AQUAPONICS AS A PRODUCTIVE REHABILITATION ALTERNATIVE IN THE MPUMALANGA HIGHVELD COALFIELDS

by

ILSE BOTHA
(2011107568)

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Centre for Environmental Management
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Supervisor: Dr Alex Weaver

This mini-dissertation is dedicated to my late father, Hennie Bruwer (30 January 1951 – 27 August 2013), who lost his life due to illness during the timeframe of my study.

ABSTRACT

The Mpumalanga Highveld Region is commonly known for its coal mining activities, especially surface mines. South Africa is still reliant on coal as its main energy source. A dilemma identified is that most of the coal reserves in Mpumalanga are (or were) located below highly productive arable land formerly used for food production such as maize. With a growing energy demand, these valuable areas of land are being impacted negatively. The post-mining land is predominantly rehabilitated to a grazing land capability instead of the pre-mining arable land capability, hindering the production of crops on those areas when mining ceases. This adds to the food security threat which South Africa is currently facing.

The National Development Plan 2030 indicated the intentions to diversify the national economy. It was identified that agricultural activities should be expanded to relieve the high levels of poverty in rural areas, and that sustainable agriculture should be the main focus. With the prevailing trends of surface coal mines expanding on available arable land, the realization of this goal might not be possible.

This study looked at aquaponics as a possible environmental management alternative that will enhance the agricultural productivity of rehabilitated mine land. An experimental site located close to Middelburg and Emalahleni was used as the base for this study to determine the financial feasibility of such a venture. Five chosen mines within a 20km radius were investigated to understand their rehabilitation practices and to prove that the sites are rehabilitated to a grazing land standard. These sites were all identified as favourable for the initiation of aquaponics.

The two post-mining land use alternatives were compared with one another to understand what the benefits and constraints are. The economic driver was a main focus, followed with a brief overview of environmental and social aspects that can be kept in mind when these land uses are established.

Keywords

Aquaponics; aquaculture and mining; post-mining land use; surface coal mine rehabilitation; food security; arable land; Mpumalanga Highveld coal mines; sustainability of aquaponics; impact of surface coal mining.

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DECLARATION

I declare that my study, “Aquaponics as a productive rehabilitation alternative in the Mpumalanga Highveld Coalfields” is my own work. This study was not submitted to any other university for examination or as part of another degree. The sources used to complete this study have been duly acknowledged and referenced as prescribed.

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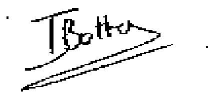

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30 January 2014
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ACCRONYMS AND ABBREVIATIONS

AASA	-	Aquaculture Association of Southern Africa
BATNEEC	-	Best Available Technique Not Entailing Excessive Cost
BGIS	-	Biodiversity Geographical Information System
COM	-	Chamber of Mines
COP17	-	Conference of the Parties, 17th Annual Meeting
CRA	-	Coaltech Research Association
DEAT	-	Department of Environmental Affairs and Tourism
DoE	-	Department of Energy
ha	-	hectare
IDP	-	Integrated Development Plans
IRR	-	Internal Rate of Return
JKC	-	Jaco-K Consulting
mamsl	-	metres above mean sea level
mm	-	millimetre
MLU	-	Mature Livestock Unit
MPRDA	-	Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)
m^2	-	square metres
m^3	-	cubic metres
NASF	-	National Aquaculture Strategic Framework
NDP	-	National Development Plan
NEMA	-	National Environmental Management Act, 1998 (Act No 108 of 1998)
NFT	-	Nutrient film technique
NPV	-	Net Present Value
NWA	-	National Water Act, 1998 (Act No. 36 of 1998)
RAS	-	Recirculating aquaculture system
SATFA	-	South African Tilapia Farmers Association
SANBI	-	South African Biodiversity Institute
WCA	-	World Coal Association
WUL	-	Water Use Licence

CHAPTER 1 – INTRODUCTION

1.1. Introduction

Surface coal mining is a common practice in the Mpumalanga Highveld Region in South Africa. Approximately 77% of South Africa's energy requirements are provided by coal (Department of Energy (DoE), *s.a.*). In addition to the local domestic use, 28% of all coal mined in South Africa is exported, ranking South Africa as the 4th largest coal exporter in the world. Coal therefore plays a key role in the South African economy, proved by the South African utility Eskom's international ranking as the No. 1 steam coal user and 7th ranking as electricity generator. Sasol also plays a key role as the leading coal-to-chemical producer in the world (DoE, *s.a.*).

Energy Minister, Dikobe Ben Martins, mentioned at the third Carbon Capture and Storage (CSS) Conference held in Johannesburg on the 1st of October 2013 that South Africa's abundant coal resources will continue being exploited to form part of the diversified energy mix (Creamer, 2013). According to the Department of Energy's deputy director-general, Mr Ompi Aphane, and Dr Steve Lennon from ESKOM, coal will remain the anchor of South Africa's power sector for at least the next 20 years (Kolver, 2013).

In contrast to the above, South Africa is also focussing on developing and moving towards a "green economy" that will reduce the risk on the environment, ecological scarcities as well as social inequities that still prevail (Siphuma, 2013). A green economy will also contribute to human well-being. This has led to the development of the South African Green Accord that was initiated after the United Nations' 17th Annual Conference of the Parties (COP17), focussing on all sorts of energy generation techniques such as clean coal technologies and renewable energy programmes, as well as the promotion of the production of locally produced goods and local employment (Siphuma, 2013). The National Development Plan (NDP) 2030 also address the development of a more diversified dynamic economy that will lower production and living costs, but that will increase the living standards of South

Africans in the still very unequal society (NDP, 2013). It also addresses environmental sustainability and a transition towards a low-carbon economy.

Another key challenge South Africa is facing at the moment is the threatening food security crisis. Food security is a priority identified by the Government, not only for South Africa, but for the African continent as a whole, as stated by the Agriculture, Forestry and Fisheries Minister, Tina Joemat-Pettersson at the 3rd BRICS (Brazil, Russia, India, China and South Africa) development meeting for Agriculture and Agrarian ministers (South African Government News Agency, 2013). The minister stated that South Africa’s priority is to increase sustainable agricultural and food production in the country and on the continent in order to feed its people and the rest of the world.

One of the visions stated in the 2030 NDP is to increase and expand agricultural development, such as irrigated agriculture and dry-land activities, in order to relieve poverty in the rural areas (NDP, 2013). The NDP states that this should contribute to access to basic services and ensure food security for local people in rural areas. Agriculture is and remains the main economic driver in rural areas and could, according to the NDP, be increased from 1.5 million hectares of irrigation land to 2 million hectares by 2030.

This brings us to a dilemma and a potential conflict for land use in South Africa. The 2012 State of the Environment Report indicated that coal mining practices in Mpumalanga transformed 12% of South Africa’s high potential arable land, which equates to 326 022 ha (O’Beirne, Napier and Johnson, 2013). In addition to this, another 13.6% are subject to prospecting for coal in the province, equating to 439 577 ha of land that could be mined in the near future. In total, this equates to 765 559 ha of high potential agricultural land in South Africa that could be lost due to coal mining activities (O’Beirne *et al*, 2013). The area of arable land at risk to be mined (439 577 ha) in the near future is almost equal to the potential 500 000 ha that the NDP refers to that should be expanded for agricultural use (NDP, 2013).

It is therefore important to understand that surface mining, and in this case specifically coal mining, reduces the availability of agricultural land for a diversified economy, poverty alleviation and food security in South Africa. Mining companies deal with this problem by aiming for rehabilitation of mining areas to productive agricultural land, mostly of a grazing land standard. It is incumbent upon environmental assessment professionals as well as environmental managers on mines to be fully aware of these challenges and to be in a position to be able to advise decision makers in mining companies and authorising bodies on feasible alternatives to the *status quo*. This study will focus on alternative methods of rehabilitating the mining areas to productive agricultural sites by looking at aquaponics as a potential end land use option.

1.2. Background to the study

Surface coal mining requires good and sound rehabilitation practices to re-establish productive land capability and land use after mine-closure. A vast majority of Mpumalanga's coal deposits are located below high quality productive arable land. Impacts on soil and land associated with surface coal mining commonly reduce the possibility to re-establish the pre-mining land capability and productive potential. The result observed in practice, defined as the *status quo*, is that most surface coal mining companies in Mpumalanga aim to re-establish grazing land capability potential for the end land use option instead of the original arable land capability.

Several best practice rehabilitation guidelines for re-establishing sustainable rehabilitated post-mining land exist in South Africa and internationally (Chamber of Mines (COM) and Coaltech Research Association (CRA), 2007). Rehabilitation of mined land is, in essence, an effort by mining companies to restore the land to a sustainable and usable state. The mining industry in South Africa does, however, acknowledge that even with best practices that are currently used, restoration of land similar to the pre-mining scenario is not practically possible. The aim, therefore, becomes to restore the land to a point where the permanent loss of land capability is minimized and to ensure that the land will still have some benefit to society.

The Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA), which is the main law pertaining to mining related practices in South

Africa, requires in Section 38 (1) (d) that rehabilitation of mines should be conducted in such a manner that the natural or pre-determined state of that specific area is reconstructed. The MPRDA also states that rehabilitation should be practical and should restore the land to the agreed end land use as was decided on during a public participation process.

According to the *COM and CRA Guidelines for Rehabilitation of Mined Land* (2007) the international objectives of rehabilitation of mines comprise three perspectives. The first perspective is that rehabilitation should ideally keep the community's wishes and needs in mind, and not only adhere to the previous land use or the *status quo*. Secondly, and the most widely accepted, is that rehabilitation should focus on restoring the pre-mining land use capability, especially agricultural use, as the majority of coal mines in South Africa occur on land of high agricultural potential. The third perspective is to prevent the net loss of biodiversity. In addition to the international objectives, the rehabilitation of mines in South Africa is currently subject to governmental pressure. Mines should therefore start considering their local Integrated Development Plans (IDP) when planning end land uses post-closure, and not only adhere to the rehabilitation *status quo* trends, but also ensure alignment with local and regional development planning objectives.

As mentioned by the COM and CRA (2007), rehabilitation practices in South Africa do not allow the land to be restored to the pre-mining scenario even with the utilisation of suggested best practices. The current scenario is that pre-mining wetland areas are rehabilitated to wilderness standards and the opencast box-cut areas are rehabilitated to a grazing standard (COM and CRA, 2007), even though it could have been of arable standard prior to mining. If areas that were of arable land capability prior to mining are generally only rehabilitated to grazing standards, that does, unfortunately, contribute to a net loss of land capability of arable land. These rehabilitation practices can therefore be assumed to be contributing to land degradation which is a priority environmental issue in South Africa (Department of Environmental Affairs and Tourism (DEAT), 2007).

The DEAT reported in the *South Africa Environment Outlook, A report on the state of the environment* (2007) that only 11% of South African land is of arable potential.

This equates to approximately 0.4 ha per capita, which is predicted to decline to around 0.3 ha per capita by the year 2030. In addition to this declining scenario, the growing population and improved standards of living add additional pressure to secure food sources for the nation. The current agricultural practices will have to become more efficient to address the future needs of the country. With less available arable land for agricultural purposes, it will become more difficult to address the food security challenges of South Africa.

Numerous factors contribute to the fact that rehabilitated mine land cannot be used for agricultural production within the first few years, even if the aim was to rehabilitate to arable potential. Generally, indigenous grass mixes are planted to help re-establish the land and to protect the land against soil erosion (COM and CRA, 2007). At some older mines, soil loss adds to the problem of restoring the land to agricultural (grazing or arable) potential (COM and CRA, 2007). This impact calls for mines to start re-evaluating the end land use options of mined areas in order to ensure sustainable post-mining land that could still be in line with a similar land use prior to mining. If the land was producing food before mining occurred (e.g. pre-mining land capability was arable land, producing crops and pastures), but cannot be rehabilitated to an arable standard post-closure, mines should evaluate other sustainable alternatives for the end land use that will secure food production.

An alternative suggested for mining to contribute to sustainability (and food security) post-closure is to look at the production of food through aquaponics. Aquaponics is defined as a bio-integrated system that links aquaculture and hydroponics with one another (Diver, 2010). Not only is aquaponics a sustainable alternative land use option as stated by Diver (2010), but it can also contribute positively and within a short period of time to the food security crisis South Africa is facing, especially in local areas where aquaponics is practised. Many of the older mines which were located in rural areas when mining commenced, are now on the boundaries of towns and cities due to urban sprawl (COM and CRA, 2007). Thus, the possibility of aquaponics as an end land use option on these mined out areas adjacent to urban areas should be explored. This can be particularly beneficial for mining areas within close proximity of towns as they could then contribute to urban sustainability in these regions. Mines can integrate the use of aquaponics into the implementation of the

IDP of the regions they are located in, which could in turn lead to a positive influence by uplifting an area or a community.

