Ash Storage Area Rehabilitation

Options Assessment

Flinders Power

October 18

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1 Introduction

1.1 Background

Flinders Power, with the assistance of McMahon Services and Succession Ecology, is rehabilitating the ash storage area (ASA) as part of decommissioning the Augusta Power Station, Power Station Rd, Port Augusta. The ASA, which includes the former Ash Dam and Polishing Pond, is over 270 ha and was used to store bottom ash from the power station mixed with sea water resulting in a silty, saline soil-like material. The objective for rehabilitation of the ASA is to place a 0.15 m red clay cover soil and then revegetate with endemic vegetation and result in an environment sympathetic to the surroundings.

Placement of cover soil commenced in January 2017. Practical difficulties were experienced due to the low strength of the ash material. Earthworks were ceased for periods of time due to inaccessibility but the dry summer conditions have resulted in the majority of the site being covered by June 2018. Vegetation, including native grasses, saltbushes and other salt-tolerant and xerophytic native shrubs, has been planted in campaigns as areas were completed. Native vegetation is relatively slow at establishing compared with annual grasses and agricultural crops. The arid climate and naturally low-nutrient soil further slow germination and establishment. The borrow source pit is also being rehabilitated with similar species.

Strong, gusty spring and summer winds have generated dust from across the entire ASA. Flinders Power has been undertaking steps to prevent significant dust from occurring again. Dust suppressants were applied to the ASA in summer 2016/17; however, storm events reduced the efficacy of the suppressant. In 2017/18, the rehabilitation was only partially completed and vegetation had not established resulting in dust generation. Once established, the native vegetation will limit the magnitude and frequency of dust generated from the site; however, until the vegetation is established other options need to be considered.

For 2018/19 the entire ASA may be considered at risk of generating dust as the vegetation is still very small in the majority of areas. To date, no areas have been observed to generate more dust than others and hence immediate options will need to address the dust potential form the entire ASA. Over time, as vegetation establishes, this is likely to change and specific measures may be appropriate to smaller areas of the ASA.

Flinders Power has continued to investigate other options which may be deployed to minimise dust generation (see Section 3 for further details) and comply with SA EPA's requirements. EPA Licence 13006 includes the following requirements for the assessment of options (Condition U-855):

The Licensee must:

1. *appoint a suitably qualified expert(s) to undertake a detailed assessment of options to prevent or minimise particulate emissions from the Premises;*
2. *ensure that the Options Assessment incudes a comprehensive investigation and assessment of best-practice options to prevent or minimise particulate emissions from dust sources at the Premises, including, without limitation*
   a) *comprehensive details of each option investigated and assessed including the technical aspects, resources involved for implementation, timelines to achieve effective dust control, known examples of the options investigated having been successfully applied elsewhere and limitations associated with each option;*
   b) *the feasibility of each option; such feasibility to also consider the risks and recommendations for dealing with such risks;*
   c) *the methodology applied and considerations involved in selecting the recommended options; and*

d) *the recommended option(s) to be taken to prevent or minimise particulate emissions and a plan for implementation of such options including specific actions and timelines*

3. *submit the Options Assessment to the EPA by the date listed below.*

Tonkin Consulting with Red Planet Innovations was contracted by Flinders Power to complete the Options Assessment nominated, which was submitted to EPA by 30 June 2018 (the nominated compliance date). EPA provided comments on 6 July 2018. This revision seeks to incorporate these comments.

1.2 Objectives

The objective of this report is to investigate and assess the potential options available to Flinders Power for the suppression of dust from the Augusta Power Station, as defined by requirements 2a-2c above. A variety of options have been investigated but the assessment has focussed on the ASA, as the most at risk aspect of the August Power Station site and on options able to be deployed across the entire ASA as the vegetation establishment prior to the 2018/19 summer is unlikely to significantly reduce dust generated. As vegetation establishment increases, this assessment matrix can be used to reassess the options for specific locations. These options may also be deployed on the borrow pit, the Flinders Power-owned portion of Bird Lake and the rehabilitated coal stockpile.

1.3 Scope

In undertaking this project, Tonkin Consulting and Red Planet Innovations have undertaken the following tasks:

- Site Visit
- Develop Options List with Flinders Power.
- Develop a table for each option of resource requirements, timing, cost, expected outcomes, proven experience
- Prepare report recommending option/s to move forward.

This Options Assessment has considered options which are likely to provide short- and medium-term dust control. Native vegetation, once established, will provide a long-term, self-sustaining solution to dust suppression.

1.4 Report Authors

As requested by EPA, Flinders Power has engaged suitably qualified and experienced experts to prepare this assessment. This report has been prepared by:

- Dr Melissa Salt, Tonkin Consulting. Melissa is a Certified Professional Soil Scientist with over 25 years' experience. Melissa started her career in research with NSW Agriculture and then moved to private industry where she has been involved in rehabilitation of agricultural land and completed landfills as well as experience in environmental management during construction projects, including rehabilitation works.
- Dr Leong Mar, Red Planet Innovations. Leong has over 20 years' experience including 10 years with DuPont where he was involved in research, development and commercialisation of products and technologies for dust management. He led the development of Australia's best performing range of dust suppression chemicals and pioneered dust management systems for coal trains in transit and coal shipping terminals. In 2014, Leong established Red Planet Innovations to provide dust management consulting advice to mining and other industries.

Curricula vitae for Dr Salt and Dr Leong can be provided upon request.

2 Wind Erosion

2.1 Wind Erosion Mechanism

Wind erosion occurs when the wind velocity exceeds the gravitational and cohesive forces of the soil. Wind erosion occurs by three mechanisms:

- soil creep: larger soil particles/aggregates (0.5-0.85 mm) tend to roll or bump across the unstable surface;
- saltation: medium sized particles/aggregates (0.1 – 0.5 mm) tend to jump or bounce across the surface but usually remain within 0.5 m of the surface. Upon impact with the ground, these particles dislodge other particles. The large area of the ASA and strong winds experienced at the site would result in saltation likely to be significantly contributing to dust generation;
- suspension: finer soil particles are suspended in the air and carried horizontally over the surface. The number of particles in suspension increases with saltation.

The latter is likely to be the main concern as it is most visually obvious and likely to move outside the property boundary; however due to the relationship with saltation, this must be considered also.

Wind erosion increases as wind velocity, turbulence and duration increases and decreases with increasing soil particle size, weight and cohesive forces, with the shape of the particles also playing a role. The two best defences against wind erosion are moisture, as moist soil is not eroded by wind, and vegetation, which protects the surface and binds the soil. The large area and open expanse of the ASA does not provide any impediment to wind, such as tortuous paths, and hence no reduction to wind velocity is realised. The ash surface consisted of fine particles with little cohesion when dry so was readily eroded by wind. The soil cover placed in 2017/18 to improve the plant growth potential was also placed to prevent wind erosion of the ash; however, though more cohesive and a broader range of particle sizes, dust was still generated.

To minimise dust generation, it is important to understand the climate which impacts the potential for soil to be moist (as influenced by rainfall and evaporation) and the strength, direction and seasonality of strong and gusty breezes; this latter aspect determines the erosivity. The climate will affect the length of time controls are required and whether controls can be oriented to a particular direction. The soil properties are also important in determining the amount of soil which is lost and at what wind speed, i.e. the erodibility. Indirectly the climate and soil also influence the types of plants which can be grown.

2.2 Wind Erosivity

The potential for wind erosion to occur is firstly controlled by the ability of the wind to erode soil, i.e. the erosivity; if there are only gentle breezes then even the most susceptible soil won't erode. Wind speed roses for Port Augusta (Figure 2.1) show frequent strong southerly winds are prevalent in summer and spring. Strong winds in Spring can occur from south east to northerly directions. Winter and autumn have a larger percentage of calm conditions with winds tending to be lower velocity; however strong southerly winds may still occur.

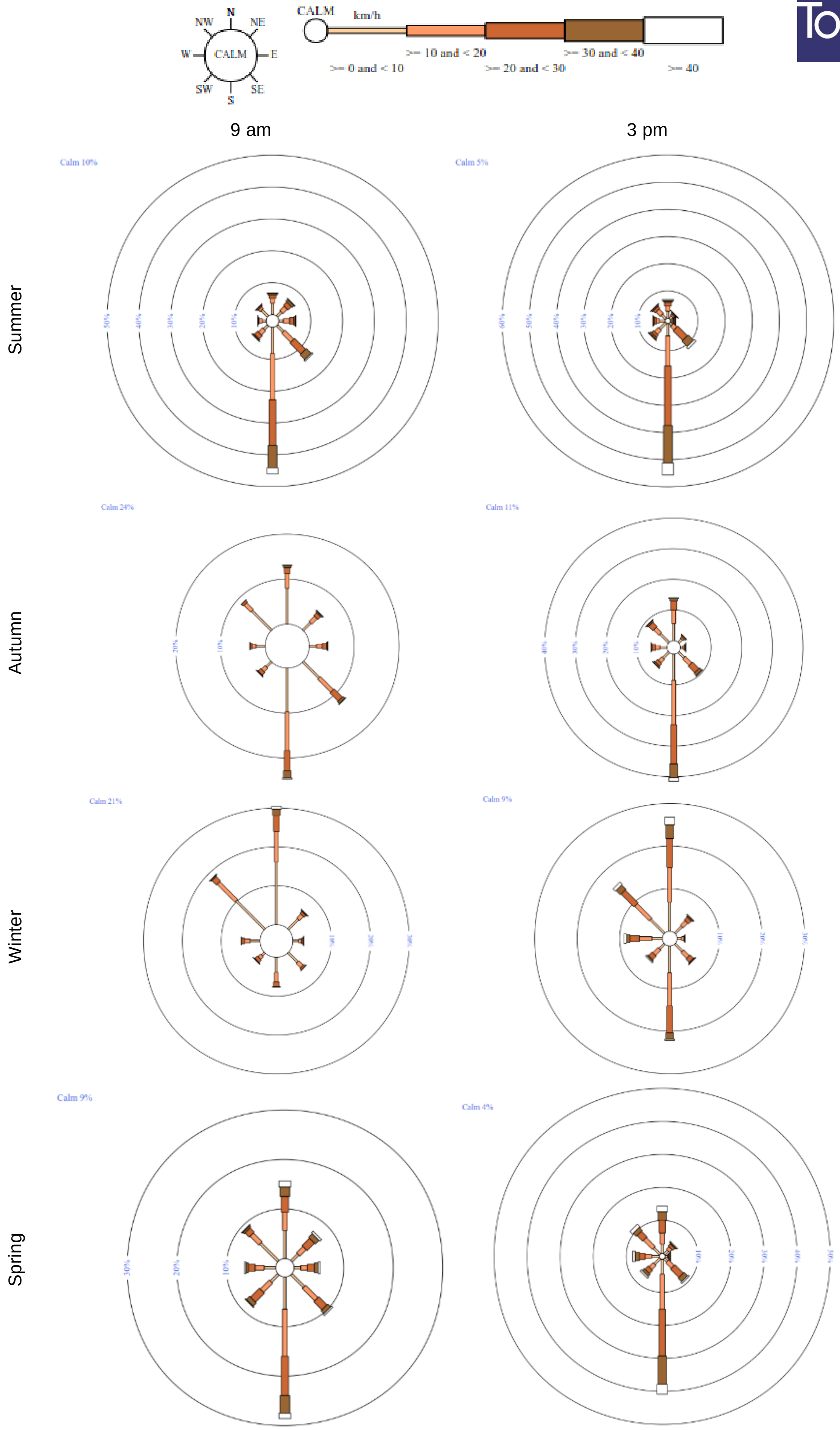

Figure 2.1 Seasonal Wind Roses for Port Augusta

2.3 Soil Erodibility

The properties which are important in affecting whether the soil is susceptible to wind erosion, i.e. the erodibility, are:

- Soil Moisture: moist soil is not susceptible to wind erosion as the cohesive forces are substantially increased.

  Port Augusta experiences an arid climate being hot persistently, dry grassland to desert. Mean annual rainfall is 263 mm, likely to occur in any month with all on average reporting < 30 mm/month (Figure 2.2) but is highly variable on a daily and monthly basis. Rainfall is exceeded by evaporation in all months of the year with evaporation significantly reduced from May to August as are daily temperatures. On average, daily minima < 2 °C occur 5 days/yr and maxima > 40 °C occur 11 days/yr. Overall, the soil is likely to remain dry for extended periods of time.

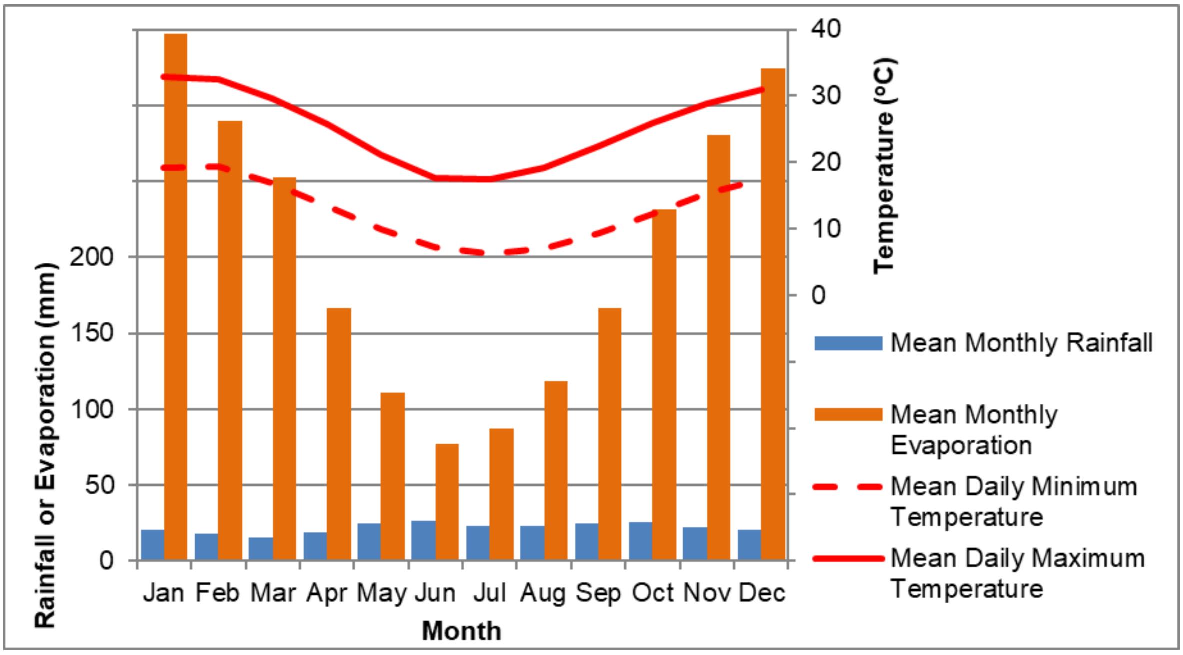

Figure 2.2 Climate Data for Port Augusta

- Soil texture: In general, the higher the clay and silt content, the higher the percentage of non-erodible clods and the lower the erodibility. The higher the proportion of fine sand the lower percentage of non-erodible clods and the higher the erodibility.
- Soil structure: well-structured soil forms aggregates which in turn resist erosion, though this depends on the aggregate size, shape and density. Where the aggregates exceed 0.85 mm, the erodibility of the soil is substantially reduced.
- Mechanical Stability: the resistance of the soil to mechanical breakdown, e.g., from ploughing, is important in resisting wind erosion, particularly on a bare surface.

Ad hoc testing of the cover soil (4 samples) has been undertaken by others (Appendix A) and indicates that the capping soil has:

- a high proportion of silt and clay with 51-68% but the remainder is predominantly fine sand which ranges from 25-38% and is likely to be erodible.
- relatively low levels of organic carbon, which assists in aggregation, so cohesion of the soil is likely to be limited.
- relatively high sodium content which tends to result in dispersive soil can lead to hard-setting surface which may resist wind erosion but if disturbed, e.g. by trafficking, is likely to

be highly susceptible to generating dust. Dispersibility also decreases mechanical stability with aggregates tending to erupt rather than break into smaller aggregates.

