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Proposed Phytoremediation at the Eskom Kilbarchan Colliery, Newcastle, KwaZulu Natal

Remediation Report

Project Number:

ESK3520

Prepared for:

Eskom Holdings SOC Limited (Eskom)

April 2016

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Report Type:	**Proposed Phytoremediation at the Eskom Kilbarchan Colliery, Newcastle, KwaZulu Natal**
Project Name:	**Remediation Report**
Project Code:	**ESK3520**

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EXECUTIVE SUMMARY

The Kilbarchan Colliery consists of a coal discard dump, underground mining and open pit areas, which were rehabilitated more than 20 years ago. The coal discard dump is again being rehabilitated. Although rehabilitated, these previously mined areas are believed to be the source of the mine affected water.

Eskom Holdings SOC Limited (Eskom) requested Digby Wells Environmental (Digby Wells) to investigate the potential of phytoremediation to address the effects and wetland deterioration that is caused by excessive mine affected water influx from mine workings. Phytoremediation utilises the physiological processes of living organisms to break down or absorb excess chemical compounds in ecosystems. The main organisms utilised are bacteria and plants as these organisms are easier to propagate and modify for selected uses. Phytoremediation is therefore considered to be the least labour and cost intensive as a medium to long term solution.

This report outlines the intention for phytoremediation, in terms of the type of vegetation (i.e. trees), quantities and area requirements, to deal with the high levels of water influx to old mine workings and high concentrations of salts in the mine affected water.

Eucalyptus and *Combretum* are large trees that are tolerant of a large range of conditions including high salt concentrations. These trees are recommended for their ability to maintain water and nutrient uptake for prolonged periods. *Eucalyptus* is not deciduous, thus ensuring high evapotranspiration rates year round and *Combretum* is deciduous which will reduce the use of water during dry periods. *Tamarix* is a highly halophytic plant and will continue salt uptake in dry periods of the year. Grass species *Sporobolus* and *Chrysopogon* are recommended for their halophytic properties in relation to their lower transpiration rates; the grass species will prevent against bare areas susceptible to erosion. The planting scheme in Figure I is recommended.

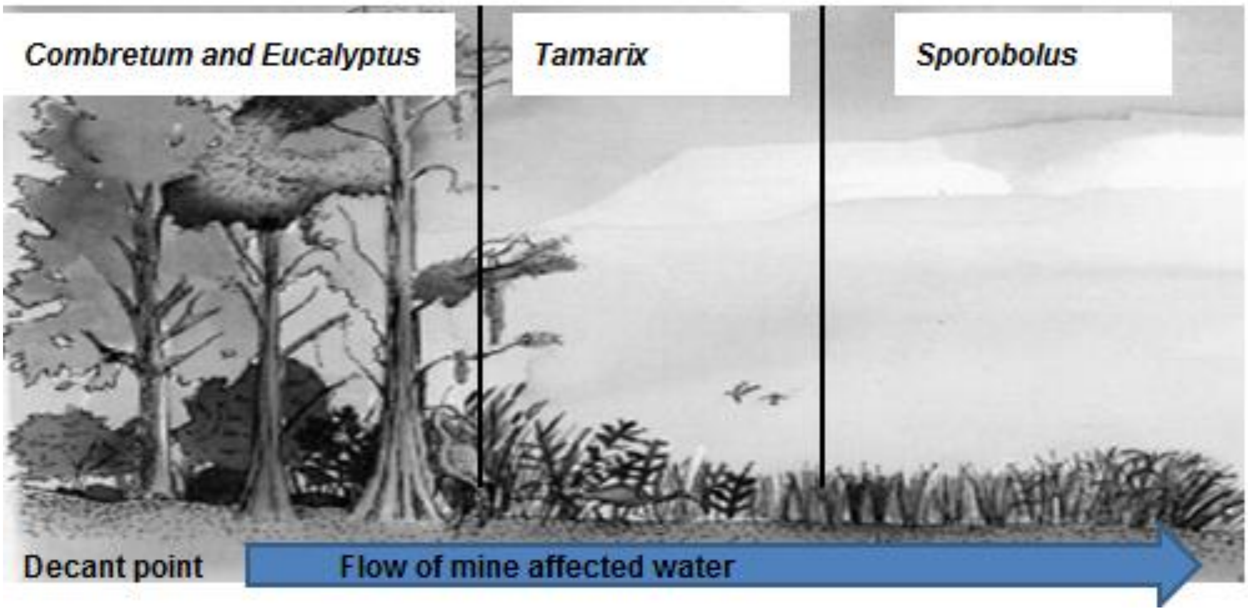

Figure I: Phytoremediation planting scheme

The proposed planting approach is proposed as long term – permanent remediation plan to address the elevated salt concentrations in the mine affected water. The scheme is also recommended so as not to overly impact and reduce on the flow of water but alleviate the impacts brought about by the highly saline water.

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ACRONYMS AND ABBREVIATIONS

AIS	Alien Invasive Species
AMD	Acid Mine Drainage
DO	Dissolved Oxygen
EC	Electrical Conductivity
IWQO	Interim Water Quality Objectives
NEMBA	National Environmental Management: Biodiversity Act
NWA	National Water Act
TDS	Total Dissolved Solids
TSFs	Tailings storage facilities

1 Introduction

The mining of coal in South Africa has historically been the backbone of the economy with coal being exported in large volumes and also used to fire many of the Coal Fired Power Stations in South Africa. The extraction of the coal itself utilises no chemical additives, however; the chemical compounds found in different coal types has the potential to negatively impact the environment, in particular the water resources. The contamination of water resources occurs primarily through the direct contact of dirty water with the natural water systems. The major issue associated with coal mining is the generation of Acid Mine Drainage (AMD) or the occurrence of mine affected water that is high in dissolved salts.

AMD occurs when water is contaminated below the ground and flows to the surface as acid. The generation of acid occurs when water comes into contact with acid generating material below the surface, such as fractured shale, coal waste rock and overburden with active compounds; the same process follows for the formation of highly saline water. The decant water from Kilbarchan Colliery is not typical AMD but is characterised as having high sodium and sulphate levels, resulting in high conductivity and Total Dissolved Solids (TDS), as well as elevated levels of chloride, iron and manganese; the pH of the decant is predominantly neutral. Acidic water has been sampled on site which is expected to occur as a result of seepage through the discard dump or emanating from the rehabilitated open pit areas. The mine affected water contaminates soils and can result in loss of vegetation; furthermore this water cannot be used for irrigation or consumption. The most significant impact, however; is the contamination of ground water which may result in the contamination of other water resources such as ground water fed wetlands and springs.