1.3. Research Question

What is the feasibility of using aquaponics as an alternative post-mining land use for coal mining areas?

In order to answer the research question more efficiently, 3 sub-questions were formulated using synonyms for the word “feasibility”.

1) Can aquaponics be a practical (reasonable / useful / workable / user friendly / applicable / sensible) post-mining land use?
2) Is it possible (attainable / achievable) to implement aquaponics on post-mining land taking note of the specific site conditions?
3) Can aquaponics be viable (sustainable / worthwhile) on post-mining land?

1.4. Objectives of the study

The objective of the study will be to determine whether aquaponics could be considered as a feasible post-mining land use option on mined out surface coal mines in the Mpumalanga Highveld Region.

This study will be conducted by gathering information from a selected experimental site where aquaponics in this region is practised. The experimental site is, however, not located on a rehabilitated mine site. Part of the study will therefore determine whether such systems can successfully be implemented on rehabilitated mine land, keeping the site conditions in mind.

The use of aquaponics as an end land use on mined out areas as compared with grazing land will be discussed from a sustainability perspective to evaluate whether aquaponics could be used as a sustainable end land use option for such sites as suggested and aimed for by the *Chamber of Mines' Rehabilitation Guidelines* (COM and CRA, 2007). The three sustainability components will, in short, be evaluated and discussed as follows:

- Economic component – This will form the main focus of the study as the financial feasibility of aquaponics based on the experimental site's design will be determined by calculating the capital costs of three different farm-size scenarios, as well as the estimated cash flows over five years. Selected economic indicators will be used to determine feasibility. This information will then be compared to the costs and possible income associated with re-establishment of grazing land (*status quo*) under current practices. The two scenarios will be compared with one another to determine whether aquaponics could be seen as a financially competitive and feasible alternative post-mining land use.
- Environmental component – This will be discussed by reviewing the requirements to initiate an aquaponics system and assessing it against environmental criteria and sub-criteria. In summary, this will be used to determine and understand if aquaponics is an environmentally friendly and practical alternative and the reasons for this status (to be determined through a literature review and as observed on the experimental site). The benefits and possible constraints to initiate aquaponics from an environmental perspective will be highlighted.
- Social component – The benefits of what aquaponics could contribute to a local community within close proximity of a mining site (to be determined through a literature review) will be briefly discussed.

The study will be concluded by suggesting scenarios where aquaponics can be most feasible in terms of location and availability of resources. It will be compared to other scenarios where grazing will remain a preferred option, or if aquaponics is considered, whether it should perhaps be practised in combination with other post-mining land uses.

An overview of the chapters in this document is as follows:

- Chapter 2 entails a Literature Review of concepts of surface coal mining and related impacts, rehabilitation practices in the Mpumalanga Highveld, as well as descriptions of the key characteristics of aquaponics.

- Chapter 3 gives an outline of the methodology followed in this study, including the steps to analyse the data and information that was obtained.
- Chapter 4 describes the bio-physical information of the greater study area, as well as the aquaponics experimental site.
- Chapter 5 deals with data analysis and provides a discussion of the results.
- Chapter 6 gives final conclusions and recommendations based on the results of the study.

CHAPTER 2 - LITERATURE REVIEW

This literature review provides an overview of the surface mining of coal and the associated impacts experienced in the field. Rehabilitation practices typical of surface coal mines in the Mpumalanga Highveld are described as well as their effectiveness. The suggested alternative end land use, namely aquaponics, and its individual components, is also described in this chapter, including some of the benefits associated with these practices.

2.1. Brief description of surface coal mining practices

Surface coal mining is the process of extracting coal via open pit strip mining methods using large trucks and shovels or draglines or a combination thereof. Surface mining methods are used when the coal seams are located at depths close to the surface. The advantage of surface coal mining is that a greater percentage of the deposit, i.e. 90% or more, can be exploited (World Coal Association (WCA), *s.a.*).

Figure 1 presents a graphic demonstration of the surface coal mining process. The first step is to strip the topsoil and subsoil layers via shovels and to remove these materials with trucks to allocated stockpiles where they are stored until final rehabilitation of the site. In some cases, soil is directly placed on available mined out areas. The second step involves blasting of overburden rock material using explosives and removal thereof to stockpiles separate from the topsoil and subsoil piles, unless directly placed into mined out voids. By then the first coal seam is exposed and ready to be drilled and blasted, if necessary, and then removed from the pit by trucks and shovels.

The geology of the Mpumalanga Highveld Coalfields entails more than one coal seam. When the first exposed coal seam is removed, the interburden rock material that occurs between the different coal seams is then blasted and removed from the pit to expose the underlying coal seam. This pattern is repeated until the final economically viable coal seam is reached and removed.

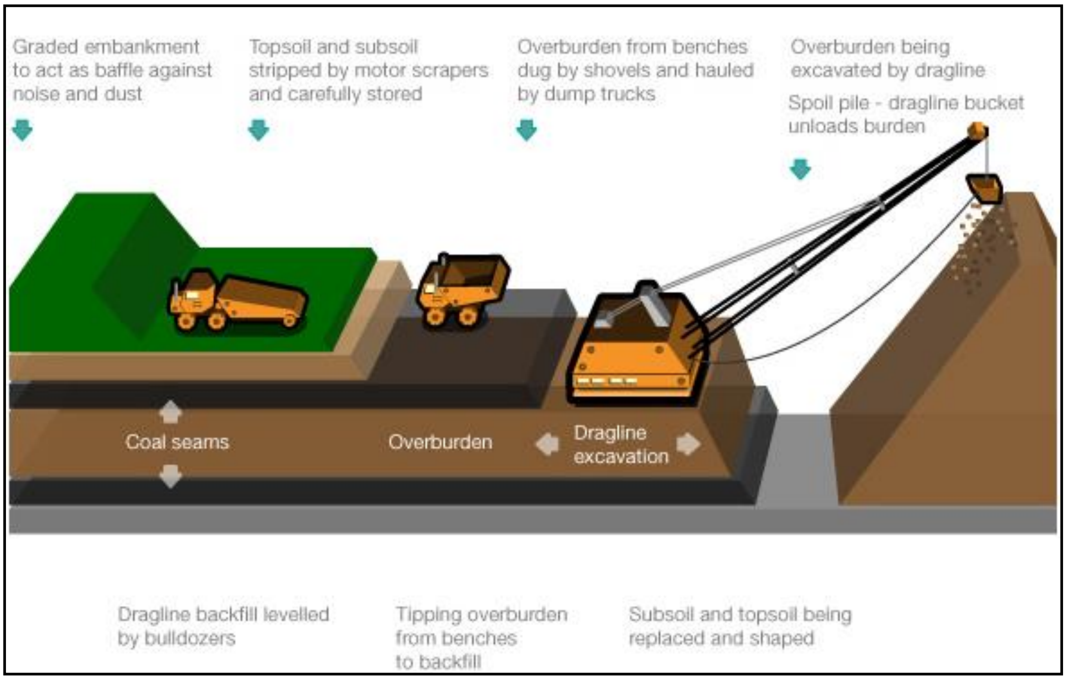

Figure 1: Schematic presentation of typical surface coal mining methods (taken from the WCA, *s.a.*)

The process continues with the rehabilitation process as indicated on **Figure 2**. At first the interburden and overburden rock material is replaced back into the mined out voids. These spoils are then levelled and the area is prepared for the replacement of subsoil and topsoil layers. Once the soils are replaced and levelled, the area is prepared for seeding, or for the other agreed end land use.

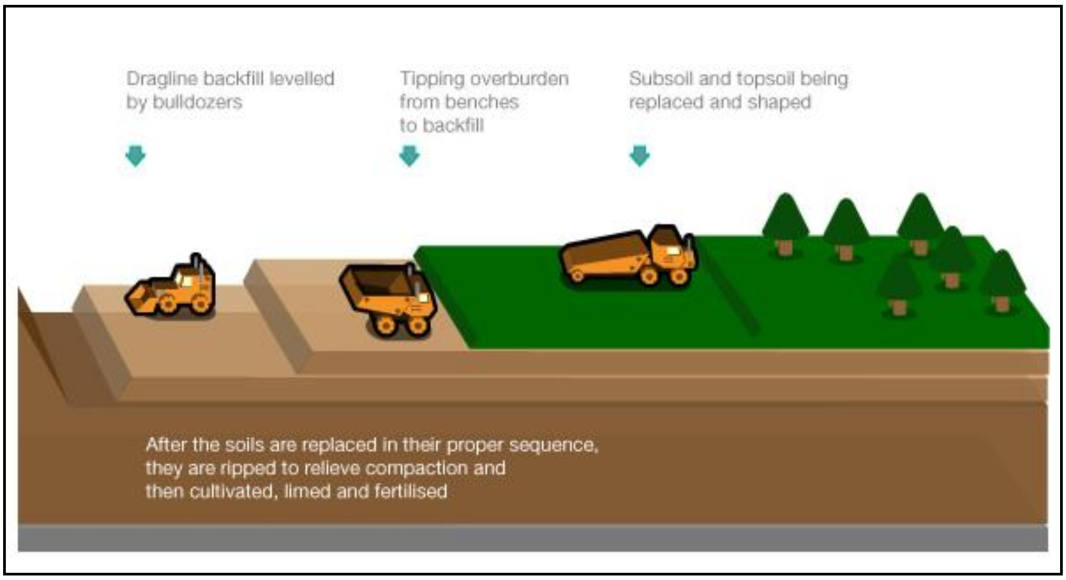

Figure 2: Schematic presentation of typical surface coal mining rehabilitation methods (taken from the WCA, *s.a.*)

2.1.1. Summary of environmental impacts associated with surface coal mining

Surface coal mining is associated with a number of negative environmental impacts, including pollution of soil, water, and air (Cogho, 2012; Maczkowiack, Smith, Slaughter, Mulligan and Cameron, 2012). An unavoidable impact associated with surface coal mining is land degradation, caused by disturbance of the natural profile of the land (Ghose, 2001). Not only does it cause the natural soil layers and geological strata to be disturbed, but it also results in the disturbance of natural hydrological cycles of specific areas, as well as significant impacts on water resources. Land degradation may also lead to soil erosion, destruction of watersheds, siltation of water resources as well the loss of a valuable resource, namely fertile soil (Ghose, 2001).

Topsoil stripping and stockpiling is an important and necessary practice of surface coal mining operations, as topsoil forms a critical element for the successful restoration of open pit mines (Ghose, 2001). Topsoil cannot always be placed directly onto mined out land. Therefore, it may be necessary to stockpile the resource for future use (COM & CRA, 2007). Poor management of topsoil and stockpiles will lower the rehabilitation value of the soils. This, in turn, has an impact on the post-mining land capability and land use once mining has ceased.

Soil loss is a regular occurrence at surface coal mines, especially older mines where soil management was not a management priority (COM and CRA, 2007). In some areas, soil was not even stripped prior to mining as it was not a requirement to do so (Cogho, 2012). Soil is a valuable resource, since it is the growth medium used by vegetation and for food production. Adequate soil stripping, stockpiling and management of this resource at a surface coal mine is therefore of utmost importance. Without the management thereof, the post-mining substrate might not comprise only soils (Mentis, 2006), and not be able to support a good vegetation cover. Soil generation (pedogenesis) is a lengthy process and takes many years. Thus, inadequate management of soils will prolong or compromise the restoration process post-mining. Other impacts on soils, especially pertaining to the restoration process, include soil compaction and erosion. This will be discussed in more detail in the following section (**Section 2.1.2**.).

As already mentioned, another major environmental impact associated with surface coal mining is water pollution with the possibility of decant post-closure. Mine affected water on site which is not adequately contained could lead to spills or discharges into the natural aquatic environment (Cogho, 2012). The focus for surface coal mines in terms of water management should be the re-use of mine affected water for mining activities whilst operational, effective separation of clean and affected water and ensuring adequate capacity for storage of affected water.

In many cases, the long term impact of mine affected water at coal mines, is acid mine drainage (AMD). The process that generates AMD is described by Mentis (2006: 193) as the "…oxidative dissolution of sulphide minerals". The minerals he is referring to are commonly found in the mine strata and spoils of coal mines. Coal itself contains approximately 10% sulphur. Half of this sulphur content generally occurs as pyrite (FeS_2) which oxidises spontaneously when it comes in contact with water and oxygen. When present, chemolithotropic bacteria could accelerate the process of pyrite oxidation by 10^6 times (Mentis, 2006).

Spontaneous combustion is also a major impact that could occur at coal mines and is usually attributed to burning spoils or coal discard. It is described as an oxidation reaction occurring in spoil materials without the presence of an external heat source (Phillips, Uludag, and Chabedi, 2011). The reaction causes the internal heat of the materials to change, increasing the temperature. This results in burning of the material with open flames present at times. Combustion could start forming prior to levelling of spoils (Mentis, 2006). Another phenomenon is when combustion takes place in the underlying spoils due to oxygen entering the spoils via cracks or sinkholes as a result of subsidence. Not only does spontaneous combustion have a significant impact on air quality, but it also results in bare patches at the surface as the topsoil becomes sterilised; hence, the soil no longer supports vegetation growth and soil erosion results.