The physical and chemical properties do not suggest the soil is likely to form stable aggregates but the formation of surface crusting would reduce potential for wind erosion. The climate of Port Augusta is arid with low rainfall and high evaporation which is likely to result in the surface materials remaining dry for extended time periods.

Based on the soil properties, the high clay content is likely to reduce the potential for wind erosion. In some areas, the lack of aggregation and moderate fine sand content of the material are conducive to wind erosion. Overall, the soil is unlikely to be regarded as highly erodible but under the right prevailing conditions, dust may be a nuisance. During summer 2017/18, the right conditions prevailed and during strong to gale force, gusty winds, dust was generated from the ASA for short periods.

3 Preliminary Options Investigations

Following 2017/18 summer, Flinders Power engaged Tonkin Consulting in March 2018 to research other options which may be deployed to minimise dust from the ASA. Four options, excluding chemical dust suppressants, were initially identified as having some potential, being:

- Porous mesh wind breaks and fences. Fences trap sediment on the windward side and reduce the wind speed on the leeward side. Fence height of 0.5 m need to be spaced approx. 4 – 14 m apart (depending on soil properties) to minimise dust. Although immediately effective, the installation of fences is labour intensive and would disturb establishing vegetation.

  Flinders Power trialled a small section of porous fences and found the trapped sediment was remobilised by cross winds. As shown in the wind roses, although strong winds are most likely southerly, northerly and westerly winds can also occur > 40 km/hr and hence the orientation of fences to account for the southerly winds does not account for these cross winds.

- Large bales. The placement of the bales in a set array increases the surface roughness thereby decreasing the wind velocity. The placement is still affected by wind direction but to a lesser extent than fences. The field scale example was limited to one trial in sand country in California (Gillies *et al*., 2015) and deployment of the bales would impact vegetation establishing on the ASA. This option has not been discussed further in this options assessment as it is not an established technique for controlling dust, would impact on vegetation growth and is a waste of a valuable resource.

- Straw checkerboard. The use of straw checkerboard is commonly used in Asia and China as well as North America. Straw is half buried in the ground at approx. 1 m squares and increases the surface roughness. Trials have shown that the majority of erosion is controlled by wind speeds at around 0.1 m from the ground and hence the straw effectively reduces sand erosion. This technique is not affected by variable wind speeds and assists in providing micro-climates for establishing vegetation; however, it is mainly deployed in sand deserts and is highly labour intensive.

- Irrigation. Irrigation is the most common form of dust suppression. Moisture increases particle cohesion and hence prevents wind erosion. Although well established as a technique, the extremely dry and windy spring and summer experienced at Port Augusta is likely to result in impractical and uneconomic quantities of water to maintain a moist surface. Irrigation can also be applied to promote vegetation growth.

  Flinders Power has been trialling sprinkler irrigation on selected areas of the ASA to determine if germination and/or establishment of native vegetation is improved. Mixed results have been achieved to date.

Flinders Power staff observed that an area where the piston bully had been working and had roughened the soil surface appeared to trap sand. A trial was established to qualitatively investigate the potential benefits of surface roughening. This included areas within the borrow pit where several 2 m wide strips have been ripped at approx. 5-10 m spacing in a crosswind direction. Visual observations will be undertaken to determine the potential impact on germination and dust generation over time. Further details are contained within the specific trial plan.

During 2018, Flinders Power has been sourcing and collecting information from suppliers on potential dust suppression techniques and discussing potential grass species which may survive on the ASA with local agronomists. In May 2018, a workshop was held at the Augusta Power Station with Flinders Power, McMahon Services, Succession Ecology and Tonkin Consulting to discuss and short-list possible options for improving dust suppression from the ASA. The basic options discussed included:

- Dust suppression. An example of the application of dust suppressants at two rates was prepared and discussed during this workshop. The soil samples were sieved prior to application and it was evident that the application impacted on the soil physical properties as the rate of water infiltration was dramatically reduced with increasing application rate. It was further noted that the duration of suppression quoted varied for specific application rates but it was unclear what factors affected the duration, e.g. surface roughness, temperature, UV, etc.
- Irrigation
- Wastewater irrigation
- Cover crops
- Mulches

From this meeting, several outcomes were agreed. It was agreed that multiple trials would be undertaken to better understand the potential success and impacts on the planted native vegetation. It was also agreed that more specialised, independent knowledge was required to understand the possible impact of dust suppressants. The specific outcomes were:

- Assess viability of seedbank and the impact of dust suppressants on native vegetation germination and on establishing/ed native vegetation, water penetration and flow and soil stability. Proposed as a glasshouse trial;
- Quantify the impact of irrigation on the germination and establishment of native vegetation in the field using impact sprinklers and water carts;
- Assess potential for cover crops, being sterile rye corn and Mundah Barley, to establish and impact, positively or negatively, on native vegetation establishment;
- Continue to monitor areas of surface roughening for minimising soil erosion;
- Engage Red Planet Innovations to assist in understanding dust suppressants;
- Sample soil to understand the soil chemical properties of the cover soil and an understanding of the likely variability in properties.

Trial plans have been prepared and trials are underway with results expected in August 2018; these plans have been submitted to EPA. Red Planet Innovations were engaged and have contributed to this report. Soil sampling was undertaken in July 2018 to address:

- Variability of the soil. Grab samples have been collected from the borrow pit walls from 0.5 m intervals. These samples will assist in defining the likely range of properties in the cover soil.
- Average properties of soil on areas of the ASA. Composite samples have been collected from the monitoring blocks and, where evident, from sub blocks with apparently differing soil surface or vegetation establishment. These samples will assist in determining if some areas are more likely to generate dust and could be subject to targeted management.
- Association of visual surface condition with soil properties. Visual assessment of the soil surface has suggested that some areas are visually distinct. Grab samples have been recovered from these areas to determine if these surficial properties can be used to identify "problem" areas.

Borrow pit samples will be analysed for particle size distribution, pH, salinity, exchangeable cations, chloride, sulfur, boron and organic carbon to determine the properties with the greatest range. These properties will then be targeted in the remaining samples to better define the soil erosion risk. Analysis results are pending with the report due in August 2018.

These trials are not being undertaken to prejudice the options assessment but to ensure that data-gaps are being investigated whilst other options are understood and assessed. Given the early stage of these trials, results are not available and hence they have not been able to inform this assessment. Once results are available this assessment can be reviewed if required.

4 Soil Covers

Soil covers change the surface erodibility by preventing wind from contacting the soil surface or by being inherently not able to be eroded, i.e. too heavy. Soil covers may also reduce the wind velocity near the soil surface by providing a rougher surface which results in more drag.

The main soil covers investigated which are consistent with the long-term goal of revegetating the site were:

- Vegetation
- Organic mulch
- Inorganic mulch/ gravel

Other options, such as bituminising, concreting or otherwise sealing the surface were not investigated as they are not consistent with the long-term goal or revegetating the site. In addition, to place the cover soil it was necessary to use low-ground pressure machinery, i.e. track machines not wheeled machines, due to the low bearing strength of the underlying ash. As a result, it would be practically difficult to construct or install a sealed surface.

4.1 Vegetation

A range of native vegetation was sown in the cover soil on the ASA with planting commencing on 103 ha in June 2017 and then 78 ha in August 2017. The remaining areas have been and are being planted in 2018. Given the vegetation on the capped ash dam is establishing, it is important to ensure that this longer-term protection measure is not compromised. The vegetation planted on the ASA focussed on native vegetation as this was required by the Native Vegetation Council and concerns that a cover crop may outcompete the native vegetation. Native grasses were included in the seed mix to provide a more rapid cover of the ASA; however, germination of these grasses has also been slow.

Vegetation cover of > 30% and preferably > 50%, significantly reduces wind erosion potential on most soil types (Leys, 2003; Natural Resources South East, 2017). Native vegetation is typically slow to establish, usually requiring at least 1-3 years depending on species and is likely to require longer in the challenging climatic and soil conditions on the ASA. In many rehabilitation programs, sterile rye corn (*Secale cereale*) is planted as a cover crop to suppress weeds and protect the soil surface whilst the native vegetation establishes (Figure 4.1). In addition to sterility to prevent colonisation, rye corn is fast-establishing (ready to graze in 30 days), tall (can be > 1 m), tolerant of a range of climate and soil conditions (including low and variable rainfall areas) provides good ground cover and residues are more persistent than other grasses. Rye corn does exhibit allelopathy (i.e. inhibits growth of other plants) on some plants species growing with it and this can persist for a few months in the crop residues (Clark, 2007).

Figure 4.1 Rehabilitation Trial Site in Melbourne (Vic) approx. one year after planting with sterile rye corn and native grasses. Rye corn is now stubble allow native grasses to emerge (Photo: courtesy of author)

Barley is known to be highly tolerant of salinity and is more readily available near Port Augusta than sterile rye corn. Barley is also fast-growing (ready to graze in 30-45 days) and tolerant of low fertility soil, though not tolerant of waterlogged conditions. Barley is not generally a strong coloniser and rarely persists into the following year without further sowing (Department of Agriculture, 1987). Mundah barley is a forage barley which is known to establish quickly and was recommended by a local agronomist. The stubble is considered to be resilient compared with oats (Natural Resources South East, 2017).

Cover crops are used widely in agriculture in South Australia and around the world for a variety of reasons, including to control wind erosion. In the South-East and Mallee regions of South Australia, cover crops are used to hold sandy soil whilst cash crops establish. Cereal rye in combination with legumes are often used for this purpose. In vegetable cropping, grasses are planted in the interrow spacing to protect soft vegetables from being damaged by wind erosion. The grass limits contact of the wind with the soil and the roots hold the soil in place. Once the grasses die, the stubble or residue continues to protect the surface. Natural Resources South East (2017) classes cover based on height (as the primary factor) as well as cover %, bulk and anchorage. The least susceptible (Class 1) are noted as having residues of 40 cm or higher, 75-100% cover, high level of plant matter and good anchorage. Moderate susceptibility (Class 4-5) has residues of 2-10 cm or variable with low to moderate bulk, majority of residues anchored and 50-75% coverage; this coverage is likely to be possible for the ASA.

Cover crops are typically planted at the same time as the other seeds. The ASA has already been sown to native vegetation so wide-spread planting of cover crops is not possible without disturbing native germinants and seed and either burying or exposing it. To manage this risk, single rows of a cover crop approx. 1 m apart can be planted to limit disturbance to native species and limit competition for light, moisture and nutrients and any potential allelopathy. Alternatively or in addition, the seeding rate may be reduced to limit competition. For the Cover Crop Trial both single rows and reduced seeding rates have been included.

Cover crop seed is available regionally and can be readily transported to site. Standard agricultural practices, including fertiliser application and machinery, are locally available. Irrigation may be useful in assisting germination and establishment of the cover crop and is currently part of a trial on the ASA. Discussion on irrigation methods and requirements is provided in Section 6 with the discussion on use of irrigation for dust suppression. No other resources are required.

Based on information from local agronomists, machinery costs for sowing are $25/ha to hire and Mundah Barley seed is $0.85/kg. Mundah barley is typically applied at seeding rates of 20 – 50 kg/ha, resulting in a cost of approx. $12,000 – $20,000 for the entire ASA. Sterile rye corn is more expensive than barley and including a fertiliser may increase the cost to closer to $30,000 – $50 ,000 for the entire ASA. Transport costs would be additional but overall this option is <$100,000 for the entire ASA. The crops are annual and hence would need to be re-established on an annual basis.

4.2 Organic Mulch

Organic mulches are typically produced from shredded timber but are not pasteurised like composts. Organic mulches are used to protect the soil in many applications and have the added advantage of promoting microbial activity, retaining moisture and increasing soil temperature. Mulches need to be purchased from reputable sources or issues with weeds may result.

Placing a mulch on the soil surface can protect the surface from wind erosion by protecting the surface. The increased roughness may also assist in reducing near-surface wind speed. During high winds the mulch may generate dust if not clean or in very high winds may become air-borne. This risk may be managed by sourcing clean mulch screened to a large particle size, e.g. > 25 mm, incorporating the mulch into the soil or applying with tackifiers, i.e. hydromulching. Incorporating the mulch would potential expose and bury native plant germinants and seed and hence has not been considered further.

Mulch could be applied by a tractor-drawn spreader; as with the mulch, this would need to be sourced from Adelaide. No other resources are required. The cost of mulch varies but 40 mm graded pine bark with no fines is quoted to cost $55/m^3. Based on a 100 mm thickness of mulch, 270,000 m^3 would be required to cover the ASA and cost around $15M. This has been quoted as delivered but assumes backloading (around 4000 semi-trailer loads) from Adelaide and application costs could double the purchase price.

Hydromulching is a process that involves spraying a mixture of fibrous mulch and soil stabilisers (tackifiers, polymers and seeds) onto the ground to help reduce erosion and foster the growth of new vegetation. This technique is often used to assist recovery of burnt areas after fires (US Forestry Service). The use of tackifiers helps the mulch remain stuck to the ground where dry mulch may not be appropriate. Dry weather may harm the effectiveness of hydromulch for preventing erosion. The advantages of hydromulch include the cost effectiveness of the technique and the promotion of vegetation growth. The disadvantages of the technique include the questionable effectiveness against dust emissions, the impact upon existing planted vegetation and the potential poor performance in very dry environments.

Hydromulch can be applied either from ground vehicles or aircraft, with the cost varying according to the availability of hydromulch services, the availability and location of water, the number of seed mixes, the accessibility and terrain, aircraft staging area location (if appropriate) and the application rates. The US Forest Service suggests that hydro mulching for burnt areas costs $US 2000-$US 3000 per acre (app $AU 6450-$AU 9700 per hectare) for aerial applications and $US 1675- $US 3000 per acre ($US 4150-$US 7450 per hectare, approximately $AU 5400-$AU 9700 per hectare) for ground applications. Spraygrass provided a quote for 3.5 ha hydromulch trial of $108,500. As a minimum this is likely to cost $5-8M (assuming some economies for a larger area).

4.3 Gravel or coarse sand

In natural desert environments, gibber or stony surfaces can be present which assist in reducing wind erosion. The gibbers are formed from the breakdown of a duricrusts (a hard mineral surface formed by evaporation) and are usually angular and can be interlocking. The rocks cover the surface or protrude into the wind and reduce velocity; however, where the gibber plains are not continuous, wind erosion can still occur during high wind events. Particles >> 1 mm generally resist wind erosion and hence a layer placed over the soil surface can allow air and moisture to penetrate into the soil. A relatively thin layer (a few cm thick) can provide adequate protection to the soil surface and would not degrade over the longer term; however, may impact the native vegetation. Damage from placement of the gravel can be limited by using small gravel, such as pea gravel which is 5-10 mm. The risk of inhibiting plant germination could be managed by a thinner layer of gravel but would reduce the effectiveness of protecting and the surface and may concentrate the wind in the spaces between the gravel and result in increased wind erosion. The other disadvantage of gravel is that it tends to either reflect or retain heat rather than modulate (as organic mulches do) and can result in increased moisture stress to plants as a result.

The largest limitation to gravel is the practical limitation on applying a thin layer to the surface of the ASA without damaging plants or exposing the ash from deep wheel ruts. Scrapers can place thin lifts of material; however; relatively high ground pressure may result in the equipment exposing ash in wheel ruts or surface heave. Graders or dozers would be likely to disturb and rip out small plants as the surface of the ASA is not smooth and even. A tractor-drawn spreader, as used for organic mulches, uses conveyors and spinning flails to distribute the material and the smaller size of the gravel damages the moving parts of the machinery.

If these practical limitations can be overcome, clean pea gravel (nominally 5-10 mm) could be spread in a 2 cm layer to ensure good surface coverage (rule of thumb is thickness is 2-4 times diameter to ensure coverage) over the surface of the ASA; this would require 54,000 m^3 of material. Assuming a bulk purchase price of $50/$m^3$, this option would cost in excess of $3M with transport (> 800 semi-trailer loads) and placement likely to increase costs to almost $5M.

5 Dust Suppressants

Dust suppressants change the soil erodibility by changing the soil structure. Through aggregating, cementing or “gluing” the soil particles together the soil structure is altered to resist erosion. The commercially-available dust suppressants discussed herein have all been proven to effectively reduce dust when applied in accordance with the manufacturer’s instructions.