The best practice to mitigate the contamination of water is prevention through keeping water away from reactive or pollutant compounds. This is not always the case, especially in previously mined out and rehabilitated sites. The Eskom Kilbarchan Colliery consisted of an underground mining area and open pit areas, which were both rehabilitated more than 20 years ago. The associated discard dump is again being rehabilitated. These previously rehabilitated areas are believed to be the source of the mine affected water. There are various treatment methods to deal with the water one of which is phytoremediation; which will be the least labour and cost intensive as a medium to long term solution.

Phytoremediation utilises the physiological processes of living organisms to break down or absorb excess chemical compounds in ecosystems – in this case, the concentrated salts in the mine water. The main organisms utilised are bacteria and plants as these organisms are easier to propagate and modify for selected uses.

2 Project Description

The Kilbarchan Colliery includes the underground mining sections namely, Kilbarchan. Underground mining commenced at the Kilbarchan Colliery in 1954 and utilised the bord and pillar mining method. Open pit mining was also implemented where the coal seam was less than 20 m below ground level (mbgl); sections of the open pit connect to the underground workings.

Following the decommissioning of Kilbarchan Colliery in 1992, the underground workings, as well as open pit areas, began filling up with water at a rate of approximately 4 000 m^3 per day (Vermeulen and van Zyl, 2011). Decant of mine affected water was first recorded in April 2004 and occurs primarily to the south, southeast and east of the discard dump, underground workings and open pit sections (Proxa, 2014). The mine affected water is characterised as having high sodium and sulphate levels resulting in high electrical conductivity (EC) and TDS. There are also elevated levels of chloride, iron and manganese (Proxa, 2014). The mine affected water has a negative impact on the surrounding water courses, particularly the Ngagane River as it does not meet the Interim Water Quality Objectives (IWQO) of the Ngagane Catchment.

Eskom is proposing that the mine affected water decanting at the Kilbarchan Colliery will be abstracted from the underground section of the mine with boreholes and pumped via pipelines to proposed water and waste treatment plants to be located at the decommissioned Ingagane Power Station. The proposed water treatment plant will be subject to a separate Environmental Impact Assessment (EIA) Process.

Phytoremediation is being proposed in addition to the active treatment options to manage the impact of decanting mine affected water on the soil and surface water resources, as well as lower the volume of water required for the active treatment. This report outlines the proposed phytoremediation passive treatment, as well as a supplementary report to be submitted with the *Eucalyptus* permit application.

3 Findings

A wetland assessment was completed to determine the extent of the decant point and which water resources are most likely to be impacted by the salt concentrations of the decanting mine affected water. The proposed active treatment location is shown in Figure 3-1. The decant points were clearly identifiable on the project site as shown in Figure 3-2. The effects of the decanting water on the soil and vegetation are shown in the figure, illustrating also the salts that remain once the water has evaporated.

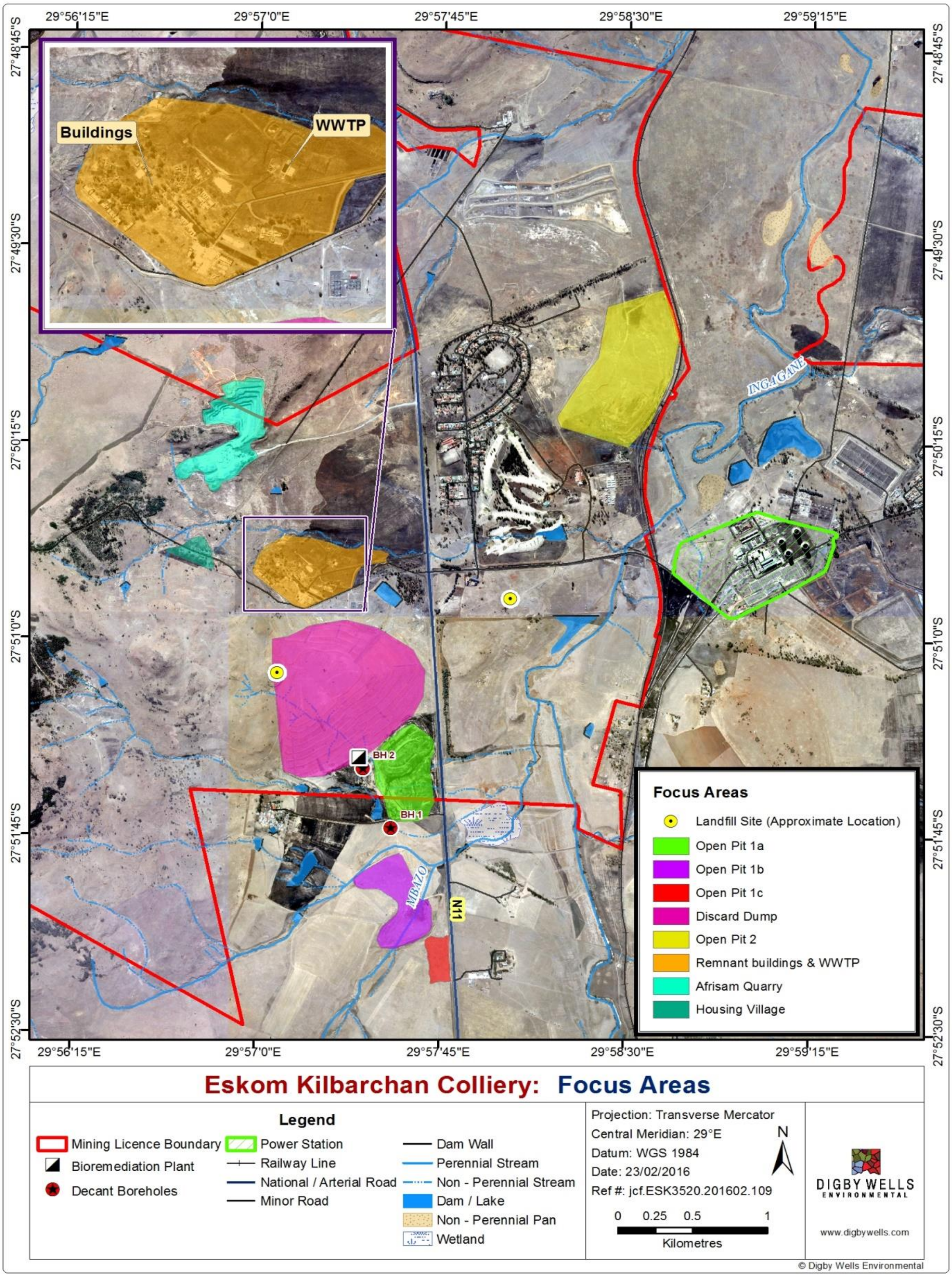

Figure 3-1: Decant points

Figure 3-2: The decant locations and effects on site

Water quality results were obtained while undertaking the Aquatic Specialist Study (March 2014) and are shown in Table 3-1. The sampling sites that would be directly affected by the decanting mine affected water are NGA3 and NGA4 as displayed in Figure 3-3. The results from these two sampling sites indicate elevated TDS which is evident as the conductivity is much higher than the prescribed range, both during the high flow and low flow seasons. The Dissolved Oxygen (DO) in the water is very low which reduces the ability of the water to support life.

