. 'Cadmium in aquatic ecosystems in Western Australia: A legacy of nutrient-deficient soils'. Journal of environmental management, Vol. 57, No. 4, pp. 283-295.

Bunemann E. K., Schwenke G. D. and Van Zwieten L. (2006) 'Impact of agricultural inputs on soil organisms—a review'. Australian Journal of Soil Research, 44, 379–406

Carter C, Ticehurst P and Cooling D, 2009. Fundamentals for Chromium (VI) Speciation and Formation – Summary of Projects FO0335 and FO0414 as relating to Western Australian Residue. Internal Alcoa report of the Technology Delivery Group.

2 References

Carter C, van der Sloot HA & Cooling D, 2009 b. 'pH-dependent extraction of soil and soil amendments to understand the factors controlling element mobility'. European Journal of Soil Science, August 2009, Volume 60, pp. 622-637.

Courtney R, Timpson JP and Grennan EF, 2003. 'Growth of Trifolium pratense in Red Mud Amended with Process Sand, Gypsum and Thermally Dried Sewage Sludge'. International Journal of Surface Mining, Reclamation and Environment, Volume 17, Number 4, December 2003 , pp. 227-233(7)

Department of Agriculture and Food WA, 2006, 'EPA Progress and Compliance Report'.

Department of Agriculture, 1993, 'Use of Bauxite Residue in the Peel Harvey Coastal Plain Catchment – Public Environmental Review'.

Department of Environment and Conservation, 2003. 'The Contaminated Sites Act 2003 (Act)' and the associated 'Contaminated Sites Regulations 2006.' See website (visited 21/04/09: http://www.dec.wa.gov.au/pollution-prevention/contaminated-sites/contaminated-sites-act.html

Department of Environmental Protection, Water and Rivers Commission and Department of Health, 2002. Western Australian Guidelines for Direct Land Application of Biosolids and Biosolids Products. February 2002.

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

Donoghue, A., Michael and Cullen & Mark. R., 2007, 'Air Emissions from Wagerup Alumina Refinery and Community Symptoms: An Environmental Case Study', Journal of Occupational & Environmental Medicine, 49(9), pp. 1027-1039, September.

ENVIRON, 2003. 'Pinjarra Refinery Efficiency Upgrade Environmental Protection Statement.' Prepared for Alcoa World Alumina, December 2003.

ENVIRON, 2008. 'Screening health risk assessment of particulate emissions from Alcoa's Pinjarra refinery residue disposal area'. Report for Ecowise, August 2008.

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

Environmental Protection Authority (EPA), 1993, 'Widespread Use of Bauxite Residue, Peel-Harvey Coastal Plain Catchment: Report and Recommendations', EPA, Perth, W.A.

Environmental Protection Authority (EPA), 2008, 'Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System', EPA, Perth, W.A.

Environmental Protection Authority, 2000, 'Widespread Use of Bauxite Residue Peel Harvey Coastal Plain Catchment - Extension of Approval Time Limit: Section 46 Report & Recommendations', EPA, Perth, W.A.

Foth, H.D. and Ellis, B.G. (1997). Soil Fertility. CRC Press LLC, Boca Raton, Florida.

FSANZ, 2001. 'Australia and New Zealand Food Standards Code'. Available online (viewed 13 Jan 2009): http://www.foodstandards.gov.au/thecode/foodstandardscode.cfm

Giller KE, Witter E, McGrath SP (1998) 'Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: a review'. Soil Biology and Biochemistry 30, 1389-1414.

Hanahan C, McConchie D, Pohl J, Creelman R, Clark M, Stocksiek C, 2004. ' Chemistry of Seawater Neutralisation of Bauxite Refinery Residues (Red Mud).' Environmental Engineering Science. March 1, 2004, 21(2): 125-138

Heady, G and Ferreira, C. Vegetation Health Analysis (Peel-Harvey coastal plain catchment)- An impact study on the use of Alkaloam (Bauxite Residue) as a soil amendment on agricultural land. Landcare Solutions, 2002.