Written by Leong Mar, Red Planet Innovations Pty Ltd

5.1 Key Issues

There are many different dynamic and static situations where fugitive dust emissions can be generated such as: unsealed roads or hard stand work areas, materials processing, transfers and stockpiles, open top rail transportation wagons and broad acre land rehabilitation/ revegetation. What is clear is there is no silver bullet or one size fits all solution to solve the dust issues in these situations. As a consequence, there are many dust suppression agents or products on the market and there are many issues to consider when selecting an appropriate dust suppression agent. This will depend on a number of factors such as:

- the application (e.g. haul roads, stockpiles, materials handling, transportation, land remediation)
- the type of material being treated (e.g. dirt, ash, coal, mineral ore, etc.)
- the properties of the material being treated (e.g. particle size fractions, chemistry, hydrophobic, hydrophilic)
- the impact on the material properties and subsequent end use of the material
- health and safety considerations for both workers and any nearby residents that may be exposed to it during and after application
- the climate or weather conditions (e.g. wind, rainfall, ambient temperatures especially extreme hot or cold)
- environmental toxicity and the applications proximity to water courses, sensitive flora or fauna
- the cost of the dust suppression agent and its efficacy
- the equipment, labour, water and other associated application costs
- ease of use.

While this may seem like an extensive list of considerations, it is important to ensure that by using a dust suppression agent to minimise fugitive dust emissions, this does not create other unintended problems. The best approach would be to conduct trials that simulate the application with a selection of the most appropriate products to determine the optimum product based on the unique set of criteria for the application.

5.2 How Dust Suppression Products Work

There are many different types of dust suppression agents are available but the underlying principle by which these agents work is the same. They all change the fundamental properties of the dusty material by:

- increasing the size or density of the particles;
- agglomerating smaller particles into larger ones;
- forming a stable crust of the material on the surface;

to make it is less susceptible for the fine particles to become and remain airborne.

At its simplest, water is usually the most commonly used dust suppression agent. Water quality and availability are important factors if it is used; however, the effect of water is short lived and is lost once the water evaporates. In some instances, the water promotes the formation of a crust that has a longer effect; however, the crust doesn't have mechanical strength or durability and it may be easily broken down by any mechanical action or strong winds.

Given the situation covered by this report, the rehabilitation of a static dust source, a 270-hectare ash storage area which already has a soil capping layer, the focus of the investigations is on products that are suitable for the broad acre land rehabilitation/revegetation application. This limits the scope to products that are applied as a surface (topical) treatment as opposed to those that may be mixed though the bulk of the dusty material. Surface dust suppression, also commonly referred to in Australia as veneering, is usually only a temporary measure and often used in conjunction with other methods such new vegetation in broad acre applications to provide more permanent dust control.

5.3 Types of Dust Suppression Products

There are many different types of dust suppression products on the market to suit the many different applications. Given the variety of potential products on the market, it is important to select the product most suitable for the application as not all products work with all applications.

Every type of dust suppression product currently available comes with its own set of features, advantages and disadvantages. Most of the products are derived from the following common categories.

- Synthetic polymer products. A variety of emulsions made from polymers such as polyvinyl acrylics and acetates, styrenes etc.
- Water absorbing salts. Hydroscopic salts such as magnesium or calcium chlorides
- Petroleum based products. Tars, emulsions or oil-based products from petroleum refining
- Organic based products. Natural polymers such as lignosulphonates and starches, molasses or oils
- Electrochemical products. Sulphonated petroleum, Ionic stabilisers,
- Clay based products. Clays such as Bentonite, Montmorillonite

Organic mulch or hydromulch described in previous sections is usually a combination of seeds with cellulose fibres (e.g. hay, wood pulp, etc.) with a natural or synthetic polymer binder product. The dust suppression agent is used to bind the fibres to form a mulch mat or capping layer over the dusty material as well as bind the dusty material.

Colourant/Dyes are often added to the dust suppression solution before application. This is used as a visual aid during application to ensure a complete and consistent application and can also be useful subsequently in identifying areas which may have been damaged.

5.4 Performance Efficacy and Durability

In general, dust control performance efficacy and durability are determined by the concentration and application rate. The concentration is the amount of active ingredients that has a binding ability (e.g. the amount of polymer solids in an emulsion) in the final solution that is sprayed onto the dusty material. The strength and durability of the crust is dependent on the concentration but so is the cost. Suppliers sometimes attempt to lower the apparent cost of their products by decreasing the amount of active ingredients in their products but increase the application rate. This negates the initial product cost as more product is required. The cost comparisons should be based on the actual recommended concentration taking into account the application rate.

The application rate is the amount of the solution applied per square metre of area. This affects the solution infiltration and the subsequent thickness of the stabilised layer or crust formed. It is generally not advised to utilise an application rate much lower than 1L per square metre or the equivalent of 1mm of rainfall to ensure the chemical penetrates the soil and doesn't form a thin layer on the soil surface.

Generally, the following is observed for most dust suppression agents:

- The higher the concentration, the greater the binding strength which produces a more stable crust. However, care must be taken to not use too much so that it affects seed germination and growth.
- The higher the application rate the greater the infiltration and the thicker the crust; however, wind erosion is a surface effect and a crust beyond a few centimetres does not offer more protection.
- A high concentration and high application rate generally produces a thicker, more stable crust but is the most costly
- A high concentration and low application rate produces a thinner stable crust. Note that a thinner stable crust can be less desirable in high wind areas as winds can get through cracks in the layer and lift off sections of the crust, exposing the underlying material
- A low concentration and high application rate produces a thicker less stable crust

Obtaining the optimum performance is often a balancing act between the concentration and application rate and cost. In this instance where seeds are also used to generate new vegetation growth, performance also includes the ability to permit or promote germination and growth.

The performance and durability are also highly dependent on the application process. The spray system should be optimised to provide a uniform coverage with the droplet size not being too small to create too much spray drift.

5.4.1 Performance testing

There are no standard test methods for determining the performance of dust suppression agents; however, there are a few methods that are often used in Australia.

- Performance of the crust against wind erosion and dust lift off is performed using a wind tunnel
- Strength and durability of the crust formed using a penetrometer.
- Dust suppression solution infiltration/penetration is done visually
- Solubility/Leaching of dust suppression agent due to rain using standard leaching tests

5.5 Assessment Against Key Selection Criteria

The key assessment criteria for this project can be grouped into three categories: environmental, operational and commercial as outlined in Section 7 and the Options Assessment Spreadsheet. The dust suppression products considered for this project, based on the information provided by the different suppliers can be grouped into three categories: Lignosulphonates, Synthetic polymer emulsions and bitumen-based emulsion.

5.5.1 Lignosulphonates

Lignosulfonates are derived from lignin, a key component that binds the cellulose fibres together in wood and obtained from the production of wood pulp. Hence the lignosulfonates can be considered from a natural source and will follow a similar degradation path in the environment to wood. Examples of lignosulphonates are Dustex and Dustac (Appendix B).

Environmental Aspects

They are classified as non-toxic and non-dangerous goods. The available data shows that using the concentrations and application rates recommended by the suppliers, the product has low to no toxicity towards aquatic or terrestrial species. They could be potential minor irritants to some people and general good occupational health and safety practices should be followed when dealing with these products. The use of the product is unlikely to inhibit seed germination or vegetation growth; however, studies noted by the manufacturers had either incorporated the product into the soil prior to planting or had applied the product to established vegetation. No studies on the impact of products on emerging native vegetation under moisture-stressed conditions are available. Any impacts from the product is likely to be limited to where it has been applied.

Lignosulfonates are water soluble which provide easier application than emulsions which may require mixing during application. Water solubility may be an issue if the product is applied in locations where heavy rainfall is frequent or during heavy rainfall; however, because of its ecotoxicology profile and no potential for bioaccumulation, it is unlikely to pose any significant issues. Heavy rainfall can also dilute the product in the crust layer reducing its effectiveness and requiring reapplication

Operational Aspects

The lignosulfonates can be sprayed using standard readily available equipment like irrigation sprays and water carts. Care should be taken to ensure the spray droplets are not too small so that they are prone to drift. The products are effective almost immediately upon application and the performance and durability is directly dependant on the concentration and application rate. An additional 4 ML of water is required to add to the product for the ASA.

Depending on the recommended concentrations and application rates, there may not be any on-going costs for the specified duration although it is recommended that reapplication of the product is performed if large areas of the treatment is damaged and still generating dust emissions. Further, it is likely that products would be applied at the lower end of recommendations to minimise impact to plants which reduces the longevity and increases the likelihood of reapplication over summer.

Commercial Aspects

An indicative cost of $1.25/L concentrate was provided for Dustac ex Perth and assuming the stated broad acre application rate 0.15 L/m^2 (or $0.19/m^2), this is a product cost of approx. $0.5M. The cost does not include transport or application and hence the total cost is likely to be closer to $1M.

5.5.2 Synthetic polymer emulsions

All of the synthetic polymer products are aqueous emulsions of a polymer (polyvinyl acetate, styrene) a surfactant and a biocide and optionally a green dye. UV stabilisers are sometimes used to slow down the polymer degradation due to exposure to UV. The major components are water and the polymer. The surfactant is used to ensure the polymer is emulsified and also aids in the dispersion and penetration into the dusty material. The biocide is used as a preservative for the product. Cellulose fibre is also often added as a mulch. This can be beneficial but if not applied correctly, the mulch can form a mat that can be lifted off by strong winds and expose unbound material underneath. Hydrobond by Spraygrass (see Appendix B for brochure) and Gluon by Rainstorm are two examples of synthetic polymers.

Environmental Aspects

All of the polymers are classified as non-toxic and non-dangerous goods. This means that they are inherently non-toxic or present in concentrations that are not classified as toxic. They could be potential minor irritants to some people and general good occupational health and safety practices should be followed when dealing with these products even though they may be non-toxic. In the concentrations and application rates recommended by the suppliers, the ecotoxicology data presented, the products are not considered to toxic to the plant, and animal species tested and therefore unlikely to inhibit seed germination or vegetation growth. Data suggest that it could be beneficial in aiding moisture retention and binding the topsoil to prevent erosion and exposure and loss or damage of the seeds (Crowley *et al.*, undated); however, studies on the potential impact on emergent native vegetation under moisture-stressed conditions were not provided. Any impacts from the product is likely to be limited to where it has been applied; however, care must be taken in in handling the liquid concentrate or applying the product if there is a chance of rain before it has dried. The advantage of polymer emulsions is once the water has evaporated, the polymers are no longer water soluble and therefore not subject to leaching.

There is a potential risk from residual unreacted monomers used to make the polymers in the solution. These monomers can be toxic but it unlikely that any significant amounts of them will remain in the final product if manufactured correctly as they are highly reactive.

Operational Aspects

The operational aspects for synthetic polymer products are similar to those noted for lignosulphonates. Spraygrass quote that approx. 20 ha/day can be covered suggesting approx. 15 days to cover the ASA. Addition of approx. 4 ML of water is required with the product.

As for lignosulfonates, there may or may not be additional application costs. Given the sensitivity around the small emergent native vegetation, it is likely that lower application rates would be selected and hence longevity would be reduced, necessitating reapplication.

Commercial Aspects

The actual product cost for the polymer as applied according to the suppliers recommended concentration and application rate varies the range of $0.30 to $0.60 per m^2. The application cost can be equivalent to or more than the product cost, resulting in a total cost of approx. $2-3M.

5.5.3 Bitumen based emulsions

The ISB9000 product is an emulsion made up of bitumen, alkyl acrylate-styrene copolymer and ionic stabilizers. The product is alkaline with a pH typically ranging between 9 and 11. When applied the product has a blue/black appearance

Environmental Aspects

The bitumen component of the product is classified as Xi Hazardous, irritating to eyes and skin and mildly irritating when inhaled but not classified as Dangerous Goods. The product also has an ammonia/kerosene odour which can be an issue for some people. The appropriate occupational health and safety measures recommended by the manufacturer should be followed to minimise any potential issues. The product has elevated ecotoxicology risks compared to the lignosulphonates and synthetic polymer products reviewed which need to be taken into consideration. The product is water soluble and therefore has the potential for leaching immediately after application. Following curing or stabilisation, there is a limited potential for leaching. However, no environmental assessment and data of the risk to water resource or aquatic ecology was provided.

Operational and Commercial Aspects

The operational and commercial aspects are similar to that for the lignosulphonate and synthetic polymer products. Some of the environmental risks of the product can be managed by good operational control before, during and after application.

The product supplied and transported to site cost estimate was $1.42/m^2, i.e. $3.8M (based on PMB Technologies). Bitumen-based emulsions are applied to a wet surface or mixed with water at between 10:1 to 50:1 water:emulsion. Based on a quoted production application rate of 0.5L/m2 this equates to 13 – 67 ML of water to mix with the emulsion prior to spreading or an additional $50-225K at SA Water's commercial rate of $3.308/kL. Application is via water cart or spray rigs and also requires the site to be aerated to allow plant germination. Assuming a 4-

week application period and $1000/day for a machinery (approx. cost of wet hiring earthmoving equipment), application will cost an additional $30K. The total cost of this option is estimated to be $4M.

6 Soil Surface Properties

Directly impacting the soil surface properties by increasing soil moisture or roughness can affect wind erosion. Irrigation reduces wind erosion by directly increasing soil moisture and indirectly increasing plant growth of both the native vegetation and a cover crop. Surface roughness reduces wind erosion by slowing the wind velocity close to the surface.

For the coming Spring and Summer, options are required to suppress dust across the entire ASA due to the slow establishment of native vegetation. As a result, these options have been considered for deployment across the entire ASA. For both irrigation and surface roughness, the area requiring treatment has a large impact on the cost, resource requirements and efficiency.

6.1 Irrigation Methods

Irrigation methods can be roughly divided into surface, sprinkler and drip irrigation.

1. Surface irrigation: a saturated wetting front is applied to land and flows across a uniformly graded paddock. Surface irrigation is the least water efficient method of applying irrigation with high losses due to evaporation and drainage. Surface irrigation is only suitable for clayey soil types and flat topography. Terraces can be formed to accommodate steeper natural terrain but the paddock must be graded to control the direction and flow rate of the applied water. This form of irrigation is usually the most labour intensive to operate and the duration (how long you must irrigate) and scheduling (how frequently you can re-irrigate one area) of irrigation will be unsuitable to keep the site moist.

   The ASA is flat but would require laser levelling to enable flood irrigation which may expose ash. The soil types are suitable but the poor efficiency would result in significantly higher quantities of water being required. This method is unsuitable.

2. Sprinkler irrigation: Sprinklers apply water at an unsaturated rate and can be suitable for a range of topography from flat to gently undulating. Droplet size and the method of application influences the efficiency as some forms of spray irrigation are impacted by strong winds. Sprinkler irrigation is suited to saline soil as irrigation water can assist in moving salt out of the soil profile; however, sprinkler irrigation is not suited to saline water as the application of salt directly on to leaves can cause leaf scalds or burns or plant death. Sprinkler irrigation has the greatest impact on farm operations and hence is often not preferred.

   The ASA has variable soil types which are saline and sodic and hence sprinkler irrigation is likely to be an effective and efficient method; however, high winds during spring and summer will reduce the efficiency and hence methods which are least affected by wind will be preferable. Centre pivot and lateral move which spray water downwards can be considered but the duration and scheduling of irrigation will be unsuitable to keep the site moist. Big gun impact sprinklers can produce a large range of drop sizes so can reduce spray drift.

3. Drip irrigation is a highly efficient form of irrigation with no aerosol production and limit effect of evaporation and wind. Water is supplied at a limited volume and slowly to the soil. Drip irrigation is suited to sandier soil types where frequent small applications are required and also to more saline water. It is particularly suited to irrigating individual plants, such as in orchards, but is highly subject to blockages if using water with high suspended solids (e.g. unfiltered wastewater, river water, etc.).

   The ASA is a large area and would require a significant number of runs of dripper pipe to provide adequate coverage. A spacing of 0.2 m emitter and lateral spacing will be required to maintain a moist surface and mitigate wind erosion and this would result in disturbance of the germinating vegetation. In addition, the small diameter pipes are relatively light and without an excessive use of anchoring pegs could be blown across the surface and off-site during hot weather and high winds. As a result, this method is considered to be unsuitable.

Methods of sprinkler irrigation range from low capital cost/high operating cost to high capital cost/lower operating cost.