Although the main focus of this study is on the impacts of surface coal mining on land and post-mining land capability and land use, the availability and quality of water plays an important role in an area in determining possible alternative post-mining land uses. The probable presence and impacts of spontaneous combustion should also be kept in mind before finalizing any other post-mining land use at a surface coal mining site.

It is inevitable that the coal mining industry in South Africa plays a profound role in environmental degradation. Adequate environmental management of the associated impacts should therefore be implemented prior to mining activities to reduce, minimize and manage the impacts on the environment. If the environmental management of a mine is undertaken in an adequate manner during the planning, construction and operational phases of a mine, it could reduce the impacts that have to be dealt with during the closure and decommissioning phases of a mine, thereby improving the status and value of the land post-mining.

2.1.2. Rehabilitation of surface coal mines in South Africa and associated impacts

As discussed under **Section 2.1**, the general practice of rehabilitation at surface coal mines consists of landscaping spoils, replacing topsoil on landscaped areas and then re-vegetation of those areas (Mentis, 2006). Infrastructure such as mine offices, beneficiation plants and workshop areas are usually demolished or decommissioned, and the area is then restored by reversing compaction of topsoil, or replacement of topsoil and seeding thereof. Where discard dumps are present, these sites are also covered with topsoil to attempt re-vegetation.

As mentioned in **Section 1.2**, the rehabilitation aim for most surface coal mining companies in the Mpumalanga Highveld is to re-establish grazing land capability potential post-mining. Many of the areas were used as arable land prior to mining (e.g. maize crop production, soya beans and or potatoes), but will most likely only be re-established to a grazing standard or potential (*status quo*). The main reason for this is the fact that less topsoil (only about 300 mm) is replaced in these areas than what was present prior to mining, reducing the possibility to plant crops at the restored site. To restore the land to its arable potential, local experience has shown that a minimum of 750 mm of soil needs to be replaced (Steenekamp, 2013, pers. comm., 17 October). If only 600 mm of topsoil is replaced which is seen as the minimum depth to re-establish arable land, then the site will end up with less than 600 mm soil depth due to compaction of soils and local loss due to erosion (Du Plessis, 2013, pers. comm., 10 December).

The first step for final rehabilitation is to establish high-production pasture using grass species that respond well to fertilizer (Mentis, 2006). A soil analysis is usually conducted to determine the amounts of lime, nitrogen, phosphate and potassium that need to be added to the soil (Mentis, 1999). A cocktail mix of seeds is usually used for the re-vegetation process. The seed mix typically comprises the herb species indicated in **Table 1**.

Table 1: Herb species generally combined in a seed mix for re-vegetating surface coal mines in the Mpumalanga Highveld (as adapted from Mentis, 1999:210)

Scientific name	Common name	Description
Chloris gayana	Rhodes grass	Robust stoloniferous grass
Cenchrus cillaris	Buffalo grass	Tufted grass
Cynodon dactylon	Kweek	Stoloniferous grass
Digitaria eriantha	Smuts finger grass	Robust tufted grass
Eragrostis curvula	Love grass (Oulands)	Tufted grass
Eragrostis tef	Teff	Annual tufted grass
Medicago sativa	Lucerne	Upright legume

It is believed that grasses have a high root material turnover (Mentis, 1999), contributing to the restoration process of soils by adding organic material to the soil profile. Pasture grasses are also used as they protect soils against erosion. The addition of fertilizer ceases when the status of native grassland has been restored. Defoliation management, i.e. grazing or mowing, however, should continue (Mentis, 1999). Care and maintenance is applied to the areas for the first 3 – 5 years.

For effective rehabilitation post-closure, the management of soils should be one of the highest priorities at a mine and should commence during the construction phase of a mining project (COM and CRA, 2007). Soil should be stripped and stockpiled as stipulated by a soil scientist in a defined guideline developed prior to any mining activities on a site. Ideally, soil should be stockpiled separately according to characteristics such as soil types and soil horizons. This is, however, not always done (COM and CRA, 2007).

Soils are in practice stockpiled in three categories according to their clay content, topsoil and subsoil, and not grouped together as commonly prescribed in the soil guidelines of a mine. The “A” and “B” horizons are usually stripped and stockpiled together, diluting the fertility status of the soil (COM and CRA, 2007), thereby increasing fertility requirements post-closure. Mentis (2006) also described this impact as an effect of soil disturbance when bringing the subsoil, saprolite and fragmented rock to the surface. These components then form part of the mixture with topsoil that is used for the top layer on a post-mining surface. The result is that the mixture often cannot support plant life. Therefore, for good rehabilitation results to re-establish plant life, the contamination of soil, especially when bulk volume soil stripping is practised on a site, should be minimized or prevented.

Another common occurrence hindering effective rehabilitation at opencast coal mines in South Africa is soil compaction (COM and CRA, 2007). Soil should also ideally be replaced in the same sequence that it was stripped (and at the same localities), but doing so increases compaction due to surface traffic at certain areas (Mentis, 2006). Soil compaction reduces porosity and water infiltration and prevents sufficient plant root penetration depths for vegetation to establish adequately. Mentis (2006) mentioned that when these soils dry, they become hardened, especially soils with low organic carbon. This results in a reduction of land capability, as crops and pastures will not be able to grow as desired due to increased erosion resulting from lower infiltration and greater runoff.

Mentis (2006) identified soil acidity as a further constraint to the restoration of grassland. He mentioned that the soils in the Eastern Highveld of South Africa are naturally moderately to slightly acidic (pH 4 to 6). Therefore, he concluded, that disturbance of soil does not necessarily influence soil acidity. However, areas where he encountered strongly acidic soils (pH < 4), were areas where AMD is present and had influenced the soils, in particular at the foot slopes of rehabilitated landscapes where seepage occurred and at areas where the soils covering the carbonaceous spoils (or discard) were very shallow. Mentis also explained that AMD causes extreme soil acidity. Impacts caused by AMD include death of vegetation, leading to prolonged plant colonisation. Without vegetation binding the topsoil, erosion is more likely to occur.

Spontaneous combustion of carbonaceous spoils and the resultant loss of vegetation could also result in bare patches on areas where soil erosion takes place, exposing inhospitable spoils (Mentis, 2006). Consideration of any other land use is restricted in areas where spontaneous combustion takes place.

In addition to the constraints mentioned above, restoration of the land in terms of soil organic carbon, nutrient pools and soil functioning, is also retarded by withholding natural defoliation practices, namely grazing by livestock (Mentis, 2006). Livestock could contribute to successful rehabilitation by promoting nutrient cycling and importing nutrients onto the land.

The COM and CRA's *Guidelines for Rehabilitation of Mined Land* (2007) has a section dealing specifically with "problem areas", including areas where topsoil was significantly lost or polluted. Rehabilitation of such areas without topsoil needs specialist advice to compile a mitigation programme that is sustainable. Solutions need to be evaluated to determine if the mitigation measures suggested will meet the long term land use plan.

2.1.3. Results and success of rehabilitated opencast coal mine land in the Mpumalanga Highveld

Prior to the enactment of the MPRDA 2002, rehabilitation was practised mostly voluntarily by the South African mining industry (Mentis, 2006). Mentis identified that a primary shortcoming is that rehabilitation objectives are not clearly identified in the industry. The mining industry strives to keep rehabilitation costs to a minimum. Certain constraints that should be kept in mind and that should form part of the planning of rehabilitation includes specifying the post-mining land capability that should be established to satisfy a certain agricultural use, to create a landscape that will minimize soil loss and will optimize vegetation establishment, and where AMD will have a minimum influence, if any.

Mentis' study (1999) on rehabilitation of coal mines suggested that aftercare of rehabilitated land and the future thereof should be clearly considered. His findings indicated that the rehabilitation paradigm as currently practised at the majority of mines (involving increasing soil fertility and re-establishment of fertilizer responsive pasture species) is indeed a useful model. He did, however, indicate that the industry should take aftercare seriously since 765 559 ha of high potential agricultural land is to be subjected to mining in the Mpumalanga Highveld region (O'Beirne *et al*, 2013). The majority of this farmland produced grain, or more specifically maize. In Mentis' opinion the first option for rehabilitation should therefore be to reintroduce maize production in those areas after mining occurred, but it is believed that only a small percentage of the rehabilitated land will be suitable for annual crop production post-mining. The second option suggested by him is therefore, to restore native grassland, but his view is that this results in a time consuming process with land of low grazing value. The third option suggested is to restore high-productive pastures (such as Smuts finger grass) for animal production. This could be the most economically viable option, but the threat would be that it could become a driver for rehabilitation to achieve economic driven benefits rather than benefits for the natural environment by re-establishing native grassland.

Mentis' (1999) fourth opinion and option is to combine the above three options. Mines are conservative in making financial provisions for rehabilitation, as it doesn't generate the same type of income as the mining operations. They therefore predominantly follow what is referred to in the industry as the BATNEEC (Best Available Technology Not Entailing Excessive Cost) principles. Lower yielding pastures leading to smaller animal production are used instead, such as the Oldfield succession, or also described as the re-establishment of native grassland. In areas where trials have been conducted to produce crops on rehabilitated land, the product yields were poor. This combination, in turn, leads to a low market demand for mine rehabilitated land (Mentis, 1999).

One can therefore ask the question: What if the land, or pieces of the land, cannot be successfully rehabilitated to the planned desired state for the long term end land use? Poor soil management in the operational phase of the mine could possibly prevent the re-establishment of pre-mining land use or another sustainable land capability class post-closure. In cases where pre-mining arable land capability potential is lost to a re-established grazing standard (as described in **Section 1.2**), this leads to a permanent loss of the land's potential to regain the pre-mining land use and land capability, as well as the ability of the land to produce crops. It therefore affirms the predicted decrease in arable land per capita made by the DEAT.

The restoration of native grassland instead of the pre-mining arable potential land or re-introduction of crops is not necessarily a negative impact, since one cannot argue that restoring the land to a natural condition (native grassland) is not acceptable or sustainable. It could, however, in terms of a growing economy and a growing population, be a constraint to the food needs of a developing country and a changing society. If the native grassland or grazing potential land was the agreed end land use as was determined and agreed upon at a public participation meeting as required in the MPRDA, then once again, this can be seen as an acceptable end land use. The MPRDA does, however, add that the end land use should also be practical.

Keeping that in mind, mines, and specifically older mines, face the fact that major societal changes could lead to their planned end land uses not being sufficiently adequate for the current needs of society. Mines located closer to towns or where communities are residing, might face greater pressure from Government and should therefore reconsider post-mining land uses whilst keeping the Integrated Development Plans (IDP) of their local areas in mind. With that said, the IDP of an area also needs to be aligned with strategic long term sustainability and should take cognisance of both the opportunities and constraints to having mineral deposits and potential mining activities within their boundaries. Mining companies can play a key role through participation in IDP processes hence earning the social licence to operate (Hoadley, Limpitlaw and Weaver, 2002).

2.1.4. Suggested alternative post-mining land uses for surface coal mines

The study conducted by Mentis (1999) affirmed that the *status quo* rehabilitation model used by surface coal mines in the Eastern Highveld Region is a useful tool and a good attempt to restore the land post-mining. However, the fact that arable land is lost due to the presence of surface coal mines is something that cannot be ignored, resulting in a national decline of land available for food production, e.g. grain foods, potatoes and soy beans which are commonly grown in the region.

According to the Population Reference Bureau's *2011 World Population Data Sheet* (2011), South Africa had a 0.6 % annual Rate of Natural Increase (RNI). Although classified as an upper-middle income class country (Population Reference Bureau, 2012), poverty is still a great problem in many areas. This is backed by the Gini Index coefficient (2009) of 63.1 on a scale where 0 represents perfect equality and 100 denotes perfect inequality (World Bank Group, 2013). To place this in context, South Africa is one of very few countries with an index exceeding 60, resulting in being ranked among the top 5 countries in the world where inequality prevails. The human population as a whole is facing threats to global food security mainly due to land degradation (DEAT, 2007). This therefore calls for mines to take land rehabilitation seriously and to regain the potential for mined land to be productive again during the post-mining phase.

The main criteria for an alternative post-mining land use compared to the current *status quo* will be to identify whether it would be classified as a sustainable end land use. To understand the term "sustainable", one can look at the basic definition of sustainability. It is generally summarized as "the ability to meet the needs of present and future generations through the responsible use of resources" (DEAT, 2007). The reason for mining companies to try and establish a sustainable end land use is to ensure that the land can continue to be productive post-mining and hence, still be able to be of value for present and future generations (COM and CRA, 2007). Sustainable solutions should therefore be explored for the current environmental situations we face with coal mines post-closure.