Table 3-1: In situ water quality results for the sites associated with the Ingagane River

Constituent	Range	NGA1	NGA2	NGA3	NGA4	NGA5	NGA6	NGA7	NGA8	NGA9	NEW1	Golf Course
High Flow												
Temperature (°C)	5 – 30	24	30	25.4	24	25.1	20	23.9	24.8	26.6	24	20.3
pH	6.9-9	6.9	8.08	7.74	7.79	7.11	7.6	7.1	7.38	7.78	7.07	7.3
DO (mg/l)	> 5	8.04	8.7	7.38	6.2	4.7	5.1	7.7	7.4	5.13	8.49	6.5
DO (% saturation)	80 - 120	95	118.7	90.7	77	55.6	75	93	87	58.8	98	84
Conductivity (µS/cm)	< 700	204	784	2200	6730	194.7	220	292	70.7	428	253	615
Low Flow												
Temperature (°C)	5 – 30	10.7	13	15	16	9.4	12	9.6	12	10.5	12.5	13
pH	6.9-9	7.4	7.13	7.6	7.4	7.09	7.43	7.5	7.8	7.2	7.4	6.91
DO (mg/l)	> 5	5	6.11	1.9	4.5	2.1	2.53	6.58	5	2.4	5.3	1.4
DO (% saturation)	80 - 120	45	59	19	47	20	24	60	58	22	57	14
Conductivity (µS/cm)	< 700	269	2640	5500	6500	327	330	425	87	750	381	545

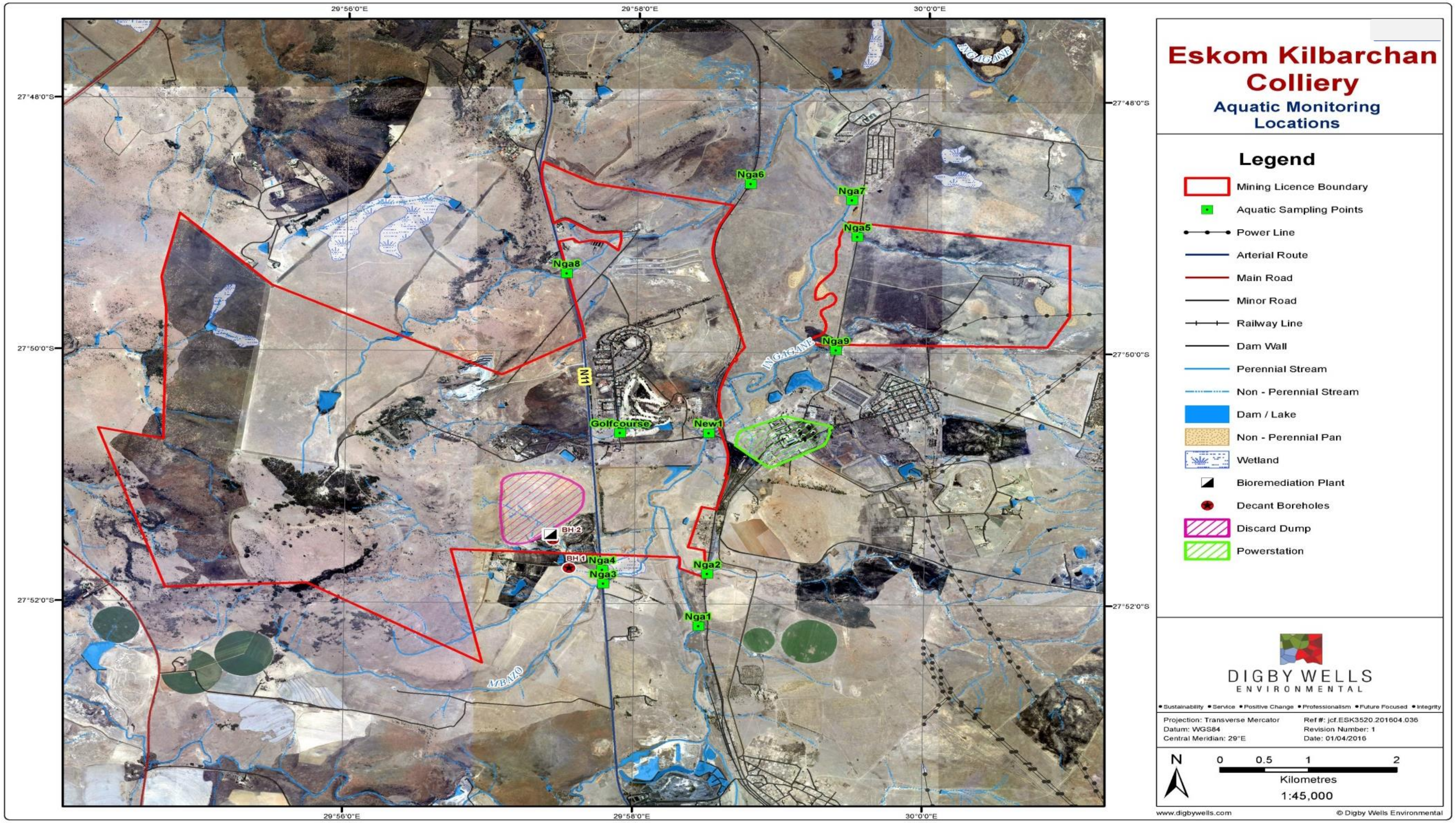

Figure 3-3: Aquatic sampling points

4 Phytoremediation Plan

Phytoremediation is often divided into two sub-categories: phytoextraction and phytostabilisation. Phytoextraction refers to the use of plants to remove harmful metals from the soil into their above-ground biomass, which can be harvested to dispose of the unwanted metals (Mendez & Maier, 2008; Salt *et al*., 1998). Phytostabilisation involves the immobilisation of harmful metals by plants to reduce the bioavailability of these metals (Mendez & Maier, 2008; Salt *et al*., 1998).