- Small impact sprinklers. These are the most utilised sprinklers on pasture and vineyards which spray a circular area of up to 35 m and either need to be manually moved to new areas and hence are only suited to small areas or are permanently installed on a 20 m x 20 m spacing. Irrigation efficiency is poor with spray highly affected by wind and evaporation. Due to the large number of sprinklers required, the installation would be labour intensive and would disturb large areas of the native vegetation resulting in these likely to be unsuitable for the entire ASA, though may be suitable in the future to target small problem areas.
- Big gun impact sprinklers. These sprinklers are the most utilised for dust suppression in mining. These permanently installed impact sprinklers spray in a circular area up to around 90 m radius and hence are installed in a much larger grid of 50 m x 50 m. The installation would disturb less area of the ash dam and have better efficiency than the smaller sprinklers; however, are more expensive. These sprinklers are more likely to be suitable for irrigation of the ASA for both larger-scale and targeted application.
- Travelling irrigators are relatively cheap and move by attaching a cable to a post placed in the direction the irrigators is to move; these systems are limited by the length of hose to supply the irrigator and are not suitable for use on uneven or soft ground (as present on the ASA) or when plants are small and easily dislodged. The application rate of these sprinklers is also limited and hence may not be able to keep the surface moist. These sprinklers are unlikely to be suitable for the ASA.
- Centre pivot or lateral move sprinklers are higher cost but are highly efficient sprinklers with spray least affected by wind and evaporation due to distribution and droplet size (Figure 6.1). These systems are more expensive and have the longest lead time.

Figure 6.1 Centre Pivot Irrigator with a Big Gun Impact Sprinkler at the end (Photo: Nelson Irrigation, nelsonirrigation.com)

6.2 Water Balance

The water balance for the ASA can be calculated using monthly rainfall and potential evapotranspiration (PET) for Port Augusta. Irrigation can be applied to provide the full complement required for optimal plant growth or can be applied to partially provide additional moisture for plant growth. SA Water's Code of Practice Irrigated Public Open Space (2015) is targeted at the irrigation of grass for recreational open space and provides guidance on irrigating the full complement (as required for Adelaide Oval turf) vs partial irrigation (as undertaken at local parks and gardens). This same consideration can be applied to the ASA; irrigation could be applied at the full complement to replace all water lost through evapotranspiration or could be applied to partially account for water losses to improve growth compared with natural conditions but without the objective of optimal growth conditions. Using this approach, the irrigation requirement for the ASA would vary from approx. 550 mm/yr to 1,700 mm/yr. For the ASA, this is equivalent to 1,500 – 4,600 ML/yr and based on SA Water commercial water use cost of $3.308/kL, this is a cost of $5M – $15M/yr, not including irrigator running costs.

Table 6.1 Water Balance and Irrigation Requirements for Port Augusta

Month	Median Rainfall (mm)	Mean Evaporation (mm)	Mean PET (mm)	Irrigation Requirement (mm)	
				Full compliment	Partial
Jan	14	347	208	245	89
Feb	10	290	174	207	76
Mar	10	252	154	182	66
Apr	10	167	107	122	42
May	20	111	70	65	13
Jun	21	77	49	37	0
Jul	18	87	55	48	7
Aug	21	118	76	71	15
Sep	19	167	109	115	33
Oct	17	232	152	171	57
Nov	18	280	177	201	68
Dec	14	324	201	235	84
TOTAL	**254**	**2,452**	**1,531**	**1,700**	**552**

Data extracted from SILO from 1967 to 2017

Irrigation assumes 90% effective rainfall and crop factor = 0.7 all year round. 80% irrigation efficiency

Partial irrigation assumes crop stress factor of 40% (i.e. actual ET is 40% of potential evapotranspiration)

The use of potable water for irrigation has concerns in terms of sustainable and responsible use of resources. In addition, the lead time to purchase large scale irrigators is long with schemes of this size not typical in South Australia. The practicality of moving centre pivots over the ash dam without getting bogged and the risks of exposing ash from deep ruts formed from the pivots are also major limitations for this option. No enquiries to SA Water have been made about the potential to purchase such large volumes of water and the ability of the current network to supply the water.

6.2.1 Alternative Water Sources

Alternative water sources may be used to supply irrigation water. SA Water's wastewater treatment plant is adjacent to the ASA and may be able to supply some water for irrigation. The Port Augusta WWTP produces approximately 0.9 ML/day during summer and more in winter. Currently, the wastewater is treated prior to discharge into Spencer Gulf.

The potential advantages of using treated wastewater are:

- Reduced cost;
- Recycling wastewater rather than using valuable potable supplies;

- Addition of nitrogen and nutrients, including trace nutrients such as zinc;
- Addition of organic carbon which increases microbial activity and soil binding.

The potential disadvantages of using treated wastewater are:

- Limitations to application, particularly during windy conditions;
- Potential impacts to workers and surrounding residents;
- High salinity and sodicity of wastewater; however, given the soil is highly saline and sodic application of wastewater can be better than using fresh water to overcome dispersion from sodicity limiting infiltration rate;
- Addition of boron in wastewater as the cover soil on the ASA appears to have naturally high boron concentrations;
- Additional water needs to be applied to assist in leaching of salt in the profile. This is likely to be difficult on the ASA.
- Potential for saline water to scald leaves of germinating and establishing plants. It should be noted that plants which are highly tolerant of saline soil conditions may be more susceptible when establishing and/or more susceptible to salt applied to their leaves.

To assess the potential advantages and disadvantages of wastewater application, Flinders Power and SA Water are proposing a 5 ha trial to measure the impact on plant growth over the coming Spring and Summer.

6.3 Irrigation for Dust Suppression

Irrigation is a common method of suppressing dust and is highly effective. The application of water to moisten the surface stabilizes the soil and prevents dust generation. This technique is widely used on mine site stockpiles where large sprinkler systems are employed to keep the surface moist. Water carts are used in construction operations to minimise dust generation. Water misters are also used in some situations to assist in dust deposition once air-borne.

Irrigation can also be completed using mobile equipment at lower cost but this is usually more labour intensive and requires a large number of traffic movements to effect. Frequent trafficking the surface of the ash dam could result in negative impacts upon the vegetation growth and long-term condition of the site.

Irrigation to suppress dust during Spring and Summer would require application rates closer to evaporation rates. Evaporation for this six-month period is in excess of 1640 mm, i.e. 16.4 ML/ha (Table 6.1). The actual irrigation rate to combat evaporation and keep the soil surface moist is likely to be higher as the evaporative demand (around 10 mm/day) would reduce the efficiency of irrigation and result in application rates needing to be almost double to provide dust suppression.

In 2014 there was a major upgrade to the coal stockpile dust suppression system at the Kooragang coal terminal in NSW. The area of the two major stockpiles at this coal terminal is approximately 186 Ha combined. The upgrade to the system cost $AU 5.3 Million and took 24 months, including upgraded big gun impact sprinklers, control valves and 6 new pumps. Water use is also a factor when considering irrigation as a solution to dust emissions.

6.4 Irrigation for Vegetation Promotion

Irrigating to promote vegetation growth with the goal of forming windbreaks is an option for erosion control. This technique would require less area to be irrigated than using the irrigation alone to suppress dust emissions, resulting in less equipment and lower volumes of water to be required, however with the spacing required for windbreaks with low height vegetation (7 to 20 metres) there may not be a large saving over irrigating the entire area. It is also noted that poor irrigation practices can result in plants with shallow root growth and water dependence and may result in selection of plants less suited to natural rainfall conditions in the longer term.

Advantages of using irrigation to promote growth of vegetation as wind breaks include the advancement of the long term goal of vegetation controlling the erosion and the lower cost than purely using irrigation to control the dust. For promoting vegetation growth, irrigation can be undertaken in winter when evaporative losses are less and hence moisture addition is more likely to be effective. The disadvantage of irrigating during winter is that the plant growth is reduced, with some plants (particularly summer-active species) growing very little or even not at all and hence the additional moisture won't benefit these plants.

Irrigation during cooler seasons to promote growth (both growth of the native vegetation and the cover crop) is more likely to be within practical and economic limits. From April to September, partial irrigation would require 5-10 mm/week to provide supplementary moisture for plant growth. This is equivalent to 0.35-0.7 ML for the entire ASA at a cost of >$1M.

Irrigation could be focussed on "problem" areas to facilitate faster establishment of plants. Trials are underway on the ASA to determine if winter irrigation can benefit the native vegetation and/or the cover crop. If successful, targeted irrigation may form part of the solution for the ASA. By commencing irrigation to the extent practical this season, the objective is to increase the vegetative cover and reduce the area of the ASA which is potentially subject to wind erosion in the future.

6.5 Surface Roughness

Increasing surface roughness can reduce dust generation by covering the soil with clods which are too large to be lifted by the wind and trapping and sand that may be moving and dislodging lighter particles. This technique is widely used in agriculture to reduce the amount of erosion where the vegetative cover is minimal or absent. Surface roughening is most effective in loamy or clayey soil and ineffective in soil which produces few clods, e.g. sandy soil; instead tillage ridges (100 mm high) can be used.

Surface roughening can be undertaken in strips rather than the entire area to catch bouncing particles before erosion reaches its maximum. Leys (2003) used 50 mm ripper points at 750 mm spacing and found that ripping at 13 km/hr produced more clods than at 6 km/hr. Wider spacings can be used to protect young crops; effective wind erosion control may be achieved by operating the implement perpendicular to or at angle to the wind and the direction of the crop rows to minimise covering young crops (University of Nebraska-Lincoln, 2010). Spacings greater than 2 m are less effective as erosion can reach its maximum rate in less than 5 m. In sodic soil, as present on the ASA, rainfall reduces the clodiness and ripping needs to be repeated. Follow-up ripping is best done between or at right angles to the first rip lines.

The biggest risk in increasing surface roughness is that if insufficient clods are produced then this technique can increase wind erosion. Also on the ASA care will be required to ensure rip lines do not pull the underlying ash to the surface. To minimise the risk of pulling ash to the surface, track lines from the piston bully may be used to roughen the surface. These have been observed to trap sand on the windward side; however, given their relatively low profile they roughness may fill with sand relatively rapidly. Trials are underway on the ASA to qualitatively investigate the longevity of piston bully roughening (Figure 6.2) and in the borrow pit the ability of deep rip lines to reduce wind erosion.

Surface roughness is reduced by rainfall or deposition of sediment in the roughened area making it smooth. Rainfall is low in Port Augusta and hence it is assumed that the degradation of clods would occur slowly and re-ploughing would only need to occur once or twice/year. The smaller tracks of the piston bully may fill with sand and this is more likely to occur in a lesser timeframe. It is assumed that surface roughing would need to be repeated at least twice/year; however, this will be informed by the trials currently underway.

Figure 6.2 Clods on Surface after using Piston Bully on ASA. Seeds have collected in the troughs from winter winds (Source: Terry Manning, Flinders Power)

7 Windbreaks

Windbreaks are effective in reducing the wind erosivity. Wind breaks reduce the velocity of the wind near the surface and deflect the wind upwards and away from the soil surface.

7.1 Trees

Windbreaks constructed from vegetation (usually trees) are commonly used for wind protection of crops and livestock. The effects of the windbreak are proportional to the height of the windbreak. Hagen (1976) suggests that for vegetative windbreaks alone to reduce wind erosion potential to low levels, a spacing of 15 to 20 times the height of the windbreak is required. Agriculture Victoria suggest that moderately dense vegetation belts (~40% Density) can provide “a considerable reduction in wind speed to a distance of at least 20H”, as well as stating that denser belts of vegetation can provide good shelter against wind protection to a distance of at least 15H and belts should be ten times wider than tall for maximum efficiency. For vegetation of ½ to 1m high this means that the spacing required will be 7 to 20 metres. The width of the windbreak primarily provides a means to manipulate the density of the windbreak (University of Missouri, 2015).

Although tree windbreaks are a relatively low cost and effective method of reducing wind velocity and hence dust, the arid climate of Port Augusta, long lead time for trees to establish an expanse of the ASA limit the practicality of this solution. This option has not been assessed further.

7.2 Porous mesh wind breaks/fences

Fences can be used to either reduce the wind speed on the leeward side or to trap material in front of them. The former type is generally referred to as a wind fence and can be made of artificial materials, brush or live vegetation; a cover crop can act as a porous wind fence. The aim of the wind fence is to reduce the wind shear on the soil, therefore reducing erosion. The performance of the fence is governed by the permeability and height of the fence and the spacing of the fences if they are arranged in an array. The shape of the pores in the fence material also impact the performance of the fence. Wind fences create an eddy area down wind of them, this effect creates a dune down wind. The positioning of this dune is governed by the porosity of the fence and the magnitude is governed by the height (Li *et al*., 2015). Li *et al*. suggests that the optimal porosity of the fence is 30-40% for a wind fence; however, Lima *et al*. (2017) suggests that the optimal porosity is 40-50%. Lima *et al*. found that when fences are arranged in an array the downwind maximum wind velocity increases over each fence, the magnitude of this increase is impacted by the porosity of the fence. With a smaller fence porosity (20%) the maximum wind velocity increased much more slowly over the array than for a higher porosity (40%) (ibid.). This research is recent and the phenomenon is not well understood. It is worth noting that fences are limited in their effectiveness when the wind is not perpendicular to the fence (Li *et al*., 2015).

Lima *et al*. conducted a study into the optimal spacing of sand fences to prevent erosion in dunes. The study found that for an array of 10 fences the optimal solution when considering the cost of the fences was a height of 50 cm exposed from the ground, with the spacing changing dependent on the properties of the soil and the porosity of the fence, the soil types considered in the study required the fence spacing to be between 4 m and 14 m. A short fence height may create issues with fence burial if large volumes of soil are being transported by the wind.

Fences are erected perpendicular to the wind direction and are well-suited to applications with one dominant wind direction. More complex configurations can be deployed but require complex modelling to ensure that wind is not inadvertently concentrated between the rows resulting in higher velocities and increased wind erosion. Fences are not designed for cross-winds; this is essentially a checkboard (see Section 7.3).

Advantages of wind fences are that the fences are likely to be successful if correctly designed and dimensioned, the fences are durable depending on the material they are constructed from.

The fences will be immediately effective once constructed. The major disadvantages of this method is the time to deploy and the damage to the native vegetation as the fence is installed in a 0.3 m x 0.3 m trench. This solution is extremely labour intensive if machinery cannot be used due to the condition of the surface. If machinery is used the trafficking of the surface could cause further erosion and damage to vegetation. Unlike the methods that use organic materials, the fences or remnants of the fences will remain for an extended period of time if not removed. Conversely, the fences are easily torn which reduces their efficacy and require frequent repairs and/or replacement. Long fence runs provide an impediment to movement on the ASA and hence will provide a nuisance to workers, including vegetation assessors, when inspecting and working on the ASA.

Basing the estimation of cost on a fence height of 1 metre, with a spacing of 7 metres results in 1430 linear metres of fence per hectare. Based on published costs of $5 per lineal metre for supply and installation in Brisbane, the fencing the cost will be approximately $7,150 per hectare, i.e. approx. $2M for the ASA. Strong winds have been assumed to tear the fence fabric and as an estimate, we have assumed replacement of 30% of fences every year; it is noted that the fences are not intended for longer term use and this may be an under-estimate. The cost for using vegetation is the same as for cover crops discussed in Section 4.1.

7.3 Straw checkerboard

Straw checkerboard erosion control is commonly used in Asia to control sand drift, especially in the desert regions of China. This technique uses partially buried barriers made from straw in a checkerboard pattern, Qiu *et al*. (2004) found that a 1m x 1m checkerboard pattern was the most effective and could almost completely control erosion in their experiments.

The straw can be of wheat, rice, reeds or other plants. Half is buried under the ground, with the other half exposed. Qiu *et al*. found that a majority of erosion is controlled by the wind speed at around 0.1m from the ground, thus a height of 0.1-0.2m is an appropriate height for the straw. The straw effectively increases the surface roughness, resulting in reduced sand flux. Qiu *et al.* (2004) found a reduction in sand flux of over 95% in their long-term experiments (Figure 1). Zhang *et al*. (2015) found that wind velocities exceeding 6 m/s (22 km/h) impacted the roughness height created by the straw due to the bending of the straw.