Hofstede HT and Ho G, (1991). 'The effect of the addition of bauxite refining residue (red mud) on the behaviour of heavy metals in compost'. In: Vernet, J-P. (Editor) Trace metals in the environment volume 1: Heavy metals in the environment. Elsevier, Amsterdam, pp 67-94

IAEA, 2002. ' Questions and Answers on depleted uranium and related topics'. In: 'Features: Depleted Uranium.' IAEA website (visited 14 Jan 2009): http://iaea.org/NewsCenter/Features/DU/du_qaa.shtml

ICRP, 2007. ICRP-103: The 2007 Recommendations of the International Commission on Radiological Protection. Annals of the ICRP, Vol 37, Parts 2 – 4. International Commission on Radiological Protection.

2 References

Jakowyna, B.N., 2000, 'Nutrients in Tributary Inflows to the Peel-Harvey Estuarine System, Western Australia: Status and trend', Water and Rivers Commission, Aquatic Science Branch, Perth, W.A.

John Consulting Services (JCS), 1996, 'Meredith Alkaloam Subcommittee Bauxite Residue Soil Amelioration Meredith Catchment Review of Monitoring Programme - Final Report', JCS, Applecross, W.A.

Kirk PWW, 1987. 'Pollution Control Legislation, Ch 3 in Heavy Metals in Wastewater and Sludge Treatment Processes', Ed. Lester, J. N. CRC Press Boca Raton, Florida.

Kullmann A, Machalett B, Lehfeldt J, Starosta KH and Felgentreu I, 1982. 'The effect of chemically modified red sludge on the heavy metal content in some plants and on water retention of sandy soil'. Arch. Acker-u. Pflanzenbau v. Bodenkd. 26, 65-70.

Lee KE and Pankhurst CE, 1992. 'Soil organisms and sustainable productivity'. Australian Journal of Soil Research 30(6) 855 – 892.

McLaughlin MJ and Smolders E. 2001. 'A rationale for the metalloregion approach to risk assessments for metals in soil – a case study for effects of zinc on microbial functions in soil'. Environmental Toxicology and Chemistry 20, 2639-2643.

McLaughlin MJ, Stevens DP, Zarcinas BA and Cook N. 2000b. 'Testing soils and plants for heavy metals'. Communications in Soil Science and Plant Analysis. 31, pp. 1661 -1700.

Molloy et al, 2005. 'Background and Scope for establishing a list of prohibited substances and guideline limits for levels of contaminants in fertilisers'. April 2005. Prepared for Product Safety and Integrity Committee, Fertiliser Working Group. Final Scoping Report.

MPL Occupational & Environmental Services, 1997, 'Certificate of Analysis TCLP Results for Agriculture WA'.

MPL Occupational & Environmental Services, 1998, Dust Level Determination Report to Agriculture WA: Meredith Region Alkaloam (Red Mud) Test and Control Sites, MPL, Myaree, W.A.

Musk, A.W., de Klerk, N.H., Beach, J.R. et al., 2000, 'Respiratory Symptoms and Lung Function in Alumina Refinery Employees', Journal of Occupational Environmental Medicine, Vol. 57, p.p. 279-283, April.

National Health and Medical Research Council (NHMRC). 2004. Australian Drinking Water Standards. Available online at: http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm

National Research Council, 1980. Mineral tolerance of domestic animals. National Academy of Sciences, Washington DC.

NEPC (National Environmental Protection Council), 1999. 'National Environment Protection (Assessment of Site Contamination) Measure 1999. Schedule B(1) Guideline on the Investigation of Levels for Soil and Groundwater. NEPC, Adelaide, 16p.

NPI, 2006. 'Chromium (VI) compounds fact sheet'. NPI website (viewed 12 Jan 2009): http://www.npi.gov.au/database/substance-info/profiles/25.html

Rivers, M., 1998, 'The Use of Bauxite Residue as a Soil Amendment in the Peel-Harvey Coastal Plain Catchment Environmental Monitoring Report - July 1998', Agriculture W.A., Pinjarra, W.A.

Rivers, M., 1999, 'Alkaloam Environmental Monitoring Report', Agriculture W.A., Pinjarra, W.A.