2.2. Brief description of aquaponics and associated practices

Aquaponics could provide an alternative, more productive and sustainable end land use option at rehabilitated surface coal mines. The establishment of aquaponics could specifically be of value for mines where agricultural land uses or capability (whether it be arable land or grazing land) cannot or could not be re-established due to various reasons mainly as a result of environmental impacts due to poor environmental management (e.g. poor soil management).

Aquaponics is understood to be a form of sustainable food production. It is a bio-integrated system linking aquaculture (fish farming) and hydroponics (the growth of plants, usually certain vegetables, herbs and fruit types, in a soilless medium such as liquid hydroponic systems or aggregate hydroponic systems) with one another (Diver, 2010). In short Diver (2010:1) described it as the "integration of hydroponics with aquaculture". **Figure 3** indicates the relationship between the two systems.

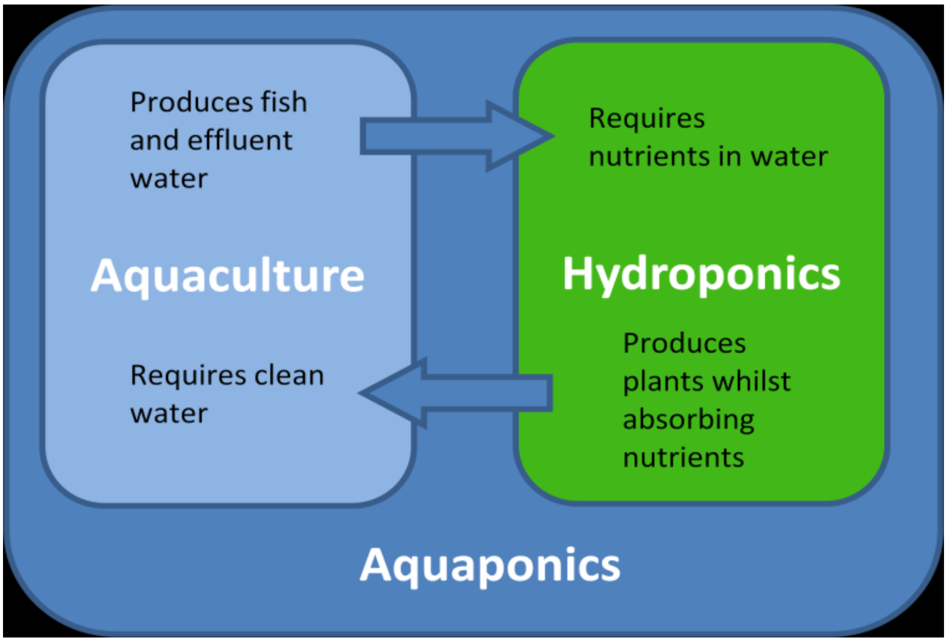

Figure 3: Simple illustration of the relation between aquaculture, hydroponics, and aquaponics (Lapere, 2010)

The main principle in an aquaponic system is that effluent from fish tanks which is rich in nutrients (such as nitrogen and phosphate) is used in hydroponic beds. These beds then act as bio-filters removing the nutrients and chemicals from the water that would otherwise build up to toxic levels in the fish tanks (Diver, 2010). The nutrients, which are the waste from the one system, namely the fish tanks, are absorbed by the plants in the hydroponic beds and act as a natural fertilizer to the other biological system.

Brief descriptions of the two components, namely aquaculture and hydroponics, which together form the aquaponic system, will be given in the following sections.

2.2.1. Aquaculture

By definition, aquaculture, or fish farming, is the cultivation of fish species, including shell fish, and commercial harvesting thereof for human consumption (Miller and Spoolman, 2012). Fish are grown in oceanic regions by means of underwater cages or in open waters. Inland fish farming is also conducted in water bodies such as fresh water ponds or lakes, as well as in rice paddies. Fish are harvested when marketable size has been reached. Fisheries and aquaculture is said to be the third major food-producing system in the world. It is on occasion referred to as the “blue revolution” since it is one of the fastest growing food production types worldwide (Miller and Spoolman, 2012).

2.2.1.1. Why Aquaculture?

With an ever growing world population, the demand for food also increases. Aquaculture therefore plays a profound role in satisfying this need as fish provide an excellent source of nutrients and animal food protein (FAO, 2012). Fish are also more affordable than other animal food types of protein. Annual consumption of fish per capita in the world increased from an average of 9.9 kg in the 1960’s to 18.4 kg in 2009. However, according to the FAO’s (2012) statistics, Africa is the continent with the lowest fish consumption.

Declining fish stocks in the world's oceanic regions pose a threat to global food security and also lead to various ecological, social and economic impacts (FAO, 2012). Aquaculture could therefore contribute to global food security.

2.2.1.2. Aquaculture production in the world

It was reported by the Food and Agriculture Organization of the United Nations (FAO) Fisheries and Aquaculture Department (FAO, 2012) that 2010 introduced a record high with a 59.9 million ton production through aquaculture. This equates to 40% of all fish produced globally. Values reported by FAO indicate that fish production through aquaculture has increased since 2006 whilst wild fish capture stayed fairly constant with a small decline. **Table 2** shows the world fisheries and aquaculture production and utilisation over the period from 2006 until 2010.

Table 2: World fisheries and aquaculture production and utilization (FAO, 2012:3)

Production	**2006**	**2007**	**2008**	**2009**	**2010**
	million tonnes				
Capture					
Inland	9.8	10.0	10.2	10.4	11.2
Marine	80.2	80.4	79.5	79.2	77.4
Total Capture	**90.0**	**90.3**	**89.7**	**89.6**	**88.6**
Aquaculture					
Inland	31.3	33.4	36.0	38.1	41.7
Marine	16.0	16.6	16.9	17.6	18.1
Total Aquaculture	**47.3**	**49.9**	**52.9**	**55.7**	**59.9**
Total World Fisheries	**137.3**	**140.2**	**142.6**	**145.3**	**148.5**
Utilisation					
Human consumption	114.3	117.3	119.7	123.6	128.3
Non-food uses	23.0	23.0	22.9	21.8	20.2
Population (billions)	6.6	6.7	6.7	6.8	6.9
Per capita food supply (kg)	17.4	17.6	17.8	18.1	18.6

FAO notes: Excluding aquatic plants. Totals may not match due to rounding.

2.2.1.3. Aquaculture in South Africa

As stated previously, Africa's contribution to aquaculture production is of the lowest worldwide. Yet, the total population of Africa was 1,051 million in 2011 (Population Reference Bureau, 2011) with some of the world's poorest living on the continent.

In South Africa, the aquaculture industry is showing signs of growth (Skelton, 2001). The two species that are mainly cultivated successfully through aquaculture activities are rainbow trout (*Oncorhynchus mykiss*) and sharptooth catfish (*Clarias gariepinus*). Others include various species of tilapia, types of carp, goldfish (*Carassius auratus*) and ornamentals.

The species of importance for this study is tilapia, specifically the Mozambique tilapia (*Oreochromis mossambicus*) and the redbreast tilapia (*Tilapia rendalli*). According to Skelton (2001) the use of tilapia species locally has not been proven to be successful as markets for the species have not been as fully established as they have in other countries. Yet, several farmers have been farming with tilapia in South Africa. The production of indigenous tilapia through aquaculture is envisaged to increase in the future as it shows great potential (Skelton, 2001).

Organisations have been established to promote aquaculture development in South Africa, such as the Aquaculture Association of Southern Africa (AASA) and the South African Tilapia Farmers Association (SATFA) (AASA, 2010). The latter is a devoted non-profit organisation that aims to increase production and consumption of tilapia (SATFA, 2013). They also focus on promoting sustainability, education, rural upliftment and interacting with government.

Some constraints that prohibit the development and growth of aquaculture in South Africa include the unjustified overregulation of the industry, especially in comparison with other types of food production industries (National Aquaculture Strategic Framework (NASF) DRAFT, *s.a.*). Also the un-coordinated institutional environment resulting in different government departments with different expectancies rising from fragmented policies and strategies. One such example is the environmental authorisations that need to be obtained prior to embarking on such a venture as well as the compliance expectancies of health and product quality standards (Lapere, 2010). In addition to this, the lack of aquaculture expertise and biophysical challenges of the South African environment has also limited the growth of this sector.

2.2.1.4. The two species of importance

The species of importance are part of the Family Cichlidae or known as cichlids (Skelton, 2001). The cichlids are classified as a large family of fresh and brackish water fish that are abundant in tropical parts of Africa, Madagascar as well as in parts of Central and South America, India and the Levant.

The two species used at the experimental site in this study are both part of the Tilapiine tribe which is a major branch of the African cichlids (Skelton, 2001). In addition to the use of certain species as fine table fish, they are also used for commercial aquaculture and as angling targets. A description of the two species as described by Skelton (2001:319, 323-324 and 325-326) is given below in **Table 3**.

Table 3: Characteristics of the two species used at the experimental site

Redbreast Tilapia ("Rooiborskurper") – *Tilapia rendalli* (Boulenger, 1896)	**Mozambique Tilapia ("Bloukurper") – *Oreochromis mossambicus* (Peters, 1852)**
Genus: *Tilapia* A. Smith, 1840	**Genus:** *Oreochromis* Günther, 1889
Naturally occurs amongst other sub-Saharan African regions, in the estuaries of Mozambique and KwaZulu-Natal, but they have trans-located throughout KwaZulu-Natal into the Highveld region.	**Naturally occurs** in eastern coastal rivers of Southern Africa, i.e. the lower Zambezi river system to the Bushmans system in the Eastern Cape, including the Pongola system and associated coastal areas and estuaries. The species have also dispersed into the inland river systems such as the lower Orange system and the western coastal regions all the way into Namibia.
Temperature tolerance: 11 – 37 °C **Salinity tolerance:** Can endure high salinity (up to 19 parts per thousand) in water.	**Temperature tolerance:** Prefer warm temperatures of above 22 °C and can tolerate up to 42 °C. Can also tolerate lower temperatures to

Redbreast Tilapia ("Rooiborskurper") – *Tilapia rendalli* (Boulenger, 1896)	**Mozambique Tilapia ("Bloukurper") – *Oreochromis mossambicus* (Peters, 1852)**
pH: Best growth in near neutral to slightly alkaline waters. Lethal limits include a minimum of pH 5 and maximum of pH 11 (Popma and Lovshin, 1995).	a certain level, e.g. below 15 °C in specifically brackish or marine waters. **Salinity tolerance:** Tolerant of fresh, brackish and marine waters. Can live in both fresh and seawater with higher salinity concentrations. Prefer standing water to fast-flowing water. **pH:** Growth conditions best in near neutral to slightly alkaline waters. Lethal limits at pH 5 and pH 11 (Popma and Lovshin, 1995).
Substrate spawning species: Pair-formation is distinctively part of the breeding cycle, and both parents guard the brood. Breeding pairs build a nest in shallow waters by removing the vegetation in an area of some 0.5 by 1.2 m. Brood chambers are then created wherein eggs and larvae are protected, and in which juveniles of up to 15 mm remain. There are several broods in one season and the fish can live up to 7 years of age.	**Mouth-brooder:** Females raise multiple broods in a season, within timeframes of 3-4 weeks per brood. Males are responsible for building the saucer-shape nests that usually occur within the sandy bottoms of river or estuary. The female mouth-broods the eggs, larvae and juveniles (also known as small fry). Juveniles remain in shallow waters and grow rapidly to reach maturity within a year, with the possibility to breed in that timeframe. This could, however, be constrained if they are residing in overcrowded conditions.
Diet: Consists mainly of water plants and algae but could also include aquatic invertebrates and small fish.	**Diet:** Mainly algae. Larger fish may, however, also feed on insects and other aquatic invertebrates.
Total length: Approximately 400 mm.	**Total length:** Adult size is approximately 400 mm.. *Oreochromis* species are usually larger than the *Tilapia* species, which is economically important to man.
Importance of species: Important aquaculture species. Also a popular angling species and of importance to control weed in dams.	**Importance of species:** Important aquaculture species and for commercial fisheries used world-wide. It is also of importance for angling and for scientific research in terms of biological, physiological and behavioural patterns.

The main reason why these two species were chosen for the aquaculture component was due to the requirement made by the Mpumalanga Tourism and Parks Agency (MTPA) that only native species should be used in order to protect the catchment area (JKC, 2011, Blenkinsop, 2013, pers. comm., 14 January). The MTPA felt that the risk of alien species entering the natural environment is too high if these species manage to escape into the natural river systems. If this happens, it could have an adverse effect and a negative impact on the environment and the natural ecology.