Hyperaccumulator plants concentrate metals in their surface biomass 100 times better than other plants in their natural environments, ideally accumulating metals at 0.01-1% of the plant biomass produced (Mendez & Maier, 2008).

Tailings storage facilities (TSFs) generally have a high acidity and a high concentration of metal salts (Mokgalaka-Matlalaa *et al*., 2013). Trees are often used for phytoremediation in TSFs, due to their ability to facilitate the hydraulic control of AMD and sometimes the direct extraction of metals from shallow groundwater (Mokgalaka-Matlalaa *et al*., 2013).

Given the large volumes of water and the elevated salt concentrations, the most feasible and suitable “natural” type of remediation would be the use of plants. The plants chosen would need to have a high transpiration rate, ability to survive and absorb high salt concentrations in the water and soils. Studies conducted in South Africa have shown that woody tree-like or trees have a better survival and success rate for phytoremediation of high salt and/or acidic soils.

The sections that follow provide an overview of the species of trees that have been considered.

4.1 *Combretum erythrophyllum* – River Bush-willow

The *Combretum erythrophyllum* (River Bush-willow) tree is an indigenous South African tree species that is commonly identified within riparian forests along rivers or streams, as described by common English name. This tree grows from a main stem that, according to the report by Stoffberg *et al*. (2008), may reach a height of approximately 5 m within 5 years and can further grow to a height of about 15 m after 50 years.

The tree has a logarithmic annual growth rate of approximately 912 mm/year in the first 5 years, 467 mm/year between 5 and 10 years, 315 mm/year between 10 and 15 years, and 240 mm/year between 15 and 20 years. The growth rate gradually decreases from 195 mm/year, between 20 and 25 years, to 113 mm/year between 40 and 45 years (Stoffberg *et al*., 2008).

The leaves and bark of this plant is widely used in southern African traditional medicine (McGaw *et al*., 2001). Thus, if it is used for phytoremediation, care should be taken that locals do not harvest it for traditional medicine.

The tree has been used as an ornamental street plant in major cities within South Africa due to its vibrant winter leaf colours. *C. erythrophyllum* has been used as a phytoremediation option on several tailings dams in the Witswatersrand Basin, Johannesburg. The tree is able to grow in elevated salinity and/or alkalinity and survive to bear seeds. This tree species is suited for high water volume and salinity uptakes and furthermore does not pose an invasive threat. This plant does not need to be removed as it is a naturally occurring plant in the Newcastle area.

Figure 4-1: *Combretum erythrophyllum* (River Bush-willow)

4.2 Eucalyptus camaldulensis – Red River Gum

The *Eucalyptus camaldulensis* (Red River gum) tree is, as all *Eucalyptus* species in South Africa, a listed alien invasive plant. *E. camaldulensis* is listed as a Category 1b alien invasive plant which means that the plant may not be propagated without a permit and any occurrence of the plant in wetland or riparian areas should be removed unless permitted. The *Eucalyptus* genus is widely cultivated in commercial forests for the production of timber, pulp and paper. This plant is the more hydrophilic (plants that have adapted to living in aquatic environments) of the *Eucalypts* and is known to grow along the river areas in its native country of Australia. This tree is able to withstand and survive high salt and acidic conditions and a vast array of other conditions including drought. This species is a hyperaccumulator of Manganese and Lead among other metals.

Mineral concentration uptake of *Acacia nilotica* L. (babool), *Dalbergia sissoo* L. (sissoo) and *Eucalyptus camaldulensis* seedlings, planted in 1998 and irrigated with municipal effluent, were studied by Singh *et al*. (2010). According to this study, *E. camaldulensis* was the best option for the rehabilitation of soil, due to a high growth rate, high productivity and great reduction in most of the soil mineral concentrations. The results for the *E. camaldulensis* are shown in Table 4-1 below.

Table 4-1 Mineral concentrations in soil (average for 90cm layer) and in 24 month old *E. camaldulensis* seedlings watered with municipal effluent (Singh et al., 2010)

Mineral	Avg. initial soil concentration (mg/kg)	Avg. foliage concentration (mg/kg DM)
N[a]	3.73	24 005
N[b]	5.31	
P[c]	4.94	1 050
K	91.52	13 350
Ca	12 175	16 270
Mg	335.27	4 298
Na	1 055	1 750
Cu	0.47	26.80
Fe	4.93	753.35
Mn	8.84	4.2975
Zn	6.62	33.39

[a] N from NH_4 for soil samples

[b] N from NO_3 for soil samples

[c] P from PO_4 for soil samples

Figure 4-2: *Eucalyptus camaldulensis* (Red River Gum)

Stape *et al.,* (2004) have shown that *Eucalyptus* trees yield transpiration rates that are relative to the annual rainfall in a region, as indicated in Table 4-2. The studies have shown that soil fertility has little to no impact on the trees' production rates and rainfall is the overriding determining factor for productivity (Proxa, 2014). It must be noted, however, that the transpiration rates were recorded for trees planted in a different geographic gradient with unique weather patterns and climatic conditions in comparison to Newcastle.

Table 4-2: Transpiration Rates for *Eucalyptus* Trees in Brazil

Rainfall (mm per Year)	Transpiration (mm per Year)
886	689
1 055	718

Rainfall (mm per Year)	Transpiration (mm per Year)
1 276	869

Stape *et al.,* 2004; Proxa, 2014

Thus, utilising Table 4-2 as a reference and the annual average rainfall for Newcastle of approximately 880 mm, the transpiration rate could be as high as 680 mm per year. Stape *et al.* (2004) utilised a forestry tree spacing of 3.5 m by 2.6 m, which equates to an area of approximately 54 ha of trees required to absorb 1 megalitre of mine affected water per day.

It must be noted, however, that the calculations provided take into account transpiration rates as opposed to absorption rates, as well as forestry spacing; absorption rates are expected to have greater quantities of water. It is anticipated that the area of 54 ha can be greatly reduced to absorb 1 megalitre of water per day. The transpiration rates used for measurement are for full grown trees, it is estimated that it will take between 3 – 4 years for seedlings to reach this point. This plant species is suitable for rehabilitation as it can tolerate high salt concentration in the soil and water. It is important that sterile plants are planted for phytoremediation to minimise the risk of invasion of the surrounding environment. The planted trees cannot reproduce and as such may be left indefinitely.