Li *et al*. (2006) found that straw checkerboards can assist topsoil development and provide an environment more conducive to vegetation development. The study by Qiu *et al.* reflected these findings with the checkerboard results in fine particles being deposited on the surface, as well as increasing the organic matter in the soil (Qiu *et al*., 2004).

Advantages of the straw checkerboard technique include the substantial effect that it has on sand fixation, the low long term environmental impact of the material, immediate effect and the positive environment it provides for vegetation growth. The major disadvantage of the straw checkerboard technique is that the installation is extremely labour intensive.

Assuming a checkerboard of 1m x 1m and assuming a small square straw bale covers 28 linear metres of checkerboard, approximately 715 bales will be required per hectare. Labour costs are additional to this but no data were found on installation times; however, as an indication, the cost for trenching from Rawlinson's construction handbook yields a cost of $94,700 per hectare, i.e. > $20M for the ASA.

8 Options Assessment

All options presented in this assessment are proven technologies for supressing dust. New and novel techniques have not been included. As a result, the options assessment has focussed in the site specific factors which will impact the suitability of the option for deployment across the entire ash dam. As discussed above, irrigation and surface roughness are highly sensitive to the area of deployment and once vegetation is more established and targeted approaches for small areas are required, these options will be further assessed. Trials are currently underway on the ASA on irrigation and surface roughness to address potential concerns in deployment in this environment.

8.1 Assessment Approach

The eleven management options discussed in the sections above have been compared against a number of criteria encompassing environmental, operational and commercial aspects to determine options which are proven to work, are likely to work on the ASA and have the lowest potential impact on the people and environment at the ASA as well as those adjacent. This assessment is qualitative and based on published information as far as practical.

The approach undertaken was to determine the best option by that with the **lowest** total points. The basis of this approach is that aspects which are most important and have the highest potential for detrimental impact score the highest, i.e. a large number multiplied by a large number, whilst the aspects which are least important and have low potential for detrimental impact have little impact on the assessment, i.e. a low number multiplied by a low number. The total score is the factor of:

- ranking aspects from no or beneficial impact (0) to worst or unacceptable detrimental impact (12); the rankings are defined for each criterion below; multiplied by
- weighting from least important (1) to most important (5). People (workers and neighbours), the longer-term strategy for rehabilitation and the environment are given a high importance compared with operational aspects.

8.2 Assessment Criteria

8.2.1 Human Health - Workers and Residents

The potential for the implementation and on-going requirements of an option and the products used to implement or maintain the option to impact on human health is of prime importance to Flinders Power. On-site workers may be impacted by direct contact or inhalation of products used in the option during their day-to-day works which can involve accessing the ASA to undertake inspections, vegetation assessment or to maintain the cover soil of the ASA. Surrounding residents' health and amenity may be impacted by dust or odour generated from or direct contact/inhalation of products used in implementing the option.

The rankings have been assigned as follows:

- 0 – no impact on human health
- 1 – unlikely but possible to provide nuisance;
- 3 – probable to cause nuisance;
- 7 – short-term impacts or impacts require additional controls;
- 12 – longer-term impacts or impacts cannot be mitigated.

8.2.2 Water – Groundwater, Surface Water

Management options may have the potential to impact on the underlying groundwater or adjacent surface water (being Bird Lake, Hospital Creek and Spencer Gulf). The groundwater is approximately level with the base of the ASA but the ash is likely to be saturated to 1-2 m below the surface. Contaminants may potentially be leached through the cover soil and ash to groundwater. Contaminants may impact surface water through direct contact from spray drift or indirectly through erosion of the cover soil or horizontal leaching; given the flat surface of the ASA, indirect methods are less likely to occur.

The rankings have been assigned as follows:

- 0 – no impact likely;
- 1 – potential minor impact from contaminants which also occur in background concentrations (e.g. phosphorus, zinc, nitrogen);
- 3 – potential minor impact from contaminants unlikely to occur in background (e.g. non-natural contaminants, cadmium, mercury)
- 7 – short term impact on local area or can be readily managed or mitigated
- 12 – longer-term impacts or impacts cannot be mitigated.

8.2.3 Vegetation – Germinating, Established and Off-site Vegetation

Management options may impact on the ability of the planted native vegetation to germinate or to continue to establish or could impact on off-site vegetation including adjacent saltbush communities and estuarine vegetation in the Spencer Gulf. On-site vegetation could be directly affected by smothering leaves or being toxic to germination or growth or indirectly affected by resulting in detrimental chemical changes in the soil. Off-site vegetation would be indirectly affected through surface or groundwater discharges (which are dealt with above) or by spray drift on to adjacent areas.

The rankings have been assigned as follows:

- 0 – no impact or likely beneficial impact
- 1 – impact unlikely
- 3 – short-term minor check to growth
- 7 – longer-term reduction in growth or may cause death to small areas
- 12 – causing death and/or failed germination

8.2.4 Application - Ease of Application, Time to Achieve Control, Durability and Longevity

The ease of application is a combined qualitative assessment of the availability of equipment, the labour required and the complexity of implementing the management option. This is a subjective ranking of management options from 1 (simplest/easiest) to 12 (complex/difficult).

The time to achieve control is management options ranked in terms of the number of months required before dust control is likely to be achieve. Given that this is unlikely to be exact, the rankings are:

- 0 – Immediate control (< 1 month to implement and achieve)
- 1 – Fast control (1-2 months)
- 3 – Some control (2-3 months)
- 7 – 3 – 6 months
- 12 - > 6 months

The durability of the management option is a qualitative assessment of the susceptibility of the management option to arid climate (i.e. hot, dry, windy, stormy) and trafficking. This is a subjective ranking of management options from 1 (most durable) to 11 (least durable).

The longevity is based on the number of times the management option needs to be implemented over the 6 months of spring and summer. The rankings are:

- 0 – Once
- 1 – 6 – 12 monthly (annually)
- 3 – 3 - 6 monthly
- 7 – 1 – 3 monthly
- 12 – Frequent (< monthly)

8.2.5 Costs - Establishment and On-going

The cost for establishing, applying or installing each option has been rounded to the nearest hundred thousand or million as the costs provided herein are indicative only. Where costs are listed as the same in the options table but it is likely that one option is more likely to have lower, similar or greater costs, the ranking has been used to differentiate.

On-going costs include the costs to re-establish the treatment based on duration and also on costs of operating pumps and buying water for irrigation options.

The management options have been ranked from least to most expensive based on Tonkin Consulting experience, published costs (e.g. Rawlinsons) or on supplied quotes.

8.2.6 Influencers to Success - Successful examples and Supplier reputation

The provision of successful examples as well as the supplier reputation has been based on information provided or background research. The rankings have been applied as:

- 0 – Used on-site successfully and/or supplier known to Flinders Power
- 1 – a number of Australian examples provided and supplier has South Australian presence or known reputation
- 3 – some examples provided and/or supplier based interstate
- 7 – examples provided but not in Australian or similar conditions or supplier reputation and/or adequate supplies limited or unknown
- 12 – new or novel technique

8.3 Options Assessment Summary

The options assessment has provided the ranking of options shown in Appendix C and summarised in Table 8.1. The assessment was undertaken as a workshop involving Brad Williams, Kym Maule and Terry Manning from Flinders Power, Dr Briony Horner from Succession Ecology and Ross Fitzgerald from McMahon Services.

As the rankings were established from least impact to most impact and the weightings were from least important to most important, the option with the **lowest score** there has the **least impact** particularly for the criteria which are most important. The options best options are:

1. Cover crop – assuming the crop is sufficiently tolerant of climatic and soil conditions to provide adequate coverage, both in terms of number of plants and height grown;
2. Dust suppressants – assuming the impact on emerging plants and germination is limited but that durability and longevity is acceptable at these potentially lower rates;
3. Surface roughness – assuming sufficient roughness can be achieved without exposing ash and that the surface does not generate dust within the range of typical strong winds in Port Augusta

Table 8.1 Summary of Total Weighted Ranking and Limitations for Options

Option		Total	Limitations and Data gaps
1A	Cover Crop	88	Durability and Successful Examples: Potential growth of barley and/or rye corn is currently being trialled as soil and climate not optimal for plant growth. If dies and remains vertical, 0.2 m high may act as wind fence but without high labour cost
1B	Mulch	142	Cost, Ease of application and impact on establishing vegetation: Placing mulch on the surface is likely to smother existing vegetation. Also, practical difficulties in placing mulch across the surface and the time required along with the cost of purchase and delivery are limiting.
1C	Gravel	176	On-site vegetation, Germination, Ease of application and Supply Too long to deploy due to transport. Available locally in limited quantities which would further exacerbate time to achieve control. Application likely to be difficult.
2A	Ligno-sulphonates	120	Unknown impact on native vegetation seedlings, Durability and On-going annual costs Potential impact on emerging vegetation is unknown and is currently being assessed. It is assumed that relatively low application rates are used to prevent impact to germination; this reduces durability and hence longevity which then increases on-going costs as re-application may be required
2B	Aqueous Polyvinyl Acetate Emulsions	130	As above, likely to be slightly more durable but is more expensive
2C	Bitumen-based Suppressants	176	As above + more likely to impact on-site workers and neighbours and vegetation.
3A	Irrigation for dust	198	Operational Aspects and Costs Unlikely to be able to apply volumes required and waste of valuable resource. Timeframes too long. Very costly in terms of capital and operating costs
3B	Irrigation for growth	189	As above; however, may be suitable for selected areas
3C	Surface roughness	132	Residents, On-site Vegetation Wind velocity at which dust will still be generated is unknown. On-site vegetation will be impacted during implementation.
4A	Wind fences	201	On-site Vegetation, Ease of Application and Time Installing fences will damage existing vegetation. Is very labour intensive which impacts the time to achieve control. If fences have to be installed by hand the costs would increase significantly
4B	Checkerboard	202	As above. Visually less impactful and reduced on-going costs but may be difficulties in sourcing correct straw type in quantities required

9 Conclusions and Recommendations

9.1 Conclusions

To meet the long-term goals of the rehabilitation of the ASA, including consideration of Native Vegetation Council requirements, the native vegetation planted on the ASA needs to be given the greatest opportunity to thrive. Once established, the native vegetation will provide a low maintenance solution to dust.

A number of options have been identified and assessed to determine the likelihood of providing additional dust control on the ASA whilst the native vegetation establishes. The options were ranked based on least to most impact and then were weighted based on least to most important criteria. The weighted rankings showed that the best options for short-term control of dust whilst native vegetation establishes are:

- Cover crop of barley and/or rye corn.
- Dust suppressants.
- Surface roughening. Trials are underway to determine the longevity of minor rip lines created by the piston bully and larger rip lines from deep ripping.

9.2 Recommendations

It is recommended that the preferred options are further investigated to resolve some of the data gaps identified and to enable a more quantitative assessment of likely performance. Trials are underway or proposed to investigate:

- the potential for barley and/or rye corn to establish on the ASA.
- the impact of dust suppressants on the germination of native seed and growth of emerging plants as well as the impact on moisture infiltration and soil strength.
- the duration of surface roughening using a piston bully on the ASA and using deep ripping in the borrow pit.
- potential for irrigation to increase germination and survival of native vegetation and cover crops.
- Potential impact of wastewater irrigation on native vegetation and surface soil. This trial is currently being develop with SA Water.

The first 4 trials have commenced and data beginning to be collected. Once these trials have provided further data, expected to be within 1-2 months, it is recommended that the options assessment matrix is updated to enable selection of the preferred option or combination of options.

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Appendix A

Preliminary Soil Analysis

SMS Geotechnical Pty Ltd
Unit 9, 21 Beafield Road Para Hills West SA 5096

Particle Size Distribution & Consistency Limits Test Report

Client:	McMahon Services Australia Pty Ltd, 26 Duncan Road, Dry Creek, SA, 5094				
Project:	Port Augusta Ash Dam Borrow Pit			**Date:**	10-Feb-17
Location:	Submitted Samples	**Job No.**	S2017.036	**Report No.**	S2017.036 / R1
Lab Reference No.	170343	**Sample Identification:**	Sample 1		

Laboratory Specimen Description: (CL) Sandy CLAY, low plasticity, red brown, approx 50% fine to coarse sand.

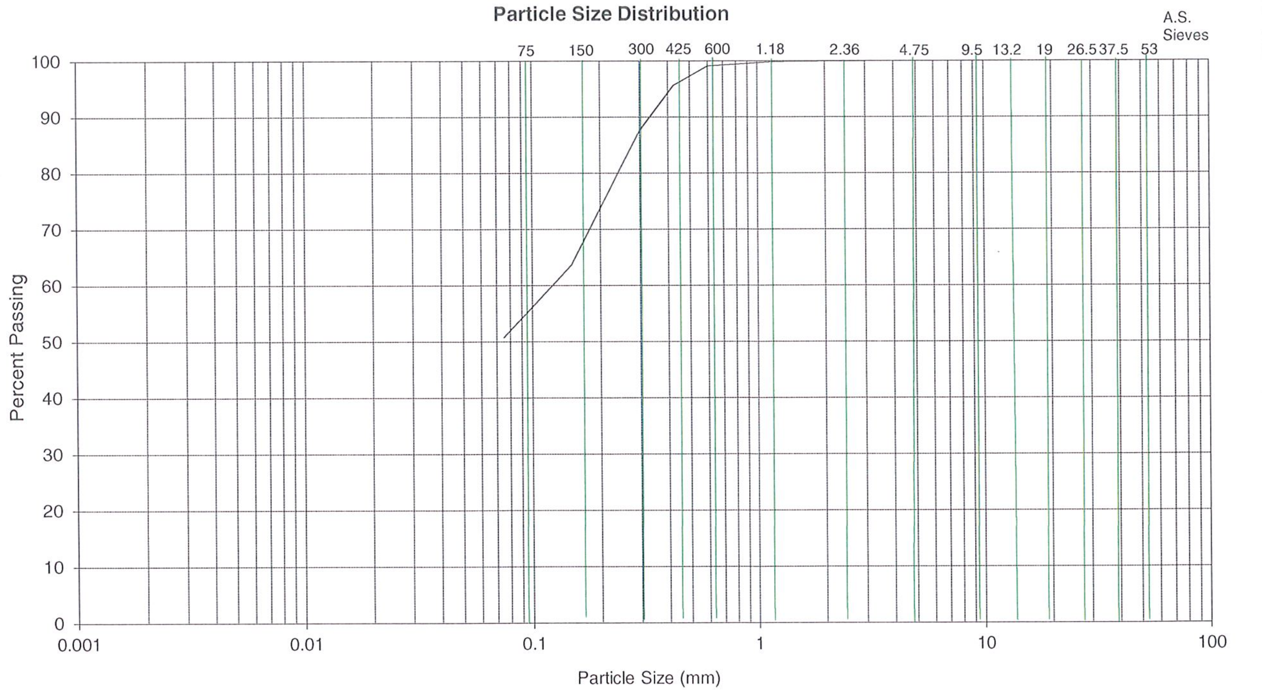
Particle Size Distribution AS1289 3.6.1

Sieve Size	% Passing	Specification
150 mm	100	
75 mm	100	
53 mm	100	
37.5 mm	100	
26.5 mm	100	
19.0 mm	100	
13.2 mm	100	
9.5 mm	100	
6.7 mm	100	
4.75 mm	100	
2.36 mm	100	
1.18 mm	100	
600 um	99	
425 um	96	
300 um	88	
150 um	64	
75 um	51	

Consistency Limits and Moisture Content

Test		Method	Result	Spec.
Liquid Limit	%	AS1289 3.1.2	22	
Plastic Limit	%	AS1289 3.2.1	10	
Plasticity Index	%	AS1289 3.3.1	12	
Linear Shrinkage	%	AS1289 3.4.1	5	
Moisture Content	%	AS1289 2.1.1	ND	

Notes : Tested as received
Sample History: Air Dried, Preparation Method: Dry Sieved
Linear Shrinkage Mould Length: 250mm,
Cracking: No, Curling: No Crumbling: No



Accreditation No. 19225

Form SMS2009 Rev2 040816

Approved Signatory, Callum Smith - Director

SMS Geotechnical Pty Ltd
Unit 9, 21 Beafield Road Para Hills West SA 5096

Particle Size Distribution & Consistency Limits Test Report

Client:	McMahon Services Australia Pty Ltd, 26 Duncan Road, Dry Creek, SA, 5094		
Project:	Port Augusta Ash Dam Borrow Pit	**Date:**	10-Feb-17
Location:	Submitted Samples **Job No.** S2017.036	**Report No.**	S2017.036 / R2
Lab Reference No.	170344	**Sample Identification:**	Sample 2

Laboratory Specimen Description: (CL) Sandy CLAY, low plasticity, red brown, approx 30% fine to coarse sand.