Rivers, M., 2001, Alkaloam Q+A Sheet: AGWEST and Alcoa distribution only, unpublished.

Roberts, FJ, and Carbon BA, 1971. Water repellence in sandy soils of south-western Australia.1. Some studies related to field occurrence. Australian Journal of Soil Research. (10), 13-20.

Robertson WJ, Jeffery RC, & McPharlin IR, 1999, 'Yield and Phosphorus Nutrition of Potatoes (Solarium Tuberosum L.) cv. 'Delaware' Grown on a Yellow Karrakatta Sand Containing Freshly- and Previously-Applied Alkaloam-gypsum', CSIRO, Perth, W.A.

Robertson, W.J., McPharlin, I.R. and Jeffery, R.C., 1994. 'Final report of investigation into the use of gypsum-amended red mud as a soil-amendment on horticultural properties on the Swan coastal plain'. Dept. of Agriculture, W.A.

Robertson, W.J., n.d., 'The Germination of Carrot Seeds (cv. 'Western Red') in a Virgin Joel Sand Mixed with Red Mud/Gypsum', unpublished.

Robertson, WJ, Jeffery, RC, & McPharlin. IR, 1997, 'Residues from Bauxite-Mining (Red Mud) Increase Phosphorus Retention of a Joel Sand Without Reducing Yield of Carrots', Marcel Dekker, Inc.

Roussel-Debet S, Deneux-Mustin S and Munier Lamy C, 2005. 'Screening the importance of soil micro-organisms on radionuclides mobility'. Radioprotection

2 References

Ryle G, 2002. 'The great mud experiment that went radioactive'. Sydney Morning Herald. May 7th 2002.

Scheffer, B., Bartels, R. & Blankenburg, J., 1985, 'Practicable Application of Red Sludge and Melanterite on Peat Bog Soils', Z. Pflanzenernaehr. Bodenk, 148, p.p. 527-535.

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

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

Smith, G.M., 1997, 'Monitoring the Heavy Metal and Mineral Status of Sheep Grazing Irrigated Pasture Established on Bauxite Residue Sand - 96HA5', Agriculture W.A., South Perth, W.A.

Smith, G.M., 1998, 'Monitoring the Mineral Status and Health of Sheep Grazing on a Rehabilitated Bauxite Residue Stockpile and on Alkaloam Amended Pasture', Agriculture W.A., South Perth, W.A.

Smith, G.M., 1998, 'The Mineral Status of Sheep Grazing on Pasture Grown on Soil Amended with Bauxite Residue - Draft 2', Agriculture W.A., South Perth, W.A.

Snars K, 2003. 'The effects of Bayer process red mud on the P retention and pH of soils.' Doctor of Philosophy Thesis, University of Western Australia, School of Earth and Geographical Sciences, Faculty of Natural and Agricultural Science, 2003.

Snars K, Gilkes R and Hughes J, 2003. 'Effect of soil amendment with bauxite Bayer process residue (red mud) on the availability of phosphorus in very sandy soils'. Australian Journal of Soil Research, 41(6) 1229 – 1241.

Sorvari J, Warne MStJ, McLaughlin MJ, Kookana R, 2008. 'Draft Report: Proposed Methodology for Conducting an Assessment of Contaminants and Ingredients in Fertilisers'. Report for the Federal Department of Agriculture, Fisheries and Forestry, February 2008.

Sri Wahyuni, A., Nikraz, H., Jamieson, E. & Cooling, D., 2006, 'Sustainable Use of Bauxite Residue Sand (Red Sand) in Concrete', Proceedings of Green Processing Conference, 5-6th June, 2006, Newcastle, NSW, Australia.

Standards Australia Committee CH/35. (1997) 'Wastes, Sediments and Contaminated Soils. Part 3: Preparation of leachates-Bottle Leaching procedure.' Australian Standard AS4439.3-1997

Stinson, J.M., 1982, 'Data Letter Re: Measurement of Bauxite Residue pH', Alcoa Technical Centre, Alumina Processes Division, 31 March.