4.3 *Tamarix usneoides* – Wild Tamarix

Tamarix usneoides (Wild Tamarix) is the only *Tamarix* species that is native to South Africa. The plant is an evergreen shrub to tree that is adapted to living in highly saline environments. The plant has an adapted root system that is able to penetrate deep water tables in arid environments and with adaptive salt glands the plant can exude excess salts. The plant is widely utilised as a phytoremediation plant in South Africa with success around tailings dams. The Wild Tamarix is one of the most effective and readily available species for phytoremediation and it is recommended that this plant be considered for phytoremediation. An example of the Wild Tamarix is provided in Figure 4-3.

Figure 4-3: *Tamarix usneiodes* (Wild Tamarix)

4.4 Sporobolus spicatus – Salt Grass

This species (Figure 4-4) is an African grass species, also known as the Salt Grass, which grows in salty conditions. This grass species is adapted to growing in wet conditions such as salt pan edges, marsh and river edges as perennial grass. Ramadan (2001) conducted a test to determine the salt accumulation and secretion by *S. spicatus* and found that accumulation of salt by the shoots increased with increasing soil salinity and was maximal during the day. At night the secretion of salts was increased to prepare the plant for the uptake of salts the next day. This plant is proposed to be utilised as a phytoremediation option as the plant has a high tolerance for soil and wet conditions. The plant grows in clumps that create a dense grass mat and as such can be grown as water retaining barrier as water moves slowly through the dense vegetation and also minimise areas of exposed soils. The grass is recommended for its dual purpose in phytoremediation.

Figure 4-4: *Sporobolus spicata* (Salt Grass)

4.5 *Chrysopogon zizanioides* – Vetiver Grass

According to Melato *et al.* (2015), Vetiver Grass is a fast-growing, perennial and sterile plant that can grow in a pH between 3.3 and 9.5 and in saline soil with a wide range in metals and an electrical conductivity of up to 47.5 dS/m.

A study done by Melato *et al.* (2015), where Vetiver Grass was grown on gold mine tailings over a period of 16 weeks, reported a bio concentration factor more than 1 and translocation factor of less than 1 for Zinc, Copper and Nickel. The concentrations observed in the soil and roots of the plant are shown in Table 4-3 (Melato *et al.,* 2015). In addition to the metal concentrations reported in Table 4-2, the concentrations of Magnesium and Manganese reportedly increased from 137 to 2 080 mg/kg and 321 to 764 mg/kg in the grass roots respectively, and Lead concentrations decreased from 1 180 to 515 mg/kg after 16 weeks.

Table 4-3 Metal concentrations in gold tailings soil samples (at start of trials) and Vetiver Grass roots (after 16 weeks of cultivation) (Melato et al., 2015)

Metal	Soil (mg/kg)	Roots (mg/kg)
Fe	18 900 ± 548	4380 ± 52.3
As	40.3 ± 1.58	18.5 ± 0.66

Metal	Soil (mg/kg)	Roots (mg/kg)
Au	0.220 ± 0.02	0.00
Cr	149 ± 4.40	35.8 ± 0.61
Cu	86.4 ± 5.24	57.4 ± 1.45
Ni	196 ± 2.27	70.6 ± 1.48
Pb	167 ± 2.70	82.0 ± 1.85
Zn	121 ± 2.39	82.4 ± 2.22

4.6 Maintenance and Monitoring

The phytoremediation plantation will require monitoring and management. The management and monitoring plan is outlined in Table 4-4.

Table 4-4: Phytoremediation Management and Monitoring

Aspect	Description of Monitoring required	Responsible Person	Frequency	Result and action
Vegetation health and condition	The plants will indicate stress levels through changes in leaf colour, dead areas and leaf firmness.	Eskom Representative	Every two months	If plants are dying move to test for water quality and increase water pumped to treatment plant
Occurrence of open surface water flow	Currently there is water flowing on the surface. An increase in vegetation cover should reduce the flow. Water quantities at the V-notch must continue.	Eskom Representative	Every two months	Increase water pumped to treatment plant
		Independent Environmental Control Officer	Annually during the wet season	Employ storm water management, where storm water is also pumped to treatment plant.
Water quality	Water quality monitoring must continue at the monitoring points affected by mine affected water and as per the EIA and EMP to be undertaken.	Eskom Representative	Every two months	Increase water pumped to treatment plant
		Environmental Control Officer	Twice a year. Dry season and wet season.	
Presence of trees in wetland	The presence of trees may be an impact in the long term and may impact the function of wetland areas (water reduction)	Independent Environmental Control Officer	Every two years	The reduction in water will be visible in desiccated wetland areas, trees with high transpiration rates will need to be removed.

5 Legal Requirements

5.1 Environmental Authorisation

The National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) identifies two classes of activities that require authorisation, those of a less significant nature requires evaluation through a Basic Assessment (BA) process and those with substantial impacts requiring a more detailed Scoping and Environmental Impact Assessment (EIA) process. These activities requiring environmental authorisation were published in the EIA Regulations, 2014, in accordance with the NEMA, in two published notices; Listing Notice 1 requires a BA process and Listing Notice 2 requires a Scoping and EIA process. An EIA process will be undertaken for listed activities associated with the active treatment component of the Project, with a Basic Assessment process undertaken for the Phytoremedation Plantation at the Kilbarchan Colliery. The Phytoremediation Plantation triggers the following listed activity:

- Listing Notice 1, Activity 30: Any process or activity identified in terms of Section 53(1) of the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004):
  - A permit is required for the plantation of *Eucalyptus* which is a Category 1b species.

5.2 Water Use Licence

The South African National Water Act; Act 36 of 1998 (NWA) uses the following definition to identify wetland areas:

"land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil."

The study site is a wetland according to the definition stated by the NWA and as such a water use licence will be required for the planting of trees in a wetland area. The identified applicable water uses are:

- Section 21(c): "impeding or diverting the flow of water in a watercourse";
- Section 21(i): "altering the bed, banks, course or characteristics of a watercourse"; and
- Section 21(j): "removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people".

A Water Use Licence will be applied for as part of the EIA process.

5.3 Tree Planting Permit

In terms of National Environmental Management: Biodiversity Act, 2004: Alien and Invasive Species Regulations, (NEMBA: AIS Regulations) 2014. A permit is required for all restricted activities related to *Eucalyptus camaldulensis*. This report has been submitted in support of the permit application.