South African consumers are not yet familiar with the tilapia species as a food source (Lapere, 2010). They still prefer saltwater to freshwater fish and are rather conservative about this. Britz, Lee and Botes (2009) also indicated in the *2009 AISA Aquaculture Benchmarking Survey* that there is no established domestic market for tilapia in South Africa. One positive point favouring tilapia as the preferred option for aquaculture production in South Africa is the growing international trend and demand for this species. Tilapia has entered new markets in the past decade, whereas they were relatively unknown only a few years ago (FAO, 2008). Thus, with marketing, it is believed that tilapia could become a preferred choice locally as well.

2.2.1.5. Methods of aquaculture

Various methods of aquaculture exist and can be used to produce fish. Four of these methods will be discussed briefly (as per explanation by Lapere, 2010) specifically to illustrate which method is most preferred for aquaponics.

1) Pond culture: Fish are produced in open earth ponds. The ponds require vast areas of land as fish are stocked at low density. The input costs in this type of aquaculture are low. Fish are fed occasionally or not at all, as the ponds usually provide enough nutrients to sustain the fish.
2) Cage culture: This method is done inside an open water body where a wire or mesh structure is used to enclose and grow the fish. Fish are fed and therefore operational and capital costs are higher than in the pond culture method.
3) Raceways: Rectangular structures are built to contain the fish. The one end acts as an inlet for freshwater and the other end acts as an outlet. No filtering is required, but fish can be stocked at higher densities. Capital costs are higher, but operational costs are seen as moderate as fish are fed.
4) Recirculating aquaculture system (RAS): RAS's can be seen as technologically advanced systems compared to the other three types of methods. The reason for

this is because water is filtered and re-used allowing higher density fish stocks. The income that can be generated can therefore be expected to be higher than that of the other methods if the size of the system is taken into consideration. With that, the capital costs are also high due the usage of pumps, filters and other equipment.

Aquaponics mainly uses the RAS method for fish production, since water is circulated in a closed system. This is also the most risky method of all four and requires some technologically advanced skills.

2.2.2. Hydroponics

Hydroponics forms an integral role in an aquaponic system. It is defined as the growth of plants in a soilless medium by exposing the plant roots to a nutrient-rich water solution (Miller and Spoolman, 2012). Hydroponic methods are usually based on two types of systems, namely liquid hydroponic systems or aggregate hydroponic systems. The difference is described below as defined by Diver (2010) and as summarized in a study by Lapere (2010):

1) Liquid hydroponic systems: These are also described as solution culture and consist of plants being suspended in water bodies from where nutrients are extracted. These systems typically consist of floating rafts or the nutrient film technique (NFT). To explain it better, this method can further be categorized in two sub types, namely:
    a. The static solution flow method: Typically uses the raft method where rafts are floated on a grow bed (the water body). Seedlings are located in the openings of the rafts in net pots, with their roots in the water. The canopies of the plants grow over the raft surface and the water is aerated with air stones. This is the most common method of static solution hydroponics used.
    b. The continuous flow solution culture method: When used in aquaponic systems, this method uses the NFT, consisting of narrow troughs. Water flows through these troughs where it reaches the plant roots, together with nutrients and oxygen.

2) Medium hydroponic systems: Also known as aggregate systems, this method uses inert, organic or mixed media as plant growth medium such as gravel, sand, expanded clay and sawdust to name a few. The media are usually contained in troughs, bags, trenches, pipes or bench setups, which are filled with nutrient-rich water. The grow bed is drained on regular intervals to ensure the plant roots are sufficiently aerated. Fertilizers or nutrients are dissolved in the water and absorbed by the plants when the system is flooded.

The hydroponic systems are in many cases within a greenhouse setup (especially in cooler climates) and can therefore be seen as a method of greenhouse production (Diver, 2010, Miller and Spoolman, 2012). The successful production in greenhouses is related to the controlled settings in terms of environmental factors in a greenhouse (e.g. heat and humidity), as well as the coordinated application of water and nutrients.

Other benefits of hydroponic food production in greenhouses were listed by Miller and Spoolman (2012) as:

- Crops can be grown nearly anywhere under variable weather conditions, since the plants are grown indoors under controlled climatic conditions.
- Controlled conditions ensure that crops can be produced all year round, increasing yields and availability of produce.
- Hydroponics requires less land than conventional agricultural methods. It can therefore be applied even in dense urban areas, including roof tops of buildings.
- The water usage is minimized through recycling, and so also fertilizer requirements since nutrients are recycled within the systems. Runoff, therefore, does not reach natural streams or rivers as these are usually closed systems.
- There is generally no need (or only a small need) for pesticides in a greenhouse if the environment is controlled effectively.
- Lastly, the possibility for soil erosion is eliminated as well as the accumulation of excessive mineral salts as occurs in conventional agricultural methods under irrigation conditions.

Hydroponics can therefore be used to increase the world's food production without serious adverse effects to the environment. Since hydroponic systems are integrated in aquaponic systems, these benefits also extrapolate to aquaponic systems.

Reasons why hydroponics is not currently a leader in world food production, is because of three main constraints as identified by Miller and Spoolman (2012):

1) Costs to establish these types of systems are high, but over time they become cheaper to operate than conventional agricultural methods.
2) The perception of high levels of technical skills required to run such systems prevents more of these production units from being established. However, the skills required to produce plants and crops in these systems is, in reality, similar to general gardening and crop production practices.
3) Hydroponics is a potential threat to farming related production companies producing inorganic fertilizers, pesticides and farm equipment.

Despite the constraints associated with this production method, large hydroponic facilities have been established in several countries such as Germany, the United States, the Netherlands and also in New Zealand (Miller and Spoolman, 2012). It is envisaged that production from hydroponics systems will increase in the future, but it will most likely not entirely replace conventional agricultural methods.

2.2.3. Benefits of aquaponics as opposed to only aquaculture or hydroponics

Probably the greatest benefit obtained from an aquaponic system is that it can be seen as a sustainable food production model (Diver, 2010). Principles that support this statement include the following:

- Integration of vegetable and fish production delivers a variety of healthy food products from one production unit.
- Two biological systems are functional off each other, as the waste products of the one system (the fish water effluent) are the nutrients for the other (liquid fertilizer for vegetable hydroponic beds), thus, enabling the recycling of nutrients.

- The hydroponic beds act as biological filters for the effluent that can then be recycled back to the fish tanks. The water is therefore re-used in a closed system, eliminating the need for constant supply of water into the system. This results in the successful production of vegetables and food with a limited supply of water.

Once an aquaponic system has been successfully established, the only constant input required is fish feed (Diver, 2010), which can also be grown within the system. This enables greenhouse growers in the United States to label their hydroponic produce as “organic”. Another advantage is that yields are obtained all year round if greenhouses are used (Miller and Spoolman, 2012). Food production can therefore be increased without additional harmful effects on the environment.

In addition to this, mines can evaluate the use of treated mine water in these systems. Similar projects have been launched in West Virginia in the United States of America (USA) where treated mine water is being used for aquaculture production as a post-mining land use at coal mines (Miller, 2008). Not only does this practice create a positive image for coal mining companies, it also secures a resource for commercial scale aquaculture in the USA. Cost savings on the reclamation of the land was also noted in the studies as aquaculture adds to revenue. Economic development impacts and results have also been determined for the aquaculture industry linked with coal mining in West Virginia where state-wide output, income and employment opportunities were calculated (D’Souza, Miller, Semmens and Smith, 2003).

Evaluating the summary given above one can understand why aquaponics can be viewed as a possible feasible option for a post-mining land use. Not only does it produce food for human consumption in a sustainable manner, it also combats the problem of land degradation since no soil is needed for the system, soil erosion cannot occur, and a build-up of excess mineral salts does not take place if compared with irrigated cropland (Miller and Spoolman, 2012). If aquaponic systems are built on rehabilitated mine land, the land can be made productive again within a relative short period of time, eliminating the issue of land degradation. Sustainability can be achieved for the land in question, which is the major aim of the mining industry for the end land use post-mining. Aquaponics can contribute positively towards the national food security crisis which is predicted by DEAT (2007) to occur by 2030. In addition to this, it can also satisfy the needs of a community (production of food, creation of jobs, and ensuring economic viability of the land), especially in times with an increasing human population requiring improved living standards.

Observing the trends of the current practices at most coal mining companies in South Africa, the main objective is to satisfy the requirements driven by governmental regulation, and to rehabilitate land to a standard that will be accepted by society and which is a sustainable land use (Maczkowiack *et al.*, 2012). By implementing a holistic view to society's needs (or in this case rather a community's needs) such as food security and contributing positively to job creation at mining operations post-closure, mines can truly start having a sustainable legacy in the areas where they operate. Aquaponic production could generate revenue that can help cover the costs of maintaining the post-mining land, the aquaponic system itself, and pay the salaries of the people involved in the project. The land could also possibly be sold off more easily.

Mines closer to towns or cities will especially be seen as ideal areas to introduce these systems. People in these areas could be employed to work in the systems. The availability of food closer to towns or cities will also contribute positively to urban sustainability and lower the carbon footprint of food distribution (or "food miles", meaning the distance food travels from the where it is produced to the market where it is sold (Deneen, *s.a.*)) in these areas. Mines initiating the production of food with aquaponic methods post-mining, will contribute positively to sustainable food production in a time where this shift is much needed (Miller and Spoolman, 2012).

CHAPTER 3 - METHODOLOGY

3.1. Introduction

This chapter explains the information gathering process and how the research was conducted, including limitations and assumptions where relevant. Based on the main research question that was formulated, the study could be classified as an evaluative study, or a combination of an evaluative and comparative study (Mouton, 2009). Both primary and secondary (existing) data was gathered that was obtained in numerical and textual format. A combination of quantitative and qualitative methodology was applied. The methodological approach that was followed can be summarized as indicated in the flow diagram, **Figure 4**.

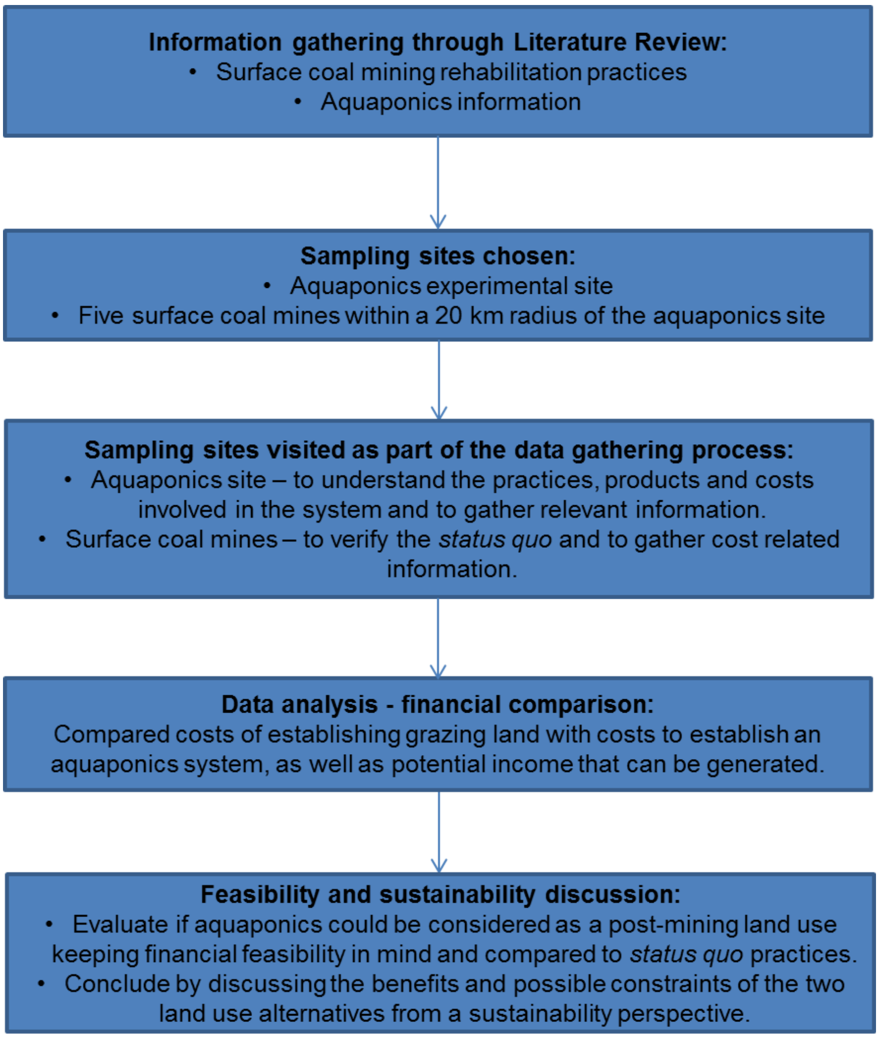

Figure 4: Flow diagram of the methodological approach

The first block in the flow diagram refers to an initial information gathering process through a literature review study regarding surface coal mining rehabilitation practices and information related to aquaponics as addressed in Chapter 2. The methodological approach of information gathering and data analysis will be explained in detail in the following sections of this chapter (Chapter 3). The broader Mpumalanga study area and the aquaponics experimental sampling site will be discussed in Chapter 4.