Summers RN, Guise NR, Smirk DD & Summers KJ, 1996a, 'Bauxite Residue (red mud) Improves Pasture Growth on Sandy Soils in Western Australia', Australian Journal of Soil Research, Vol. 34, pp. 569-581.

Summers, K.J., O'Connor, B.H., & Fox, D.R.,1993, 'Radiological Consequences of Amending Soils with Bauxite Residue/gypsum Mixtures, Australian Journal of Soil Research, 31, pp. 533-538.

Summers, R. N. and Bradby, K. 1993. 'Use of Bauxite Residue in the Peel-Harvey Coastal Plain Catchment.' Public Environmental Review, submitted to Western Australia Environmental Protection Authority, April 1993.

Summers, R., Van Gool, D., Guise, N.R., Heady, G.J. & Allen, T., 1999, 'The Phosphorus Content in the Run-off From the Coastal Catchment of the Peel Inlet and Harvey Estuary and its Associations with Land Characteristics', Agriculture Ecosystems and Environment, Vol. 73, pp. 271-279.

Summers, R.N., & Pech, J.D., 1997, 'Nutrient and Metal Content of Water, Sediment and Soils Amended with Bauxite Residue in the Catchment of the Peel Inlet and Harvey Estuary, Western Australia', Agriculture Ecosystems and Environment, Vol. 64 (3), pp. 219-232.

Summers, R.N., & Smirk, D.D., 1992., 'Using Bauxite Residue to Conserve Agricultural Nutrients in Sandy Soils', Proceedings International Bauxite Tailing Conference, Western Australia, November 1992.

Summers, R.N., 2000, 'Code of Practice for the Distribution and Application of Alkaloam (bauxite residue) for Broadacre Agriculture and Horticulture in the Peel-Harvey Coastal Plain Catchment', December.

Summers, R.N., Bolland, M.D.A. & Clarke, M.F., 2001, 'Effect of Application of Bauxite Residue (red mud) to Very Sandy Soils on Subterranean Clover Yield and P Response', Australian Journal of Soil Research, Vol. 39 (5), pp. 979-990.

URS

2 References

Summers, R.N., Clarke, M.F., Pope, T. & O'Dea, T., 2000, Comparison of Single Superphosphate and Superphosphate Coated with Bauxite Residue for Subterranean Clover Production on Phosphorus-leaching Soils', Australian Journal of Soil Research, Vol. 38, pp. 735-744.

Summers, R.N., Guise, N.R. & Smirk, D.D., 1993, 'Bauxite Residue (Red Mud) Increases Phosphorus Retention in Sandy Soil Catchments in Western Australia', Fertilizer Research, Vol. 34, pp. 85-94.

Summers, R.N., Rivers, M.R., & Clarke, M.F., 2002, 'The use of Bauxite Residue to Control Diffuse Phosphorus Pollution in Western Australia – A win-win-win outcome', Department of Agriculture, W.A.

Summers, R.N., Smirk, D.D. & Karafilis, D., 1996(b), 'Phosphorus Retention and Leachates from Sandy Soil Amended with Bauxite Residue (red mud)', Australian Journal of Soil Research, Vol. 34 (4), pp. 555-567.

Tacey WH, Ward S C and Summers KJ 1984. 'Soil improvement with bauxite residue'. Journal of Agriculture (WA), 25:92-93.

The West Australian, 2002. 'Farmers damn mud trial, Red mud studies raise questions, Polluted, toxic mud, Jan. 21, Perth (2002) 29.

Townsend MC, Enterline PE, Susman NB, et al, 1985. 'Pulmonary function in relation to total dust exposure at a bauxite refinery and alumina-based chemical products plant. American Review of Respiratory Diseases, 1985; 132: pp. 1174-80.

Toxikos (2003). 'Health Risk & Toxicological Assessment of Emissions from the Upgraded Alcoa Pinjarra Alumina Refinery'. R. Drew, Toxikos Pty Ltd, 14 November 2003.

United States Environmental Protection Agency, 1999. ' Background report on fertiliser use, contaminants and regulations'. Report for USEPA by BATTELLE.