6 Limitations

The following are limitations to the phytoremediation of salts using plants:

- Most research performed on plants for the use for phytoremediation is based on phytoremediation use on gold tailings dams in Johannesburg (Witwatersrand Basin) area;
- There is limited research and studies on saline water rehabilitation;
- The plants recommended have not been put through thorough trials for salt uptake and phytoremediation; and
- The planting scheme suggested has not been utilised in this manner previously. It is recommended after consultation with the Department of Water and Sanitation was held, where the reduction of streamflow was the main flaw of using monospecific stands of trees.

7 Environmental Impact and Risk Assessment

The proposed Phytoremediation Plantation may result in impacts and risks to the environment and have been detailed in the Basic Assessment Report. An environmental impact is a positive or negative effect on an environmental aspect or receptor and will occur as a result of an activity. Environmental risks, should they occur, will result in impact on environmental aspects. The predominant risk associated with the Phytoremediation Plantation is the spread of *Eucalyptus*, a category 1b invasive species. However, it has been recommended that sterile *Eucalyptus* species are utilised, resulting in the risk of invasive species spreading being negligible.

Impacts associated with the plantation are provided in Table 7-4, below and have been rated according to their significance.

7.1 Methodology for Environmental Impacts

The methodology utilised to assess the significance of potential impacts associated with the phytoremediation plantation is discussed in detail below. The significance rating formula is as follows:

Significance = Consequence x Probability

Where

Consequence = Type of Impact x (Intensity + Spatial Scale + Duration)

And

Probability = Likelihood of an Impact Occurring

In addition, the formula for calculating consequence:

Type of Impact *(Nature) =* ***+1*** *(Positive Impact) or* ***-1*** *(Negative Impact)*

The matrix (Table 7-2) calculates the rating out of 147, whereby intensity, extent, duration and probability are each rated out of seven as indicated in Table 7-1. The weight assigned to the various parameters is then multiplied by +1 for positive and -1 for negative impacts.

Impacts are rated prior to mitigation and again after consideration of the mitigation has been applied; post-mitigation is referred to as the residual impact. The significance of an impact is determined and categorised into one of seven categories (The descriptions of the significance ratings are presented in Table 7-3).

It is important to note that the pre-mitigation rating takes into consideration the activity as proposed, (i.e., there may already be some mitigation included in the engineering design). If the specialist determines the potential impact is still too high, additional mitigation measures are proposed.

Table 7-1: Impact Assessment Parameter Ratings

Rating	Intensity/Replaceability		Extent	Duration/Reversibility	Probability
	Negative Impacts (Nature = -1)	**Positive Impacts (Nature = +1)**			
7	Irreplaceable loss or damage to biological or physical resources or **highly** sensitive environments. Irreplaceable damage to **highly sensitive** cultural/social resources.	Noticeable, on-going natural and / or social benefits which have improved the overall conditions of the baseline.	<u>International</u> The effect will occur across international borders.	Permanent: The impact is irreversible, even with management, and will remain after the life of the project.	Definite: There are sound scientific reasons to expect that the impact will definitely occur. >80% probability.
6	Irreplaceable loss or damage to biological or physical resources or **moderate to highly** sensitive environments. Irreplaceable damage to cultural/social resources of **moderate to highly** sensitivity.	Great improvement to the overall conditions of a large percentage of the baseline.	<u>National</u> Will affect the entire country.	Beyond project life: The impact will remain for some time after the life of the project and is potentially irreversible even with management.	Almost certain / Highly probable: It is most likely that the impact will occur. <80% probability.

Rating	Intensity/Replaceability		Extent	Duration/Reversibility	Probability
	Negative Impacts (Nature = -1)	**Positive Impacts (Nature = +1)**			
5	Serious loss and/or damage to physical or biological resources or **highly** sensitive environments, limiting ecosystem function. Very serious widespread social impacts. Irreparable damage to highly valued items.	On-going and widespread benefits to local communities and natural features of the landscape.	Province/ Region Will affect the entire province or region.	Project Life (>15 years): The impact will cease after the operational life span of the project and can be reversed with sufficient management.	Likely: The impact may occur. <65% probability.
4	Serious loss and/or damage to physical or biological resources or **moderately** sensitive environments, limiting ecosystem function. On-going serious social issues. Significant damage to structures / items of cultural significance.	Average to intense natural and / or social benefits to some elements of the baseline.	Municipal Area Will affect the whole municipal area.	Long term: 6-15 years and impact can be reversed with management.	Probable: Has occurred here or elsewhere and could therefore occur. <50% probability.

Rating	Intensity/Replaceability		Extent	Duration/Reversibility	Probability
	Negative Impacts (Nature = -1)	Positive Impacts (Nature = +1)			
3	Moderate loss and/or damage to biological or physical resources of **low to moderately** sensitive environments and, limiting ecosystem function. On-going social issues. Damage to items of cultural significance.	Average, on-going positive benefits, not widespread but felt by some elements of the baseline.	Local Local extending only as far as the development site area.	Medium term: 1-5 years and impact can be reversed with minimal management.	Unlikely: Has not happened yet but could happen once in the lifetime of the project, therefore there is a possibility that the impact will occur. <25% probability.
2	**Minor loss and/or effects** to biological or physical resources or low sensitive environments, not affecting ecosystem functioning. Minor medium-term social impacts on local population. Mostly repairable. Cultural functions and processes not affected.	Low positive impacts experience by a small percentage of the baseline.	Limited Limited to the site and its immediate surroundings.	Short term: Less than 1 year and is reversible.	Rare / improbable: Conceivable, but only in extreme circumstances. The possibility of the impact materialising is very low as a result of design, historic experience or implementation of adequate mitigation measures. <10% probability.

Rating	Intensity/Replaceability		Extent	Duration/Reversibility	Probability
	Negative Impacts (Nature = -1)	**Positive Impacts (Nature = +1)**			
1	**Minimal to no loss** and/or effect to biological or physical resources, not affecting ecosystem functioning. Minimal social impacts, low-level repairable damage to commonplace structures.	Some low-level natural and / or social benefits felt by a very small percentage of the baseline.	Very limited/Isolated Limited to specific isolated parts of the site.	Immediate: Less than 1 month and is completely reversible without management.	Highly unlikely / None: Expected never to happen. <1% probability.