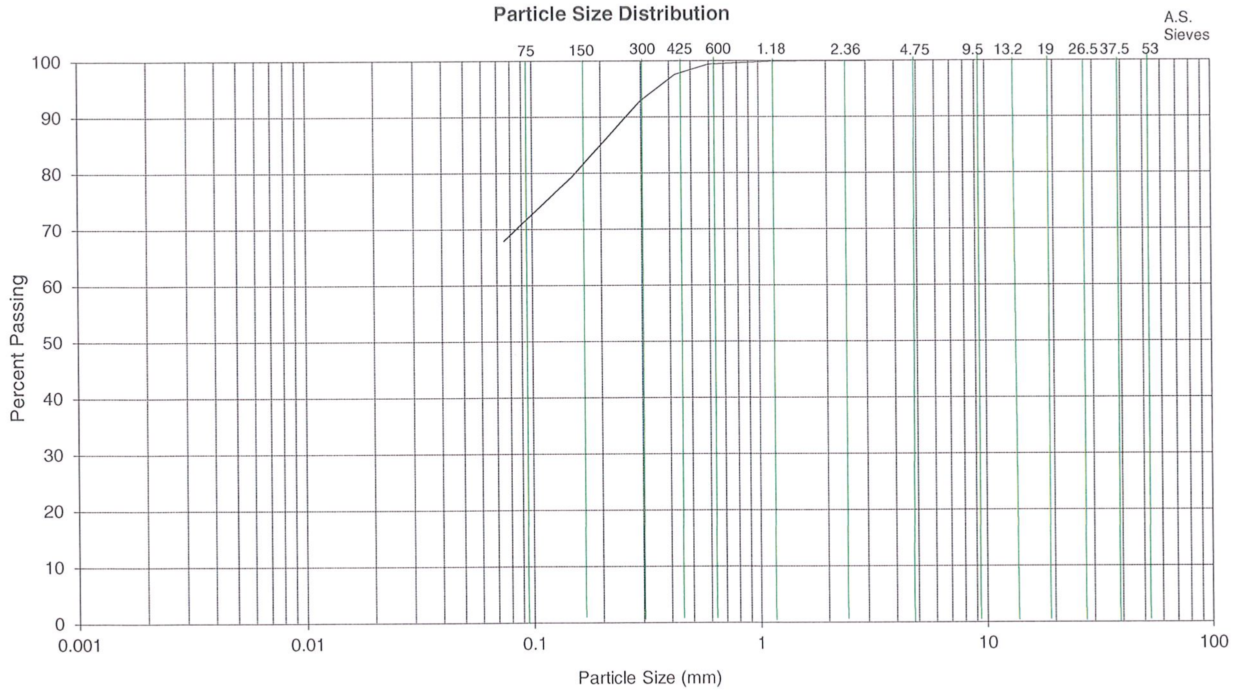
Particle Size Distribution AS1289 3.6.1

Sieve Size	% Passing	Specification
150 mm	100	
75 mm	100	
53 mm	100	
37.5 mm	100	
26.5 mm	100	
19.0 mm	100	
13.2 mm	100	
9.5 mm	100	
6.7 mm	100	
4.75 mm	100	
2.36 mm	100	
1.18 mm	100	
600 um	99	
425 um	98	
300 um	93	
150 um	79	
75 um	68	

Consistency Limits and Moisture Content

Test		Method	Result	Spec.
Liquid Limit	%	AS1289 3.1.2	30	
Plastic Limit	%	AS1289 3.2.1	15	
Plasticity Index	%	AS1289 3.3.1	15	
Linear Shrinkage	%	AS1289 3.4.1	8	
Moisture Content	%	AS1289 2.1.1	ND	

Notes : Tested as received
Sample History: Air Dried, Preparation Method: Dry Sieved
Linear Shrinkage Mould Length: 250mm,
Cracking: No, Curling: No Crumbling: No



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SMS Geotechnical Pty Ltd
Unit 9, 21 Beafield Road Para Hills West SA 5096

Particle Size Distribution & Consistency Limits Test Report

Client:	McMahon Services Australia Pty Ltd, 26 Duncan Road, Dry Creek, SA, 5094				
Project:	Port Augusta Ash Dam Borrow Pit			**Date:**	10-Feb-17
Location:	Submitted Samples	**Job No.**	S2017.036	**Report No.**	S2017.036 / R3
Lab Reference No.	170345	**Sample Identification:**	Sample 3		
Laboratory Specimen Description:	(CL) Sandy CLAY, low plasticity, red brown, approx 35% fine to coarse sand.				

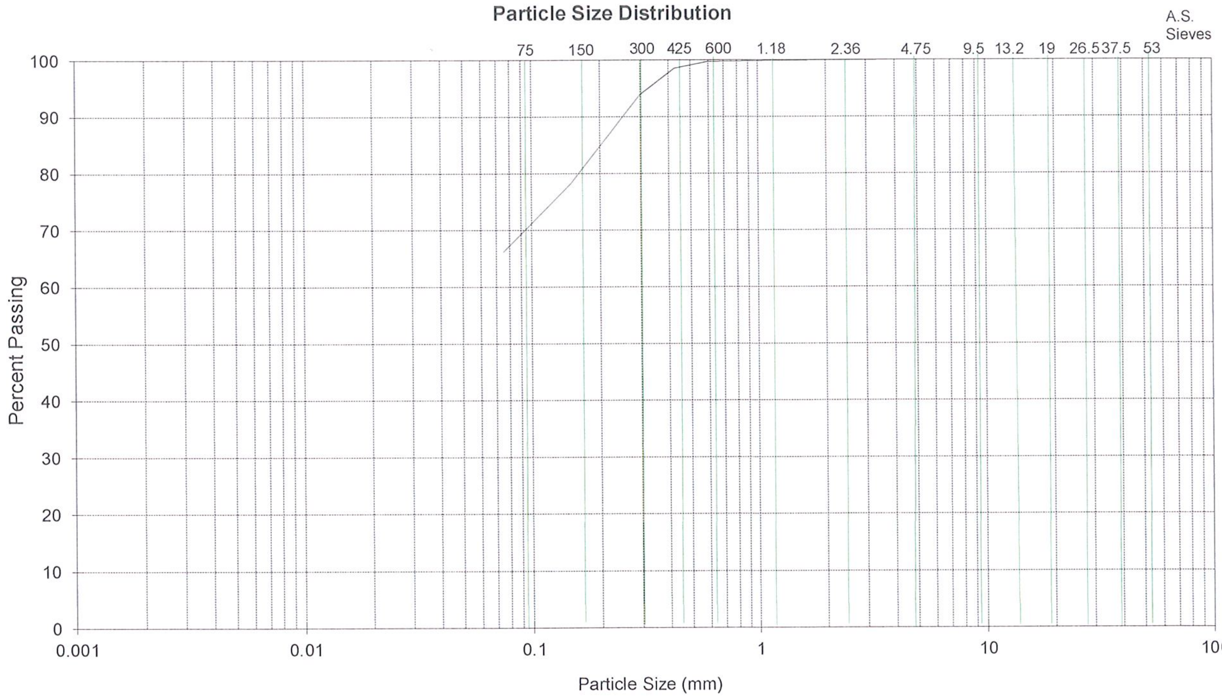
Particle Size Distribution AS1289 3.6.1

Sieve Size	% Passing	Specification
150 mm	100	
75 mm	100	
53 mm	100	
37.5 mm	100	
26.5 mm	100	
19.0 mm	100	
13.2 mm	100	
9.5 mm	100	
6.7 mm	100	
4.75 mm	100	
2.36 mm	100	
1.18 mm	100	
600 um	100	
425 um	99	
300 um	94	
150 um	78	
75 um	66	

Consistency Limits and Moisture Content

Test		Method	Result	Spec.
Liquid Limit	%	AS1289 3.1.2	24	
Plastic Limit	%	AS1289 3.2.1	12	
Plasticity Index	%	AS1289 3.3.1	12	
Linear Shrinkage	%	AS1289 3.4.1	6.5	
Moisture Content	%	AS1289 2.1.1	ND	

Notes : Tested as received
Sample History: Air Dried, Preparation Method: Dry Sieved
Linear Shrinkage Mould Length: 250mm,
Cracking: No, Curling: No Crumbling: No



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SMS Geotechnical Pty Ltd
Unit 9, 21 Beafield Road Para Hills West SA 5096

Particle Size Distribution & Consistency Limits Test Report

Client:	McMahon Services Australia Pty Ltd, 26 Duncan Road, Dry Creek, SA, 5094				
Project:	Port Augusta Ash Dam Borrow Pit			**Date:**	10-Feb-17
Location:	Submitted Samples	**Job No.**	S2017.036	**Report No.**	S2017.036 / R4
Lab Reference No.	170346	**Sample Identification:**	Sample 4		

Laboratory Specimen Description: (CL) Sandy CLAY, low plasticity, red brown, approx 50% fine to coarse sand.

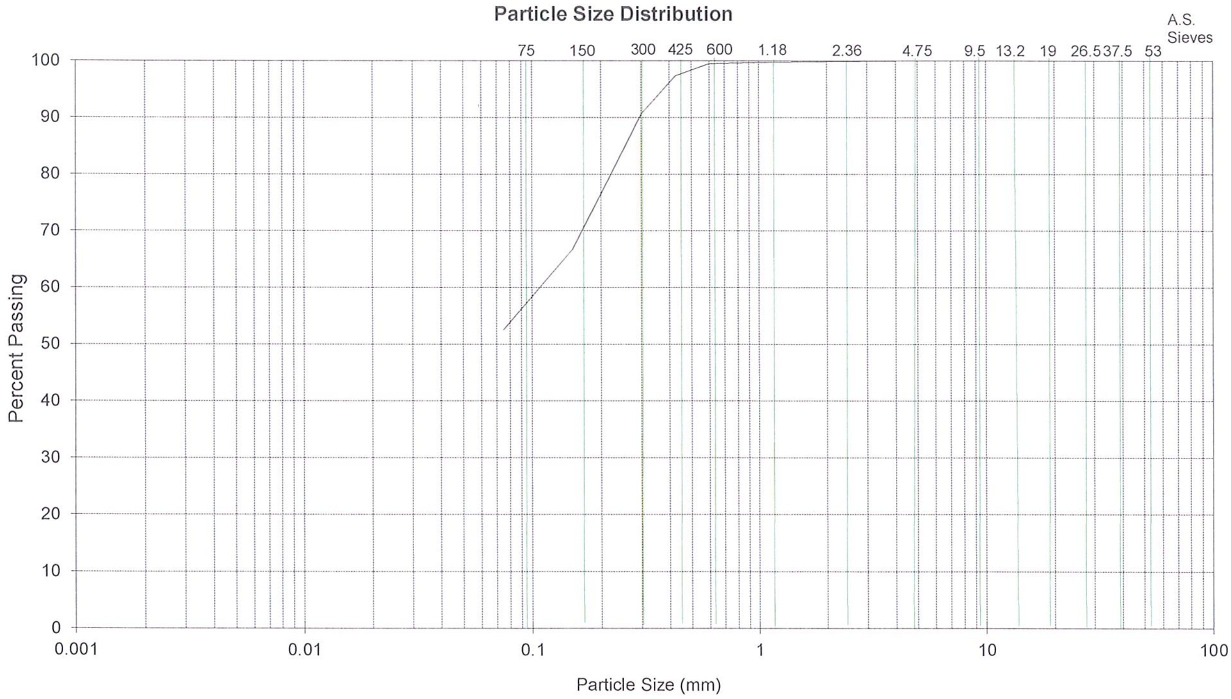
Particle Size Distribution AS1289 3.6.1

Sieve Size	% Passing	Specification
150 mm	100	
75 mm	100	
53 mm	100	
37.5 mm	100	
26.5 mm	100	
19.0 mm	100	
13.2 mm	100	
9.5 mm	100	
6.7 mm	100	
4.75 mm	100	
2.36 mm	100	
1.18 mm	100	
600 um	100	
425 um	97	
300 um	91	
150 um	67	
75 um	53	

Consistency Limits and Moisture Content

Test		Method	Result	Spec.
Liquid Limit	%	AS1289 3.1.2	18	
Plastic Limit	%	AS1289 3.2.1	10	
Plasticity Index	%	AS1289 3.3.1	8	
Linear Shrinkage	%	AS1289 3.4.1	2.5	
Moisture Content	%	AS1289 2.1.1	ND	

Notes : Tested as received
Sample History: Air Dried, Preparation Method: Dry Sieved
Linear Shrinkage Mould Length: 250mm,
Cracking: No, Curling: No Crumbling: No

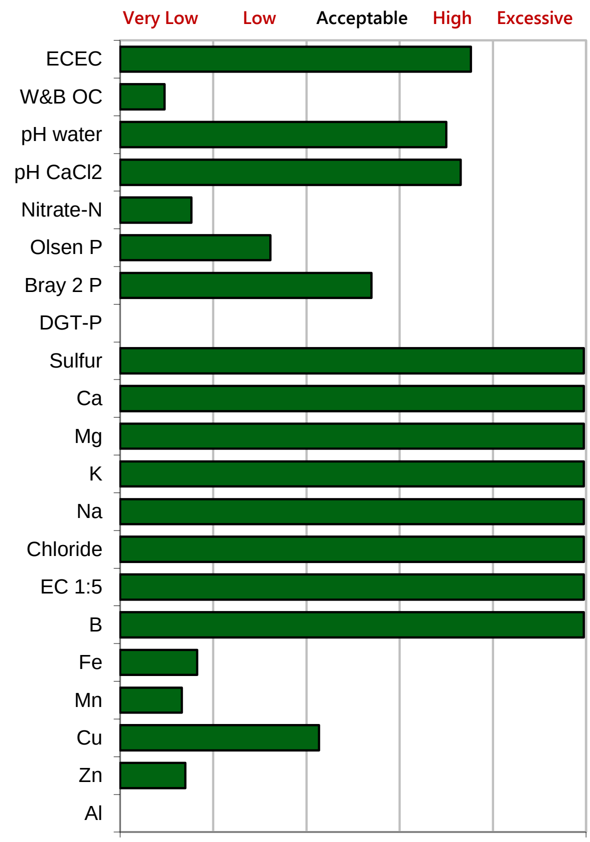


Approved Signatory, Callum Smith - Director

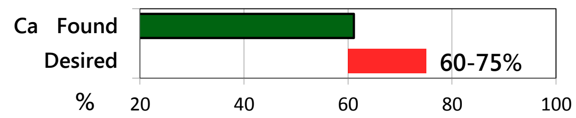
Premium Soil Analysis

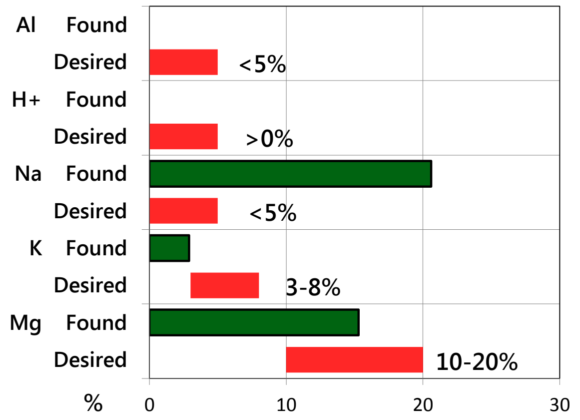
Customer: MCMAHON SERVICES
Agent: APAL
Sample Name: SAMPLE 1
Crop: NATIVE VEGETATION
Control 24133
Lab No.: ZZ004
Date: 13-Feb-17

		Unit	Desired Level	Level Found
	ECEC	c.mol/kg	12 - 25	40.43
	Organic Carbon (W&B)	%	>2.0	0.45
	Total Nitrogen (Dumas)	%		NR
	pH 1:5 (Water)		6.0 - 7.0	8.25
	pH 1:5 (CaCl2)		5.5 - 6.5	8.06
Exchangeable N-P-S	Nitrate - N	ppm	10 - 50	3.6
	Ammonium - N	ppm	-	1.0
	Olsen Phosphorus	ppm	15 - 20	8
	Bray 2 Phosphorus	ppm	30 - 60	67
	PBI unadjusted		<100	89
	MCP Sulfur (S)	ppm	10 - 20	109.3
Exchangeable cations	Calcium (Ca)	ppm	> 1200	4953
	Magnesium (Mg)	ppm	> 200	753
	Potassium (K)	ppm	> 120	459
	Sodium (Na)	ppm	< 160	1918
	Exch. Aluminium (Al)	c.mol/kg	< 0.5	NT
	Exch. Hydrogen	c.mol/kg	-	NT
Salt	Chlorides (Cl)	ppm	<300	3416
	Salinity EC 1:5	dS/m	< 0.15	2.50
Trace Elements	Boron (B)	ppm	0.5 - 2.0	5.87
	DTPA Iron (Fe)	ppm	10 - 70	4
	DTPA Manganese (Mn)	ppm	5 - 50	1.6
	DTPA Copper (Cu)	ppm	0.5 - 5.0	0.65
	DTPA Zinc (Zn)	ppm	1.0 - 5.0	0.33
Ratios	Ca:Mg RATIO		2 - 8	3.99
	Grass Tetany Risk Index		< 0.07	0.04
Exchangeable cation	Calcium	% Ca	60 - 75	61.1
	Magnesium	% Mg	10 - 20	15.3
	Potassium	% K	3 - 8	2.9
	Sodium	% Na	<5	20.6
	Exch. Aluminium	% Al	<5	NT
	Exch. Hydrogen	% H	>0	NT



Exchangeable Cation % (eCEC)





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Tel.: 08 8332 0199 Fax: 08 83612715 Email: info@apal.com.au Website: www.apal.com.au

NR Test not requested

DGT-P desired ranges & critical levels exist for limited crop types.