3.2. Sampling sites

3.2.1. Aquaponics site

An experimental aquaponic system approximately 15 km south of Middelburg, Mpumalanga was used as the base of this study. Visits were made to the site (14 January, 7 June and 27 July 2013) to fully understand the operational procedures of the system.

Successful production of vegetables and fish were observed at the facility, although not fully commercial when the study was conducted. Vegetables were successfully harvested and sold, but fish had not yet been sold when the information was gathered. It must be kept in mind that the experimental site is not located on a rehabilitated mine site. The study will therefore also assess whether an aquaponics system could be built on rehabilitated mine land. Site conditions of mine rehabilitated land will play an important role in decision making if such a system is considered as a post-mining land use option.

3.2.2. Surface coal mine rehabilitated areas

The current practices or *status quo* of rehabilitation on surface coal mines in the Mpumalanga Highveld Region was discussed in Chapter 2, **Sections 2.1.2** and **2.1.3**. In order to prove that mining companies in the region aim to re-establish mined land to a grazing standard as the *status quo*, information pertaining to this statement had to be gathered from a few selected sites.

Purposeful sampling methodology was applied. Surface coal mines within a 20 km radius from the aquaponics site were considered for inclusion in the study. It was assumed that site conditions in the chosen radius from the site would be similar to that of the aquaponics site in terms of bio-physical characteristics. It can therefore also be assumed that if aquaponics could be successfully established at the experimental site, it could also be successfully established within the selected radius area due to similar site conditions. Refer to **Figure 5** overleaf for an indication of the 20 km radius around the aquaponics experimental site.

Five mines from three different mining groups were chosen for the study. The mines were initially approached through personal communication to obtain their interest in the study and all agreed to participate.

3.3. Data gathering

3.3.1. Aquaponics data and information gathering

Apart from understanding how the system and the individual components work, an understanding had to be gained of aquaponics as a whole. It was necessary to determine whether it is a practical and user friendly activity that could be implemented at mine rehabilitated sites keeping possible constraints that could hinder implementation of such a system on rehabilitated land in mind. Although literature labels aquaponics as a sustainable activity, this had to be verified in the view of implementing it in a post-mining context.

Data was gathered on the aquaponic system to understand how the components fit into each other. A schematic diagram of the system layout was drawn which is discussed in Chapter 4 (**Section 4.2.1.3**, **Figure 12**). The diagram explains the layout of the system and how the components work in relation to each other.

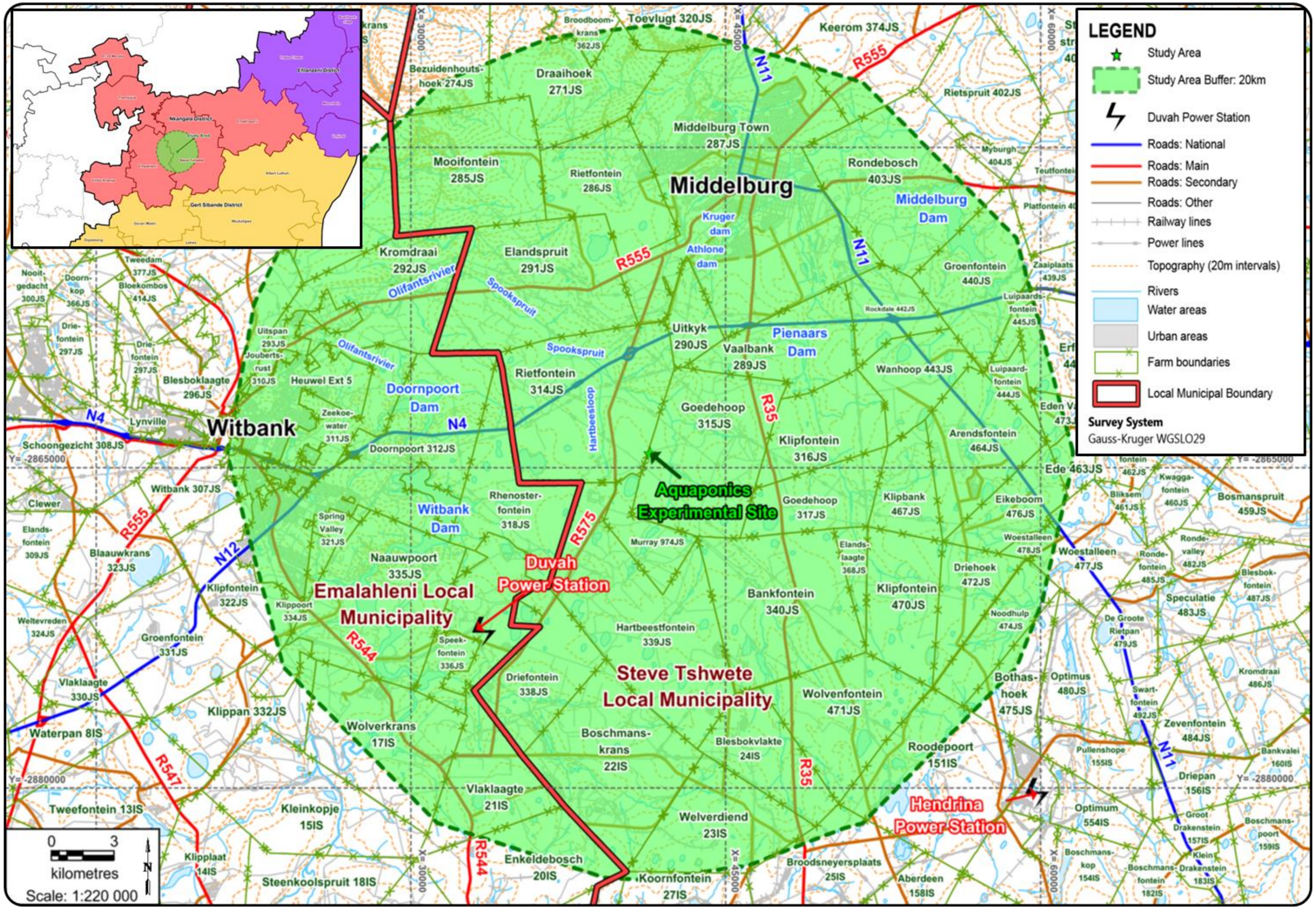

Figure 5: 20 km radius around the aquaponics experimental site (Produced by F de Hart, 2013)

The reference to the establishment of an aquaponics system will be based on a design similar to the setup at the experimental site as indicated on **Figure 12**. Other relevant information regarding the aquaponics data that was gathered and that is necessary for this study is described in **Section 4.2.1.1** in Chapter 4.

The fish species (as discussed in Chapter 2, **Section 2.2.1.4** and Chapter 4, **Section 4.2.1.1**) were verified as being produced in the system. A variety of vegetables are grown successfully that can be considered when implementing such a system. Currently the vegetables produced at the site are sold to restaurants and speciality food stores in Middelburg. The vegetables grown are also popular on the farmer's market as was verified during a visit to the Witbank Produce Market (16 October 2013).

Numeric data that was collected included estimated capital costs for an aquaponic system as based on the general layout of the system located at the experimental site (**Figure 12** in Chapter 4, **Section 4.2.1.3**). Potential income was estimated using a financial model developed by Blenkinsop (2013, pers. comm. 27 July) (from here onwards referred to "the Blenkinsop model"). This information will be utilised to determine economic feasibility. The flow diagram in **Figure 6** summarises the data gathering process related to the aquaponics component of the study.

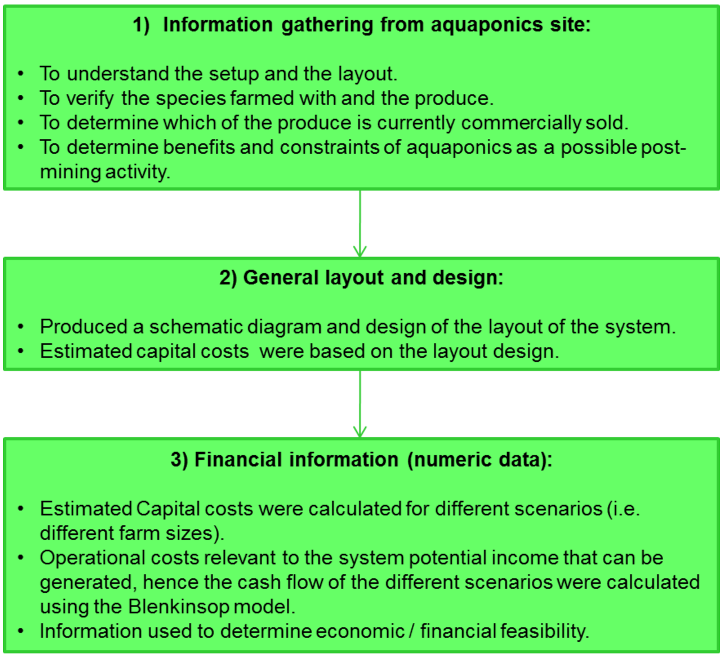

Figure 6: Aquaponics information and data gathering process

3.3.2. Rehabilitation data and information gathering

Site visits were scheduled with the staff, e.g. Environmental Superintendents or Rehabilitation Officials, at the three mine groups (five mines) that were approached to take part in the study. The purpose of the meetings was to discuss the research with the site's staff, to gather the necessary rehabilitation practice information from the sites, and to verify the commitments in the EMPRs of the sites regarding the *status quo* and the actual rehabilitation practices taking place on the sites. These meetings were held in the months from August through to December 2013. A confidentiality agreement was undertaken with the selected mining groups and agreement reached not to publish their identities in the study, since confidential information would be revealed.

A structured open-ended questionnaire (**Annexure A**) was compiled to lead conversations at the meetings in order to obtain all relevant information on the rehabilitation practices. Points discussed during the interview session that were included in the questionnaire are shown in **Figure 7**.

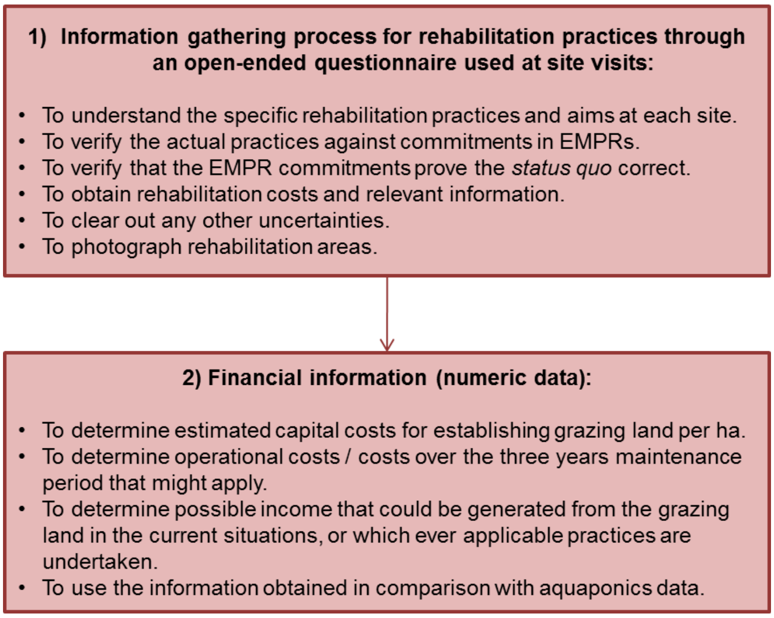

Figure 7: Rehabilitation information and data gathering process

After each meeting and site visit, the information obtained was summarised in an *Excel* spreadsheet. The EMPR commitments were also compared with the pre-mining land use and land capability of the site (if available). Finally, the practices were compared with the *status quo* and to test compliance with the EMPR commitments.

Financial information obtained for rehabilitation of mining areas to grazing standard included:

- Costs to replace topsoil and prepare the land for seeding;
- Costs of fertilizers and lime used;
- Costs of seeds used;
- Labour and maintenance costs; and
- The possible income that can be generated was also determined for cutting, baling and hence, selling of the grass (or other applicable practices of the sites).

The financial information gathered will be compared with financial information to establish an aquaponics system. The results obtained from this exercise are included in Chapter 5.

3.4. Data Analysis

The evaluative nature of this study promoted the idea of conducting a comparative analysis of the data that was obtained for the two alternative land uses. The financial data would be used as a main focus to measure the feasibility of aquaponics from an economic perspective and to compare it to the re-establishment costs of grazing land as the *status quo*. The data analysis process was divided into four different stages or steps as indicated in the flow diagram in **Figure 8**.