Table 7-2: Probability/Consequence Matrix

Significance																																					
-147	-140	-133	-126	-119	-112	-105	-98	-91	-84	-77	-70	-63	-56	-49	-42	-35	-28	-21	21	28	35	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147
-126	-120	-114	-108	-102	-96	-90	-84	-78	-72	-66	-60	-54	-48	-42	-36	-30	-24	-18	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126
-105	-100	-95	-90	-85	-80	-75	-70	-65	-60	-55	-50	-45	-40	-35	-30	-25	-20	-15	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
-84	-80	-76	-72	-68	-64	-60	-56	-52	-48	-44	-40	-36	-32	-28	-24	-20	-16	-12	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84
-63	-60	-57	-54	-51	-48	-45	-42	-39	-36	-33	-30	-27	-24	-21	-18	-15	-12	-9	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63
-42	-40	-38	-36	-34	-32	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
-21	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
-21	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Consequence																																					

Table 7-3: Significance Rating Description

Score	Description	Rating
109 to 147	A very beneficial impact that may be sufficient by itself to justify implementation of the project. The impact may result in permanent positive change	Major (positive) (+)
73 to 108	A beneficial impact which may help to justify the implementation of the project. These impacts would be considered by society as constituting a major and usually a long-term positive change to the (natural and / or social) environment	Moderate (positive) (+)
36 to 72	A positive impact. These impacts will usually result in positive medium to long-term effect on the natural and / or social environment	Minor (positive) (+)
3 to 35	A small positive impact. The impact will result in medium to short term effects on the natural and / or social environment	Negligible (positive) (+)
-3 to -35	An acceptable negative impact for which mitigation is desirable. The impact by itself is insufficient even in combination with other low impacts to prevent the development being approved. These impacts will result in negative medium to short term effects on the natural and / or social environment	Negligible (negative) (-)
-36 to -72	A minor negative impact requires mitigation. The impact is insufficient by itself to prevent the implementation of the project but which in conjunction with other impacts may prevent its implementation. These impacts will usually result in negative medium to long-term effect on the natural and / or social environment	Minor (negative) (-)
-73 to -108	A moderate negative impact may prevent the implementation of the project. These impacts would be considered as constituting a major and usually a long-term change to the (natural and / or social) environment and result in severe changes.	Moderate (negative) (-)
-109 to -147	A major negative impact may be sufficient by itself to prevent implementation of the project. The impact may result in permanent change. Very often these impacts are immitigable and usually result in very severe effects. The impacts are likely to be irreversible and/or irreplaceable.	Major (negative) (-)

7.2 Predicted Phytoremediation Impacts

The potential positive and negative impacts associated with the Phytoremediation Plantation have been detailed in the Basic Assessment Report. A summary of the significance of the identified impacts, prior to and post the implementation of mitigation measures, as well as the mitigation measures, is provided in Table 7-4.

Table 7-4: Summary of Pre-Mitigation and Post-Mitigation Significance Ratings for Impacts associated with the Phytoremediation Plantation

Environmental Aspect	Potential Impact	Pre-Mitigation					Mitigation Measures	Post-Mitigation				
		Extent	Duration	Intensity	Probability	Significance		Spatial	Duration	Intensity	Probability	Significance
Surface Water	Streamflow reduction and increased salt concentrations	3	6	3	5	Minor (negative) (-60)	No mitigation measures applicable.	3	6	3	5	Minor (negative) (-60)
	Reduced decant volumes improving water quality of catchment	3	6	3	6	Minor (positive) (+72)	No mitigation measures applicable.	3	6	3	6	Minor (positive) (+72)
Fauna and Flora	Transformation of habitats	2	6	3	5	Minor (negative) (-55)	▪ To reduce the spread of invasive species, an alien invasive management plan should implemented by removing all invasive species that may become established by the disturbed environment; ▪ Develop and implement a monitoring programme to ensure all species proposed to be used for the phytoremediation plantation remain within the proposed footprint. Should species start to grow elsewhere they should be removed and disposed of.	2	4	3	4	Minor (negative) (-36)
	Potential loss of biodiversity due to habitat transformation	2	4	3	6	Moderate (negative) (-54)	No mitigation measures applicable.	2	4	3	6	Moderate (negative) (-54)
Aquatics	Sedimentation of water resources impacting aquatic ecology	4	3	3	6	Minor (negative) (-60)	▪ A phased approach should be implemented where only the vegetation in the footprint of the Phytoremediation Plantation should be impacted upon, thereby limiting the exposure of soil to wind and surface water runoff erosion; ▪ Ideally planting should be done in the dry season to limit the effects of surface water runoff as a result of rain; ▪ Berms and sediment traps should be employed to capture soil runoff; and ▪ A minimum of a 100m buffer from the edge of the riparian zone should be enforced to avoid impacts, or vehicles driving in sensitive riparian areas.	3	3	2	3	Negligible (negative) (-24)
	Fertiliser runoff may impact aquatic ecology	4	4	4	6	Minor (negative) (-72)	▪ A minimum of a 100m buffer from the edge of the riparian zone should be enforced to avoid impacts, or vehicles driving in sensitive riparian areas; ▪ The use of berms to prevent the runoff of nutrients into the aquatic ecosystem; and ▪ Precision farming techniques should be used to calculate the right amount of fertiliser to be used, to prevent excess application.	3	4	3	4	Minor (negative) (-40)

Environmental Aspect	Potential Impact	Pre-Mitigation					Mitigation Measures	Post-Mitigation				
		Extent	Duration	Intensity	Probability	Significance		Spatial	Duration	Intensity	Probability	Significance
Wetlands	Loss of wetland habitat for plantation	3	6	4	6	Major (negative) (-78)	▪ There is no mitigation for the loss of these wetlands. ▪ A wetland offset strategy is recommended which is in line with Eskom policy.	3	6	4	6	Major (negative) (-78)
	Reduced mine affected water will reduce the impact on surrounding wetlands	3	6	3	6	Minor (positive) (+72)	No mitigation measures applicable.	3	6	3	6	Minor (positive) (+72)
Soil, Land Use and Land Capability	Loss of topsoil through compaction and erosion	2	6	5	3	Minor (negative) (-39)	▪ Ensure proper storm water management designs are in place; ▪ If erosion occurs, corrective actions (erosion berms) must be taken to minimise any further erosion from taking place; ▪ If erosion has occurred, usable soil should be sourced and replaced and shaped to reduce the recurrence of erosion; and ▪ Rehabilitate in accordance with the Rehabilitation Plan.	2	2	3	2	Negligible (negative) (-12)
Social	Improved health and safety risks and aesthetic qualities	3	7	6	6	Moderate (positive) (+96)	No mitigation measures applicable.	3	7	6	6	Moderate (positive) (+96)