Van Zwieten L, Rust J, Kingston T, Merrington G, Morris S (2004) 'Influence of copper fungicide residues on occurrence of earthworms in avocado orchard soils'. The Science of the Total Environment 329, 29-41.

Vlahos S, Summers KJ, Bell DT and Gilkes RJ, 1989. 'Reducing phosphorus leaching from sandy soils with red mud bauxite processing residues'. Australian Journal of Soil Research. 27: 651-62.

Ward SC, 1983. 'Growth and fertilizer requirements of annual legumes on a sandy soil amended with fine residue from bauxite refining'. Reclamation and Revegetation Research. 2, 177-190.

Wayne SJ, McLaughlin MJ, and Kookana R, 2008. 'Draft Report: Proposed Methodology for Conducting an Assessment of Contaminants and Ingredients in Fertilisers'. CSIRO report for the Federal Department of Agriculture, Fisheries and Forestry, 29 February 2008.

Whittaker, C. W., Armiger, W. H., Chichilo, P. P. and Hoffman, W. M. (1955). 'Brown mud from the alumina industry as a soil liming material'. Soil Science Society Proceedings. 288-292.

Williams CH and David DJ, 1973. 'The effect of superphosphate on the cadmium content of soils and plants. Australian Journal of Soil Research, 11(1) 43 - 56

Zweiten, 2006. 'Impact of Agricultural Inputs on Soil Organisms'. Australian Journal of Soil Research.

Alkaloam® Project Administration and Approval Processes

Department of Primary Industries, State of Victoria, 2007. A Guide to Victorian Fertilisers. June 2007. Available online: http://www.dpi.vic.gov.au/

EPA Victoria, 2009. Secondary Beneficial Reuse Notification. Industrial Waste Resource Guideline. Available online: http://www.epa.vic.gov.au/waste/industrial-waste-guidelines.asp).

USEPA, Sector Strategies Division, 2002. Beneficial Reuse of Foundry Sand: A Review of State Practices and Regulations. Sector Strategies Division, Office of Policy, Economics and Innovation, US Environmental Protection Agency, December, 2002.

Benefit Cost Analysis

Atech, 2000. Cost of algal blooms. Reported submitted to Land and Water Resources Research and Development Corporation and Murray-Darling Basin Commission. Land and Water Resources Research and Development Corporation, Canberra.

Australian Government, 2007. Best practice regulation handbook, Canberra.

Department of Agriculture Western Australia (DAWA), 2003. Gross margins guide: Representative gross margins for crop and livestock enterprises of the agricultural regions of Western Australia.

2 References

Lavell. K, Summers. R, Weaver. D, Clarke. M, Grant. J, Neville. S., 2004a. An audit of the uptake of agricultural nutrient management practices in the Peel-Harvey catchment. Department of Agriculture, Western Australia.

Lavell. K., 2004b. Findings of a nutrient management social survey. Unpublished.

Pretty, J. N., Mason, C. F., Nedwell, D. B., Hine, R. E. Leaf, S. and Dils, R. ,2003. Environmental costs of freshwater in England and Wales. Environmental Science & Technology, 37: 201-208

Steffensen, D. A., 2008. Economic cost of cyanobacterial blooms. In Hudnell, H. K. (Ed.) Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs Series: Advances in Experimental Medicine and Biology, 619: 855-865.

URS, 2003. Economic evaluation of the cost of algal blooms in Central Gippsland. Draft report prepared for West Gippsland Catchment Management Authority, Traralgon, Victoria.

URS, 2005. Implementation Measures that Support, Influence, Encourage or Require Uptake of Best Management Practices for Nutrient Management, Report prepared for WA Department of Agriculture.

URS, 2007. State of Play: Peel-Harvey Eastern Estuary Catchment Environmental Assessment Discussion Paper, Report prepared for Department of Water.

Weaver, D.M., Neville, S.D, Summers, R.N and. Clarke M.F., 2004. Reducing nutrient discharge from agriculture through the implementation of BMPs – how far can we go? Paper presented to 2004 River Symposium

Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of the Centre for Sustainable Resource Processing and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 20 December 2007.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between February 2008 and November 2009 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties.

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