<u>Step 1: Analyse the rehabilitation data and the aquaponics data separately</u>

Data and information obtained for re-establishing grazing land as described in **Section 3.3.2** will be discussed and summarised in **Section 5.1.1** in Chapter 5. Each mine's scenario and practice will be discussed. The following approach will be followed:

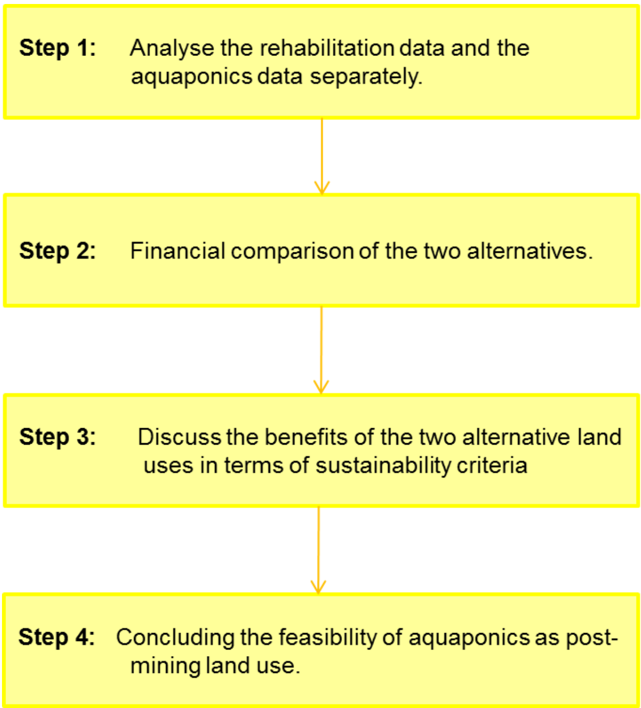

Figure 8: Data analysis flow diagram

- Qualitative data and information that was obtained from the sites will be presented in table format followed by photographs that were taken of rehabilitated land re-established to grazing potential at each site.
- Quantitative numeric data consisting of the costs to rehabilitate the mines' sites to grazing land will also be included in tables and in a summarizing graph.
- The potential income to be generated (according to the current practices) from the mine's rehabilitated sites will then be discussed for comparison.

Data gathered for the aquaponics systems as described in **Section 3.3.1** will in general be discussed and also presented in tables in **Section 5.1.2** in Chapter 5. The data will consist of the following:

- Interpretations will be made based on information obtained and observations recorded at the experimental site, through market related information and through literature review.
- Estimated costs to establish an aquaponics system similar to the one at the experimental site was determined for three different size systems and will be presented in tables and a summarizing graph.

- The potential income (cash flow) that can be generated was also determined using the Blenkinsop model (pers. comm. 27 July 2013). This will be included in tables summarized and summarized in graphs.

Step 2: Financial comparison of the alternatives

This will be done by:

- Comparing the costs to re-establish grazing land (current practices) with the costs to establish an aquaponics system.
- Comparing the potential income of the two alternatives.
- Discussing the potential feasibility of aquaponics from a financial perspective in comparison with the *status quo* and related practices.

A conclusion will be made on the financial feasibility of aquaponics and whether it can be viewed as a feasible and competitive post-mining land use. Due to the highly competitive and cost-conscious environment in which coal mining occurs, it was felt that financial feasibility should get special attention. BATNEEC principles generally apply to mining houses, and therefore, financial feasibility might be the first question raised when a land use alternative such as aquaponics is suggested for implementation.

Step 3: Discuss the benefits of the two alternative land uses in terms of sustainability criteria

The benefits of aquaponics were briefly discussed in Chapter 2, **Section 2.2.3** (and to some extent also discussed as part of **Section 2.2.1.1** and **Section 2.2.2** under the individual components namely aquaculture and hydroponics), as part of the literature review. Taking this into consideration the two land use alternatives' benefits and possible constraints will be discussed in the light of sustainability criteria, as a 'sustainable end land use' is the main aim for any mining company to reach when restoring the land. The sustainability criteria (economic, environment and social components) and associated sub-criteria and indicators will be included in a sustainability matrix (**Table 31**) based on the potential benefits to the mining company. This could help to guide a mine when a decision has to be made whether aquaponics should be considered as a feasible post-mining land use.

In summary, the sustainability matrix will focus on whether aquaponics can be seen as an environmentally sustainable, socially sustainable (in terms of food security for a growing human population and possible job creation opportunities) and economically sustainable (costs and revenue produced) post-mining land use option in the South African, and specifically the Mpumalanga Highveld context.

Step 4: Concluding the feasibility of aquaponics as post-mining land use

The conclusion will determine whether aquaponics as an end land use will be a feasible sustainable solution for surface coal mining companies to consider post-closure and whether it will meet their rehabilitation aims. Constraints that could possibly hinder the implementation of aquaponics on post-mining land (e.g. environmental impacts associated with the mined land) will be briefly identified. The most feasible options of using aquaponics as an end land use compared to or in combination with other land uses will also be discussed.

3.5. Limitations of the study

A key limitation to this study is that in most instances secondary data which was obtained from different sources was used. Certain questions were raised but the exact clarity was not always given and hence, assumptions had to be made. These assumptions will be clearly stated where appropriate.

CHAPTER 4 - DESCRIPTION OF THE STUDY AREA

This chapter gives a brief description of the bio-physical characteristics of the study area. It also gives a thorough description of the aquaponics experimental site.

4.1. Brief description of the bio-physical characteristics of the study area

The study area is located in the Mpumalanga Highveld Region of South Africa, within close proximity to the city of Emalahleni (previously known as Witbank) and the town of Middelburg. The area is located in the jurisdictional area of the Nkangala District Municipality (NDM) and falls under the management of the Steve Tshwete and Emalahleni Local Municipalities (**Figure 9**).

There is one power station, namely the Duvha Power Station, located within the specified study area (within the selected 20 km radius) which is indicated in **Figure 5** (refer to **Section 3.2.2**). There are also a number of dams present in the area.

The study area is situated in the central margin of the Witbank Coalfields. Coal is found in the sedimentary rocks in the Vryheid Formation of the Ecca Group, within the northern part of the main Karoo Basin (Mine A1, 2009). Coal mining is thus a common practice in the area. The shallowness of the coal seams in many of the mining areas lends itself to surface coal mining practices rather than underground mining.

4.1.1. Natural vegetation of the area

The study area falls within the Grassland biome which is further divided into four bioregions based on annual rainfall. According to Mucina & Rutherford (2006) the particular area is part of the Mesic Highveld Grassland bioregion, which is the largest of the four. This bioregion is categorized as a high rainfall area.

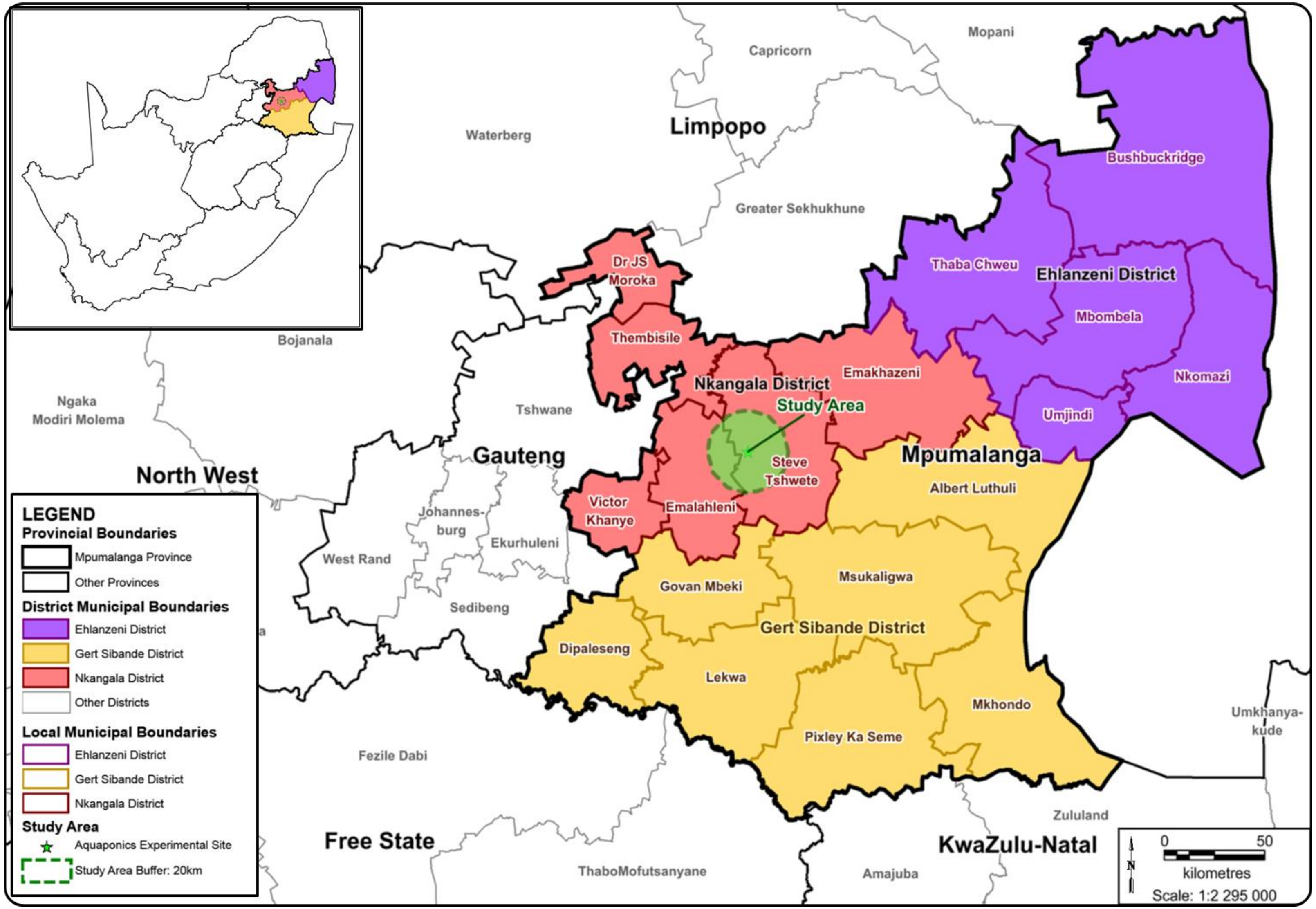

Figure 9: Locality of the study area indicated on a Regional Layout Plan (Produced by F de Hart, 2013)

The vegetation types associated with the Mesic Highveld Grassland, specifically pertaining to the study area, is that of the Rand Highveld Grassland and the Eastern Highveld Grassland. Mucina & Rutherford (2006) numbered these vegetation units as Gm11 and Gm12 respectively. A summary of the units are given in **Table 4**:

Table 4: Characteristics of the Rand Highveld Grassland and the Eastern Highveld Grassland (Mucina & Rutherford (2006:399-401))

Indicator	Rand Highveld Grassland (Gm11)	Eastern Highveld Grassland (Gm12)
Regional Locality	Parts of Gauteng, the Free State, Mpumalanga and North-West.	Parts of Mpumalanga and Gauteng.
Locality in terms of the study area	Extends from Pretoria to Witbank and all the way to Stoffberg.	Extending from Belfast in the east, to Johannesburg (East Rand) in the west and further south towards Bethal, Ermelo and Piet Retief.
Elevations	1300 – 1635 mamsl*, but could extend to 1760 mamsl*	1520 – 1780 mamsl*, but could also occur at lower elevations such as 1300 mamsl*
Landscape	Variable landscape with widespread sloping plains. Ridges are characterised on the higher lying areas across the undulating landscape.	Slightly to moderate undulating plains, with low hills and areas where depressions are formed and where pans occur.
Vegetation	Predominantly "sour" grassland belonging to the genera *Themeda*, *Eragrostis*, *Heteropogon* and *Elionurus* from the grass family *Poaceae.* Vegetation associated with the rocky outcrops is mainly sour shrub land.	Plains contain typical short and dense Highveld grass compositions consisting of genera *Aristida*, *Digitaria*, *Eragrostis*, *Themada* and *Tristachya*. Sour grasses and woody species are found in the rocky outcrop areas.
Conservation status	Endangered (with only 1% of the natural state of the unit that is protected).	Endangered (only an extremely small portion is currently protected in statutory and private reserves).
Conservation target	24%	24%
Transformation	Cultivation practices, but also due to plantations, dams and urbanization.	Transformation (44%) linked with cultivation, mines, dams, urbanization and plantations.
Erosion	7% has been exposed to moderate-high levels of erosion.	Low levels of erosion.

Indicator	Rand Highveld Grassland (Gm11)	Eastern Highveld Grassland (Gm12)
Alien vegetation	7% of unit consists of *Acacia mearnsii* (generally known as the black wattle).	Infestation not common, but becomes a problem in disturbed areas, i.e. predominantly *Acacia mearnsii* (black wattle).