8 Conclusions and Recommendations

The phytoremediation to be performed on site will aim to reduce the high levels of water influx to the underground mine workings and high concentrations of salts in the mine affected water, which in turn contaminates the soil and surface water sources. The site is currently impacted and it would be best to not only address the water problem alone, but the plant types selected for remediation should also address the biodiversity aspects. The *Eucalyptus camaldulensis* tree can survive stressful environments and take up lots of water; however, this plant is a listed Category 1b invasive and requires a permit. The *Combretum erythrophyllum* tree is a riparian tree that is able to adapt to saline environments. *C erthrophyllum* is an indigenous tree and has a lower water usage when compared to the *Eucalyptus* plants; however, this tree may not be able to address the elevated salinity effectively in isolation. *Tamarix usneoides* is a native halophytic (salt loving or salt tolerant) plant that is well adapted for survival in high saline water. This plant is adapted to survival in desert environments through its root system that can reach deep water tables and has been used in many rehabilitation interventions for its halophytic capabilities. This plant displays invasive characteristics through the alteration of its surroundings as it deposits excess salts to the ground through salt glands in the leaves to increase the surface salt concentration. *Sporobolus spicatus* is a grass species that is adapted to surviving in high saline environments and is a species that will offer vegetative cover that will slow water down for extended accumulation of salt and reduce water flow into water resources.

It is recommended that the planting scheme represented in Figure 8-1 (Appendix A – Phytoremediation Planting Plan) be used; this will place the big trees with high transpiration rates within proximity to the decant point and the high salt intake plants with lower transpiration rates further from the decant point and closer to wetland areas. Furthermore, the presence of a halophytic grass species will slow water flow and allow time for the uptake of salts in the water.

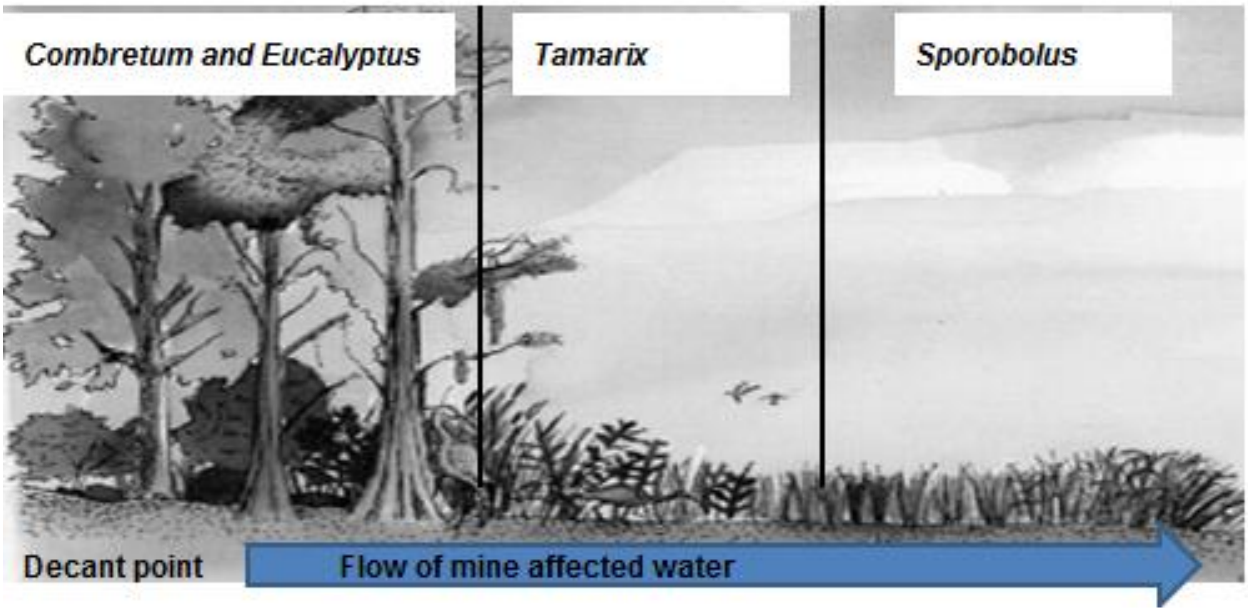

Figure 8-1: Phytoremediation planting scheme

The proposed planting scheme is designed to address different levels of water and salt contamination as such:

- *Eucalyptus* and *Combretum* will be planted at the source point due to their deep penetrating roots so as to intercept mine affected water at the underground level. The aerial extent of the *Eucalyptus* and *Combretum* potential plantation is approximately 42 ha. In addition, *Combretum* and Vetiver Grass is recommended for a further 11 ha;
- *Tamarix* is planted as an intermediate plant that will address both surface flowing and groundwater and also hyperaccumulate the salt. The area identified for the potential Tamarix plantation is 66 ha; and
- *Sporobolus* and Vetiver Grass will be planted to deal with surface flowing mine affected water and also act as a water diffuse barrier before water enters nearby water resources. This accounts for approximately 56 ha.

The potential impact of using the larger (high transpiration rates) trees alone is that they may substantially reduce streamflow, reducing the volume of water available which would increase the concentration of salts in the water. An elevated salt concentration in the mine affected water may lead to higher salt levels flowing into nearby water resources.

The purpose of phytoremediation is to offer a long term - permanent solution to an environmental impact. The management of the phytoremediation is necessary to ensure the relevance and effectiveness to the impact. The seepage of mine affected water is not expected to cease in the foreseeable future and cannot be stopped; therefore it is recommended that the phytoremediation be implemented as a permanent feature.

The *Eucalyptus* trees that should be planted will be sterile trees that do not pose a threat of spreading and the *Combretum* trees are site specific and require large volumes of water to establish. The *Tamarix* is an evergreen shrub that is easily removable in areas that it is not wanted and will not spread significantly from the planted area. The grass species are seasonal plants that will regulate their growth and dying back with seasons and will not spread from the site. For these reasons it is recommended that the plants be left indefinitely to deal with continued affected water (not only by mining) in the area, unless their presence is determined to hinder vital ecological processes.

9 Way Forward

Based on the recommendation provided in this report, Digby Wells Environmental will update this report in support of the required licences/approvals for the preferred option for phytoremediation. Eskom and Digby Wells will need to agree on the plants to be utilised, the quantities and the location of the phytoremediation plantation. The current area identified for the phytoremediation occurs on private land and Eskom will require an agreement with the landowner for the use of this land. Alternatively new areas will need to be identified.

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Appendix A: Phytoremediation Planting Plan