NT Not tested. Exchangeable hydrogen/aluminium test valid for acid soils only.

Premium Soil Analysis

Customer:
MCMAHON SERVICES

Agent:
APAL

Sample Name:
SAMPLE 1

Crop:
NATIVE VEGETATION

Control 24133

Lab No.: ZZ004

Date: 13-Feb-17

		Unit	Desired Level	Level Found
Phosphorus	Colwell Phosphorus	ppm	-	**NR**
	DGT Phosphorus	µg/L	-	**NR**
	Total Phosphorus	ppm	-	**NR**
Traces	Cobalt	ppm	-	**NR**
	Molybdenum	ppm	-	**NR**

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NR Test not requested

Premium Soil Analysis

Customer: MCMAHON SERVICES

Agent: APAL

Sample Name: SAMPLE 2

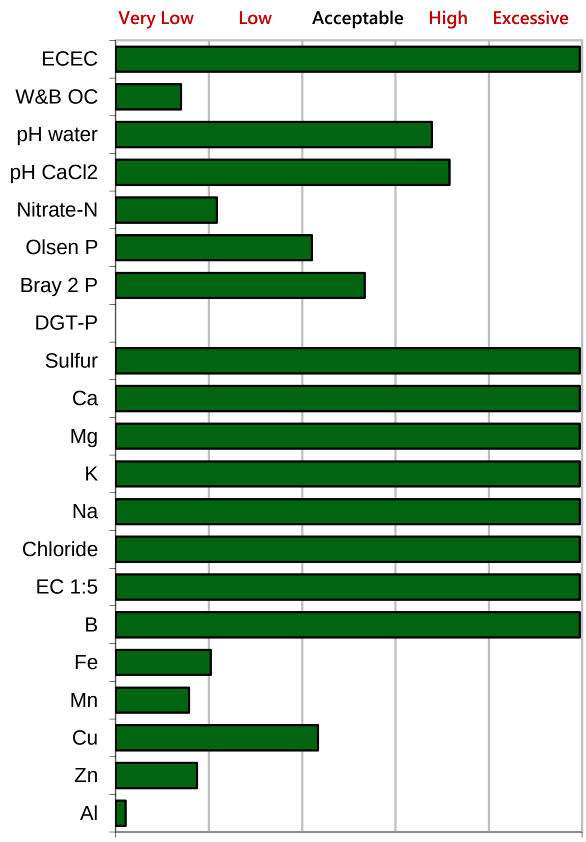
Crop: NATIVE VEGETATION

Control 24133

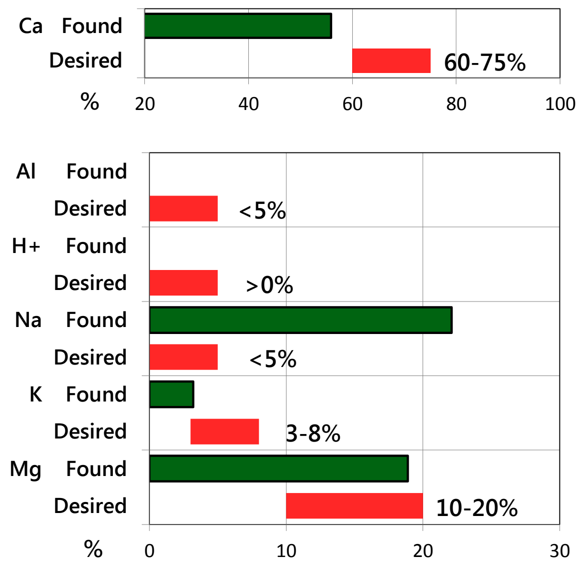
Lab No.: ZZ005

Date: 13-Feb-17

		Unit	Desired Level	Level Found
	ECEC	c.mol/kg	12 - 25	54.56
	Organic Carbon (W&B)	%	>2.0	0.66
	Total Nitrogen (Dumas)	%		NR
	pH 1:5 (Water)		6.0 - 7.0	8.03
	pH 1:5 (CaCl2)		5.5 - 6.5	7.91
Exchangeable N-P-S	Nitrate - N	ppm	10 - 50	5.1
	Ammonium - N	ppm	-	1.7
	Olsen Phosphorus	ppm	15 - 20	10
	Bray 2 Phosphorus	ppm	30 - 60	65
	PBI unadjusted		<100	119
	MCP Sulfur (S)	ppm	10 - 20	104.6
Exchangeable cations	Calcium (Ca)	ppm	> 1200	6107
	Magnesium (Mg)	ppm	> 200	1252
	Potassium (K)	ppm	> 120	681
	Sodium (Na)	ppm	< 160	2766
	Exch. Aluminium (Al)	c.mol/kg	< 0.5	<0.02
	Exch. Hydrogen	c.mol/kg	-	<0.02
Salt	Chlorides (Cl)	ppm	<300	5087
	Salinity EC 1:5	dS/m	< 0.15	3.60
Trace Elements	Boron (B)	ppm	0.5 - 2.0	5.61
	DTPA Iron (Fe)	ppm	10 - 70	5
	DTPA Manganese (Mn)	ppm	5 - 50	1.9
	DTPA Copper (Cu)	ppm	0.5 - 5.0	0.85
	DTPA Zinc (Zn)	ppm	1.0 - 5.0	0.41
Ratios	Ca:Mg RATIO		2 - 8	2.96
	Grass Tetany Risk Index		< 0.07	0.04
Exchangeable cation	Calcium	% Ca	60 - 75	55.9
	Magnesium	% Mg	10 - 20	18.9
	Potassium	% K	3 - 8	3.2
	Sodium	% Na	<5	22.1
	Exch. Aluminium	% Al	<5	0.0
	Exch. Hydrogen	% H	>0	0.0



Exchangeable Cation % (eCEC)



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NR Test not requested DGT-P desired ranges & critical levels exist for limited crop types.

NT Not tested. Exchangeable hydrogen/aluminium test valid for acid soils only.

Premium Soil Analysis

Customer:
MCMAHON SERVICES

Agent:
APAL

Sample Name:
SAMPLE 2

Crop:
NATIVE VEGETATION

Control 24133

Lab No.: ZZ005

Date: 13-Feb-17

		Unit	Desired Level	Level Found
Phosphorus	Colwell Phosphorus	ppm	-	NR
	DGT Phosphorus	µg/L	-	NR
	Total Phosphorus	ppm	-	NR
Traces	Cobalt	ppm	-	NR
	Molybdenum	ppm	-	NR

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ASPAC

NR Test not requested

Premium Soil Analysis

Customer:
MCMAHON SERVICES

Agent:
APAL

Sample Name:
SAMPLE 3

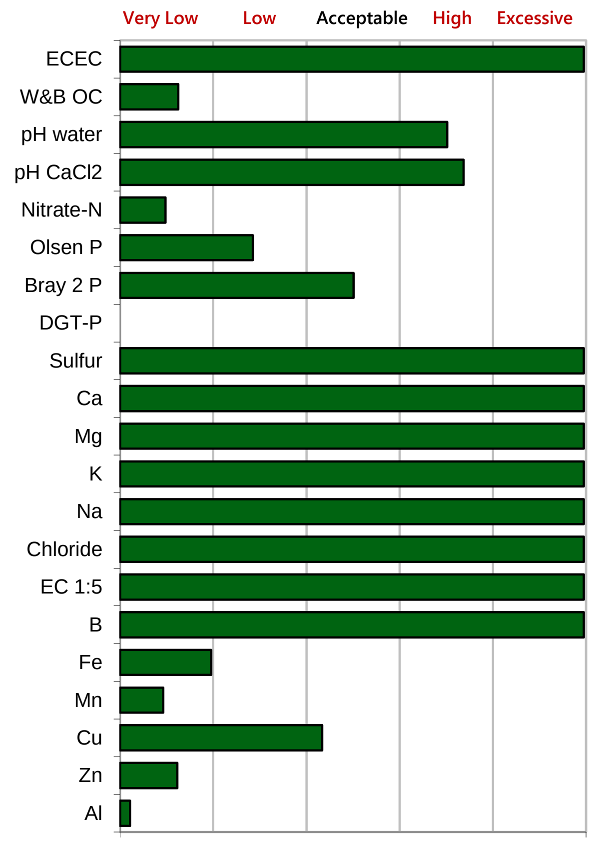
Crop:
NATIVE VEGETATION

Control 24133

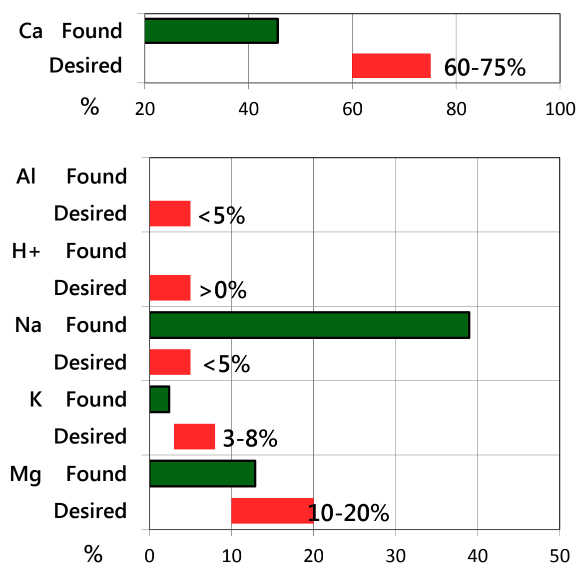
Lab No.: ZZ006

Date: 13-Feb-17

		Unit	Desired Level	Level Found
	ECEC	c.mol/kg	12 - 25	73.53
	Organic Carbon (W&B)	%	>2.0	0.59
	Total Nitrogen (Dumas)	%		NR
	pH 1:5 (Water)		6.0 - 7.0	8.27
	pH 1:5 (CaCl2)		5.5 - 6.5	8.12
Exchangeable N-P-S	Nitrate - N	ppm	10 - 50	2.3
	Ammonium - N	ppm	-	1.0
	Olsen Phosphorus	ppm	15 - 20	7
	Bray 2 Phosphorus	ppm	30 - 60	53
	PBI unadjusted		<100	143
	MCP Sulfur (S)	ppm	10 - 20	1197.9
Exchangeable cations	Calcium (Ca)	ppm	> 1200	6723
	Magnesium (Mg)	ppm	> 200	1156
	Potassium (K)	ppm	> 120	699
	Sodium (Na)	ppm	< 160	6593
	Exch. Aluminium (Al)	c.mol/kg	< 0.5	<0.02
	Exch. Hydrogen	c.mol/kg	-	<0.02
Salt	Chlorides (Cl)	ppm	<300	5425
	Salinity EC 1:5	dS/m	< 0.15	5.10
Trace Elements	Boron (B)	ppm	0.5 - 2.0	12.70
	DTPA Iron (Fe)	ppm	10 - 70	5
	DTPA Manganese (Mn)	ppm	5 - 50	1.1
	DTPA Copper (Cu)	ppm	0.5 - 5.0	0.85
	DTPA Zinc (Zn)	ppm	1.0 - 5.0	0.29
Ratios	Ca:Mg RATIO		2 - 8	3.53
	Grass Tetany Risk Index		< 0.07	0.04
Exchangeable cation	Calcium	% Ca	60 - 75	45.6
	Magnesium	% Mg	10 - 20	12.9
	Potassium	% K	3 - 8	2.4
	Sodium	% Na	<5	39.0
	Exch. Aluminium	% Al	<5	0.0
	Exch. Hydrogen	% H	>0	0.0



Exchangeable Cation % (eCEC)



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NR Test not requested

DGT-P desired ranges & critical levels exist for limited crop types.

NT Not tested. Exchangeable hydrogen/aluminium test valid for acid soils only.

Premium Soil Analysis

Apal

Customer:
MCMAHON SERVICES

Agent:
APAL

Sample Name:
SAMPLE 3

Crop:
NATIVE VEGETATION

Control 24133

Lab No.: ZZ006

Date: 13-Feb-17

		Unit	Desired Level	Level Found
Phosphorus	Colwell Phosphorus	ppm	-	NR
	DGT Phosphorus	µg/L	-	NR
	Total Phosphorus	ppm	-	NR
Traces	Cobalt	ppm	-	NR
	Molybdenum	ppm	-	NR

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ASPAC

NR Test not requested

Premium Soil Analysis

Apal

Control 24133

Customer: MCMAHON SERVICES

Sample Name: SAMPLE 4

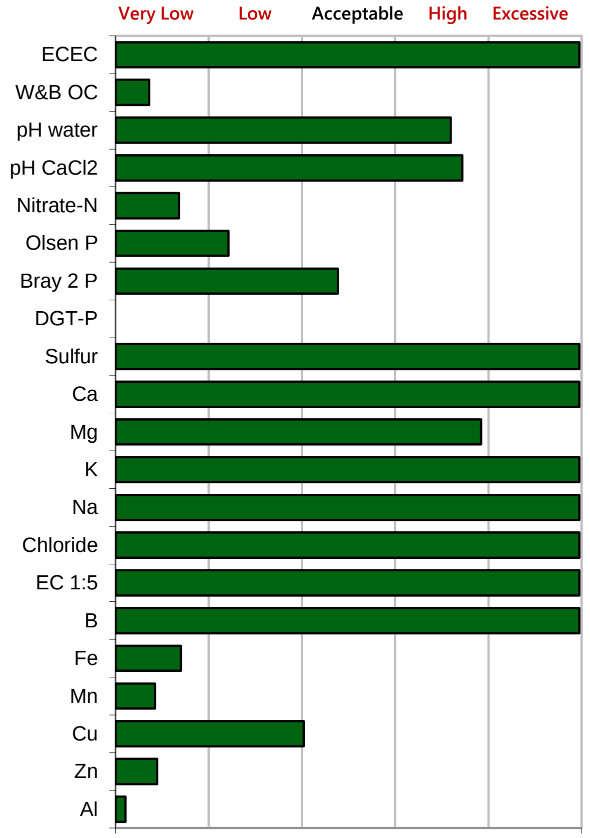
Lab No.: ZZ007

Agent: APAL

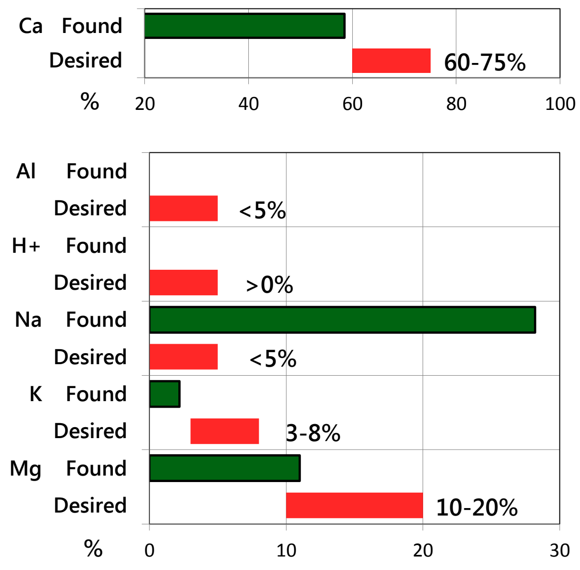
Crop: NATIVE VEGETATION

Date: 13-Feb-17

		Unit	Desired Level	Level Found
	ECEC	c.mol/kg	12 - 25	43.81
	Organic Carbon (W&B)	%	>2.0	0.34
	Total Nitrogen (Dumas)	%		NR
	pH 1:5 (Water)		6.0 - 7.0	8.44
	pH 1:5 (CaCl2)		5.5 - 6.5	8.19
Exchangeable N-P-S	Nitrate - N	ppm	10 - 50	3.2
	Ammonium - N	ppm	-	1.0
	Olsen Phosphorus	ppm	15 - 20	6
	Bray 2 Phosphorus	ppm	30 - 60	44
	PBI unadjusted		<100	107
	MCP Sulfur (S)	ppm	10 - 20	771.3
Exchangeable cations	Calcium (Ca)	ppm	> 1200	5135
	Magnesium (Mg)	ppm	> 200	588
	Potassium (K)	ppm	> 120	382
	Sodium (Na)	ppm	< 160	2844
	Exch. Aluminium (Al)	c.mol/kg	< 0.5	<0.02
	Exch. Hydrogen	c.mol/kg	-	<0.02
Salt	Chlorides (Cl)	ppm	<300	2910
	Salinity EC 1:5	dS/m	< 0.15	2.90
Trace Elements	Boron (B)	ppm	0.5 - 2.0	9.44
	DTPA Iron (Fe)	ppm	10 - 70	3
	DTPA Manganese (Mn)	ppm	5 - 50	1
	DTPA Copper (Cu)	ppm	0.5 - 5.0	0.57
	DTPA Zinc (Zn)	ppm	1.0 - 5.0	0.21
Ratios	Ca:Mg RATIO		2 - 8	5.30
	Grass Tetany Risk Index		< 0.07	0.03
Exchangeable cation	Calcium	% Ca	60 - 75	58.5
	Magnesium	% Mg	10 - 20	11.0
	Potassium	% K	3 - 8	2.2
	Sodium	% Na	<5	28.2
	Exch. Aluminium	% Al	<5	0.0
	Exch. Hydrogen	% H	>0	0.0



Exchangeable Cation % (eCEC)



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ASPAC

NR Test not requested

DGT-P desired ranges & critical levels exist for limited crop types.

NT Not tested. Exchangeable hydrogen/aluminium test valid for acid soils only.

Premium Soil Analysis

Customer:
MCMAHON SERVICES

Agent:
APAL

Sample Name:
SAMPLE 4

Crop:
NATIVE VEGETATION

Control 24133

Lab No.: ZZ007

Date: 13-Feb-17

		Unit	Desired Level	Level Found
Phosphorus	Colwell Phosphorus	ppm	-	NR
	DGT Phosphorus	µg/L	-	NR
	Total Phosphorus	ppm	-	NR
Traces	Cobalt	ppm	-	NR
	Molybdenum	ppm	-	NR

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NR Test not requested

Appendix B

Dust Suppressant Examples

Appendix C

Detailed Options Assessment

Option Assessment Matrix

ID	Option		Environmental Aspects							Operational Aspects				Commercial Aspects				TOTAL
			Workers	Residents	Groundwater	Surface Water	On-site vegetation	Germination	Off-site vegetation	Ease of application	Time to achieve control	Durability	Longevity	Establishment cost	On-going cost	Successful examples	Supplier reputation	
	WEIGHTING		5	5	4	4	4	4	3	4	4	2	1	3	3	2	1	
1	Soil Cover																	
1A	Cover crop - barley/rye corn	Summary	No impact. Herbicide use is not proposed in cover crops due to their single season growth	No impact. Herbicide use is not proposed in cover crops due to their single season growth	Very low fertiliser application at sowing is unlikely to leach to groundwater	Cover crop likely to reduce runoff	Some competition for water, nutrients and light. Managed by reduced seed rate and row spacing	Allelopathy may limit germination if seeding rates are too high. Sowing cover crop may bury or expose ungerminated native seed reducing viability. Managed by reduced seed rate and row spacing	Use of sterile or non-colonising plants	Can be sown using conventional machinery with some modifications in spacing	Established in 1-3 months. Best planted in early winter to ensure control effective at start of Spring. Late winter still possible. Spring may result in high temperatures before crop establishes	Affected by climate and soil. Early indications from trials suggest rye corn and barley can grow to at least 10 cm in one month	Will die at the end of each season so will have to be resown in winter if required in following year	<$100K with use of contract seeding	Replanting would be required annually until native veg. established, i.e. on-going cost of < $100K	Used widely in agriculture and rehabilitation projects in Mallee and South East (see DEWNR)	Local suppliers who have visited site and trials commenced and appear promising	
		Rank	0	0	0	0	3	3	0	2	3	5	1	2	4	7	1	88
1B	Mulch - 40 mm bark chip placed 100 mm thick	Summary	Increased difficulty in trafficking due to loose surface.	Potentially cause a major nuisance on adjoining roads if becomes wind-borne. Manage by using 40 mm back chip	Break down over longer term and low in nutrients	May be blown into adjoining streams. Anaerobic decomposition can occur	Small emerging plants likely to be smothered and/or damaged during placement	Unlikely to be affected, may be benefited	Unlikely to impact adjacent vegetation if 40 mm bark chip used	Some difficulty in spreading across ASA and use spreader but can be undertaken using earthmoving equipment	Transport and placement likely to take 1-3 months but immediate once applied	Slowly broken down by UV and soil micro-organisms. May be moved by wind or damaged by trafficking	Likely to remain for at least 1-2 years	$15M	No annual cost through may benefit from raking to re-cover exposed areas	Used widely in rehabilitation projects but not in this area	Contact with Adelaide-based supplier.	
		Rank	1	3	0	1	7	1	0	6	3	2	0	10	3	3	1	142
1C	Gravel - 5-10 mm pea gravel > 20 mm thick	Summary	Increased difficulty in trafficking due to loose surface.	No impact	Inert product so no impact	Inert product so no impact	Likely to damage or smother existing vegetation	May impact germination temporarily. Can increase temp or lead to frost damage of seed	No impact	Practically difficult to spread across ASA but can be undertaken using standard machinery or specialised machinery	Transport and placement likely to take 1 month but immediate once applied. Supply may be limiting due to other competing uses for gravel locally and hence likely to take longer	Cover may be affected by foot trafficking or machinery getting bogged. Not broken down	Infinite	$5M	No on-going cost	Used in gardens and some hardstand areas. Larger scale often replaced with bitumen or concrete	No supplier identified. Locally available but in limited quantities due to competing uses	
		Rank	1	0	0	0	12	7	0	9	3	1	0	7	1	7	7	176
2	Dust suppressants																	
2A	Ligno-sulphonates	Summary	Potential inhalation irritant if exposed to spray drift during application	Spray drift may be a nuisance	soluble in water so potential for leaching but low toxicity towards aquatic and terrestrial species, and no potential for bioaccumulation		Noted to have little or no impact on established plants. May be beneficial due to moisture retention and additional nutrients. Suffocation risk is not well-defined for emerging plants and is being assessed in greenhouse trials	does not inhibit germination, might be beneficial due to moisture retention and additional nutrients	unlikely to have impact beyond where it is applied, unless applied aerially	Applied using standard equipment, water carts, spray rigs. Can be aerially applied	dust control effective once applied and dry. Application likely < 1 month	Affected by mechanical, rain and wind damage. Biodegradable	3-12 months depending on application rate and concentration. Lighter rates lead to less risk of plant damage but shorter longevity. Likely to use lower rates to limit vegetation damage so likely to be stable for 3-6 months	$0.5M to supply so estimated to be $1M to supply and apply	Reapplication at least annually	Many examples available. Dustac used at Rio Tinto Dampier Port (WA), BHP Port Hedland (WA), Wheatstone Project Pilbara Coast (WA), Brajkovich Demolition Swan Valley (WA)	Based in WA. Product supplied for glasshouse trial	
		Rank	3	3	1	1	3	0	0	3	1	8	3	3	7	1	3	120

ID	Option		Environmental Aspects							Operational Aspects				Commercial Aspects				TOTAL
			Workers	**Residents**	**Groundwater**	**Surface Water**	**On-site vegetation**	**Germination**	**Off-site vegetation**	**Ease of application**	**Time to achieve control**	**Durability**	**Longevity**	**Establishment cost**	**On-going cost**	**Successful examples**	**Supplier reputation**	
		WEIGHTING	5	5	4	4	4	4	3	4	4	2	1	3	3	2	1	
2B	Aqueous Polyvinyl Acetate emulsions	Summary	potential skin and eye irritant if exposed to spray drift during application	Spray drift may be a nuisance	once polymer is dry, not soluble in water. Potential leaching of other minor components in formulation		No data. Anecdotal evidence suggest no impact. Suffocation risk not well-defined for emerging plants but being assessed in greenhouse	does not inhibit germination, might be beneficial due to moisture retention and additional nutrients	unlikely to have impact beyond where it is applied, unless applied aerially	Applied using standard equipment, water carts, spray rigs. Can be aerially applied	dust control effective once applied and dry. Application likely < 1 month	Affected by mechanical, rain and wind damage. Broken down by UV over time	3-12 months depending on application and mechanical, rail, wind damage. As above, likely to require reapplication over summer	Approx. $2-3M	Reapplication at least annually possibly more	A number of successful examples inc. Kanmantoo Copper Mine (SA); CSEnergy (Qld)	A number of suppliers and already known to FP. Products supplied for glasshouse trial	
		Rank	3	3	1	1	3	0	0	3	1	8	3	5	9	1	1	130
2C	Bitumen-based	Summary	potential skin and eye irritant if exposed during application. Managed by protective clothing	spray drift may be a nuisance with an ammonia/ kerosene odour	product is water soluble and some leaching may occur	product is water soluble and there is limited potential for leaching	no data. Anecdotal evidence suggest no impact. Suffocation risk not well-defined for emerging plants	does not inhibit germination at application, might be beneficial due to moisture retention. Requires use of aerator	unlikely to have impact beyond where it is applied, unless applied aerially	Applied using standard equipment, water carts, spray rigs. Requires use of purpose-built aerator. Needs to be applied to wet surface or mixed with water	dust control effective once applied. Application likely approx. 1 month	Affected by mechanical, rain and wind damage.	3-12 months depending on application and damage. As above, likely to require reapplication over summer	$4M	Reapplication at least annually possibly more	examples provided by PMB: Banana Shire Council (Qld), Cannington Mine (Qld). Also mention BHP, Rio Tinto and others but unclear if used for roads or dust suppression	PMB Technologies HQ in NSW. No office in SA	
		Rank	3	3	3	3	7	1	0	3	1	7	3	6	10	3	3	176
3	**Soil Properties**																	
3A	Irrigation for dust suppression (not including wastewater application)	Summary	Unlikely to impact works unless wastewater applied	Unlikely to affect residents unless wastewater applied. However, loss of pressure may result given large volumes required and perceived waste of resource	Leaching may occur to groundwater of salt and phosphates from ash; however given the ASA is in contact with groundwater this is unlikely to be significantly above current levels	Impact to surface water unlikely	Limited benefit, if any		No impact	Very difficult to supply water at rates required. Extension of existing water pipe required. Approval from SA Water required	Supply time for irrigation equipment large enough is likely to be closer to 12 months	Affected by wind and evaporation	Daily application would be required	Costs >> $5M	Water costs > $10M but would not be able to supply this amount of water so > $1M likely	Most widely used dust suppressant in the world	SA suppliers but not well-known to FP. Companies not willing to quote	
		Rank	0	3	0	0	0	0	0	8	12	11	12	9	11	1	7	198
3B	Irrigation for vegetative growth (not including wastewater application)	Summary	May impact trafficability during winter	Unlikely to affect residents. May be some perceived waste of resource	As above	Impact to surface water unlikely	Some benefit likely		No detrimental impact	Water can be supplied at rates required using a wider range of equipment. Extension to existing water pipe required. Possibly require approval from SA Water	Supply time for irrigation equipment is likely to be 6 - 12 months given large area	Affected by wind and evaporation but as applied in winter less of an issue than above	Weekly application required	Costs > $5M	Water costs $1M likely	Widely used to grow crops. Benefit/impact to salt-tolerant xerophytes less well known. Trials being undertaken on site.	SA suppliers but not well-known to FP. Companies not willing to quote	
		Rank	3	1	0	0	0	0	0	7	12	10	12	8	8	3	7	189

ID	Option		Environmental Aspects							Operational Aspects				Commercial Aspects				TOTAL
			Workers	Residents	Groundwater	Surface Water	On-site vegetation	Germination	Off-site vegetation	Ease of application	Time to achieve control	Durability	Longevity	Establishment cost	On-going cost	Successful examples	Supplier reputation	
		WEIGHTING	5	5	4	4	4	4	3	4	4	2	1	3	3	2	1	
3C	Increased surface roughness using piston bully or seeder (i.e. small rip lines)	Summary	Unlikely to impact workers; however in high winds dust may still be generated. Minor risk of exposing ash	If undertaken whilst soil is moist unlikely to affect. May still generate dust during high wind events. Minor risk of exposing ash	No impact	Dust may be blown into surrounding water	Will damage or kill established vegetation in areas ripped. By increasing spacing between tynes may reduce impact		No impact	Earthmoving equipment currently located on site and agricultural equipment available locally	Will require at approx. 1 - 4 weeks to affect; longer timeframe if combined with seeding cover crop	Affected by strong winds and rain	May need to be reworked at least annually	Machinery hours - likely to be < $100K	Likely to be required to be undertaken twice during summer	Used in agriculture (see reference list) but results vary with soil properties. Trials being undertaken at site appear promising	Supplied in-house	
		Rank	1	7	0	1	7	3	0	1	1	6	3	1	5	3	1	**132**
4	**Wind Breaks**																	
4A	Porous wind breaks/fences - assumed fencing materials	Summary	Will provide nuisance from impediment to movement	Possibly visual impact. May be blown off-site	No impact	Unlikely but possible	Affected during construction. Fences every few metres but disturb approx 0.3 m metre width and will expose or bury plants		Impact unlikely but possible if fences tear	Installation is labour intensive	Deployment likely to take a number of months and cross-winds may reduce efficacy	Can be easily damaged and torn by wind and traffic and often susceptible to UV breakdown	Depending on damage but given ease of tearing is likely to be annually or less	$2M	Assuming 30% replacement every year approx. $750K	Used in smaller areas, e.g. for dune control. Papers from Brazil, China and Belgium	Suppliers not contacted but a number available	
		Rank	3	3	0	1	7	3	1	10	7	4	3	4	6	7	1	**201**
4B	Straw checkerboard	Summary	Will provide nuisance from impediment to to movement but less than fences	Possibly visual but highly limited	No impact	Unlikely but possible	Affected during construction. Straw every metres and disturbs approx 0.1 m metre width and will expose or bury plants		No impact	Installation is labour intensive	Deployment likely to take a number of months	Will be broken down over time but likely to be years	Unlikely to require replacement within a few years	> $20M	May require some maintenance if trafficked but likely to remain effective even with some damaged due to spacing	Used in sandy conditions overseas, e.g. China, Canada (see reference list)	No contact. Hay bales of correct straw type may be difficult to source in sufficient numbers	
		Rank	3	1	0	1	7	3	0	11	7	3	0	11	2	7	7	**202**