*metres above mean sea level

Figure 10 indicates the study area in relation to the two vegetation units. The information was retrieved from the South African Biodiversity Institute (SANBI) Biodiversity Geographical Information System (BGIS) website (SANBI, *s.a.*).

4.1.2. Regional climatic data

The climatic data as provided by Mucina & Rutherford (2006) for the two vegetation units is given in **Table 5**.

Table 5: Climatic data (taken from Mucina & Rutherford (2006:390-391))

Indicator	Rand Highveld Grassland (Gm11)	Eastern Highveld Grassland (Gm12)
Annual precipitation	570 – 730 mm	650 – 900 mm
Mean Annual Precipitation	654 mm	726 mm
Annual Precipitation Coefficient of Variation	27 %	25 %
Mean Annual Temperature	15.8 °C	14.7 °C
Mean Frost Days	28 days	32 days
Mean Annual Potential Evaporation	2184 mm	1926 mm
Mean Annual Soil Moisture Stress	76 %	73 %

Thunderstorms regularly occur during summer seasons. Lightning, heavy rains, strong winds and sporadic hail are common occurrences during storm events. The storms are sometimes confined to small areas with varying rainfall over a relatively small area (Mine A1, 2009).

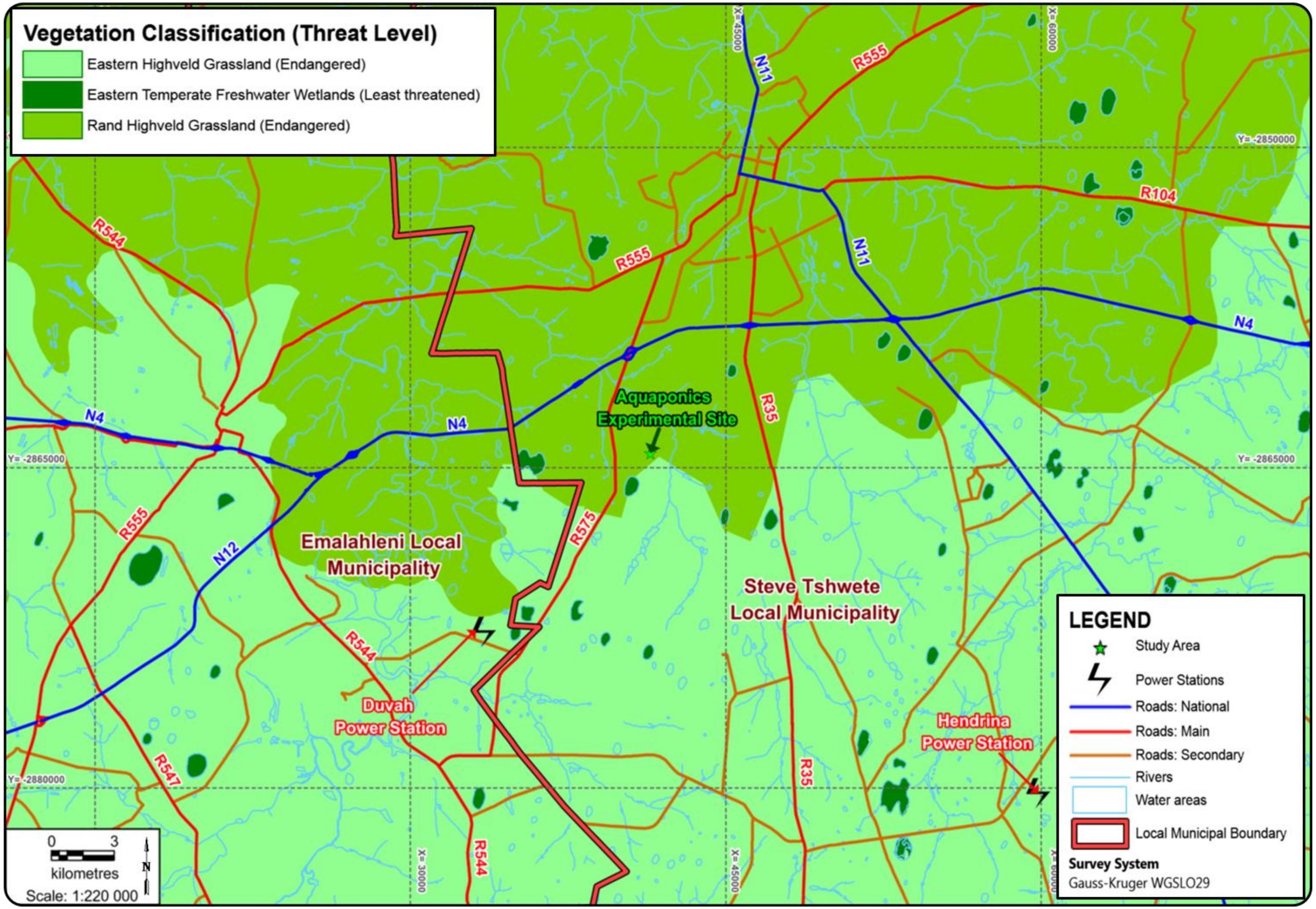

Figure 10: Vegetation Map (SANBI BGIS, *s.a.*) indicating the two vegetation units of importance within the vicinity of the study area (Produced by F de Hart, 2013)

4.1.3. Soils, land uses and land capability generally associated with the study area

The Mpumalanga Highveld area is an agricultural hub in South Africa. High quality arable soils are favourable for the cultivation and maize is the predominant crop farmed in the Mpumalanga Highveld Region (Brand South Africa, *s.a.*).

The vast majority of the land area that was investigated is used for agricultural purposes, including both maize production and grazing land, but mining activities are also prevalent. Soils associated with the area include red to yellow sandy soils commonly found on shales and sandstones of the Karoo Supergroup (Mucina & Rutherford, 2006). Glenrosa and Mispah soil forms are associated with the rocky outcrops.

4.2. Locality and descriptions of the selected sites

4.2.1. Aquaponics experimental site

An Aquaponics system was constructed approximately 15 km south of Middelburg and 20 km east of Emalahleni (Witbank) on Portion 6 of the Farm Goedehoop 315 JS. The site is easily accessible from the R575 provincial road and within close proximity of the N4 national highway which links with the N12 national road towards the west. The footprint of the site is approximately 40 000 m^2 or 4 ha (Jaco-K Consulting (JKC), 2011), and was previously used for agricultural grazing purposes. The locality of the site is indicated on **Figure 11**.

The site was initially established for the purpose of climate change mitigation research using algae, and was then expanded to include an aquaponics experimental site (Blenkinsop, 2013, pers. comm., 19 November). Other agricultural activities as well as mining activities are practised within close proximity to the site.

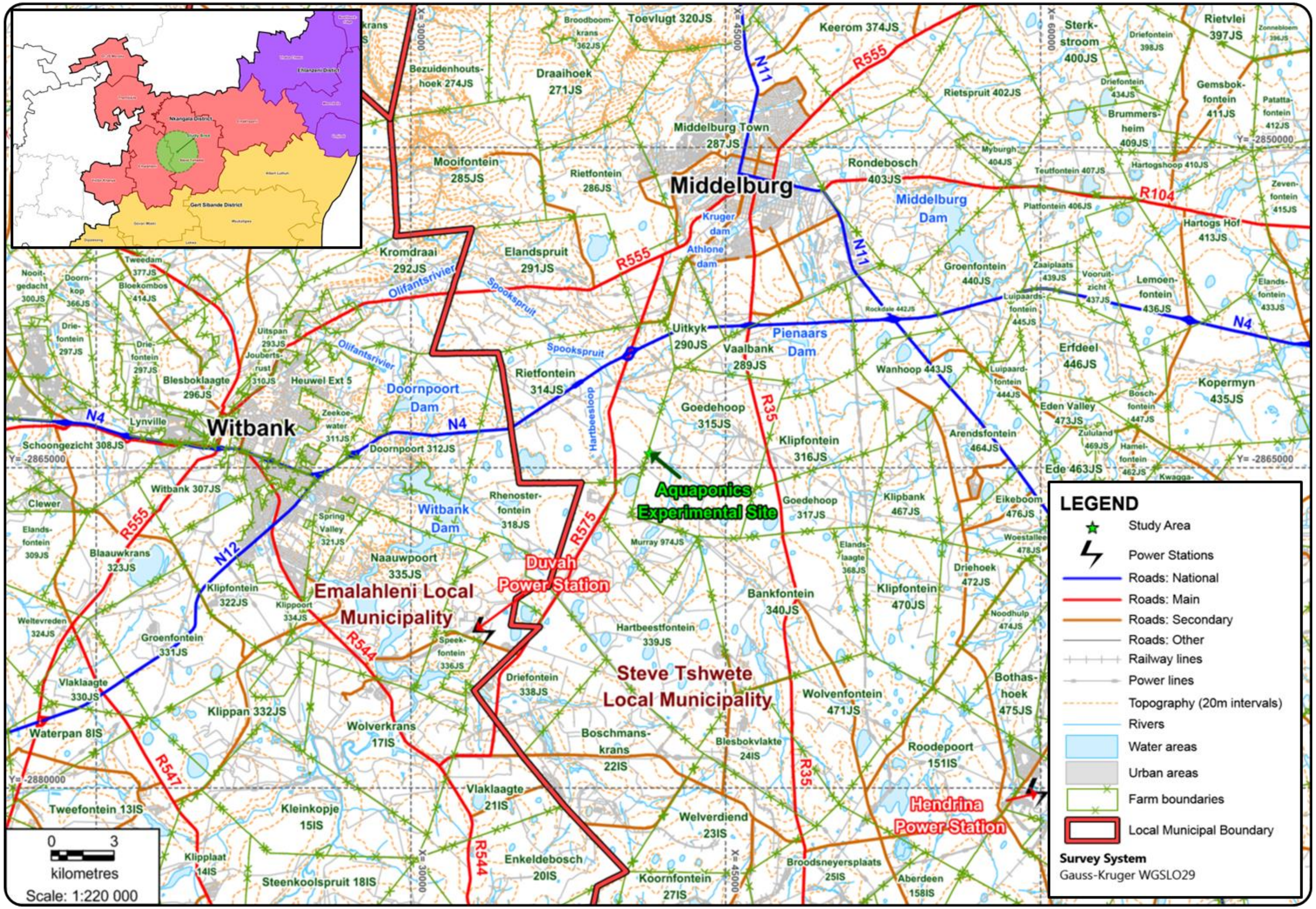

Figure 11: Locality plan of the Aquaponics experimental site (Produced by F. de Hart, 2013)

4.2.1.1. Development of the system

The aquaponics facility consists of an aquaculture component which is linked with a hydroponic gravel bed component as broadly described in **Section 2.2**. The site was developed in January 2012 by building ponds and tunnels to produce the two fish species described in **Section 2.2.1.4**. These species are endemic to the catchment area and were required by the Mpumalanga Tourism and Parks Agency (MTPA) to be used in the aquaculture production unit (JKC, 2011; Blenkinsop, 2013, pers. comm., 14 January). Vegetables are grown in the tunnels and are currently sold to restaurants and specialised grocers in the town Middelburg.

Water from the aquaculture facility which is enriched with fish waste based nutrients is circulated into the adjacent hydroponic gravel beds. This ensures the optimal use and re-use of water, and prevents the release of nutrient-rich water back into the natural environment. Water was initially obtained from a dam located at the site until the system could re-circulate the water. Water is occasionally topped up from that same dam as needed.

The system was designed to have minimal energy requirements by implementing gravity principles to circulate the water from one end to the other (JKC, 2011). Water that is re-circulated back to the pond sections has to be pumped. Energy efficient techniques were applied, but alternatives are continuously being investigated. Diesel generators were initially used, but currently power is supplied by ESKOM.

The tunnels are insulated to regulate the heating requirements of the system, especially during the winter months (JKC, 2011). Heat could alternatively be enhanced by the use of a combination of solar water and air heating, although this is an expensive option. No heating was added to the system during the past winter, since the insulation of the tunnels (double layered) proved to be adequate (Blenkinsop, 2013, pers. comm., 19 November).

When the activity was initially planned, the production targets for fish were 36 000 kg per year (wet weight) (JKC, 2011). The production would then be steadily increased to approximately 180 000 kg per year.

4.2.1.2. Operational overview of the system

To fully understand how the system works and how the different components fit into each other, a schematic diagram of the layout of the system was drawn and is included as **Figure 12**.

Briefly described, the system works as follows: Fish are cultivated in the fish ponds. Water from the fish ponds flows to either the duckweed ponds (duckweed is cultivated to use as fish feed) or to the gravel beds (via a settling pond). Water from those two components then flows towards a sump. Water is pumped from the sump (via UV sterilization lighting) towards the bio-filter before re-circulating back into the fish ponds. The syphon indicated in the gravel bed, is to regulate the water (tidal) flow in the beds. The water is re-circulated in the system every 4 – 6 hours.

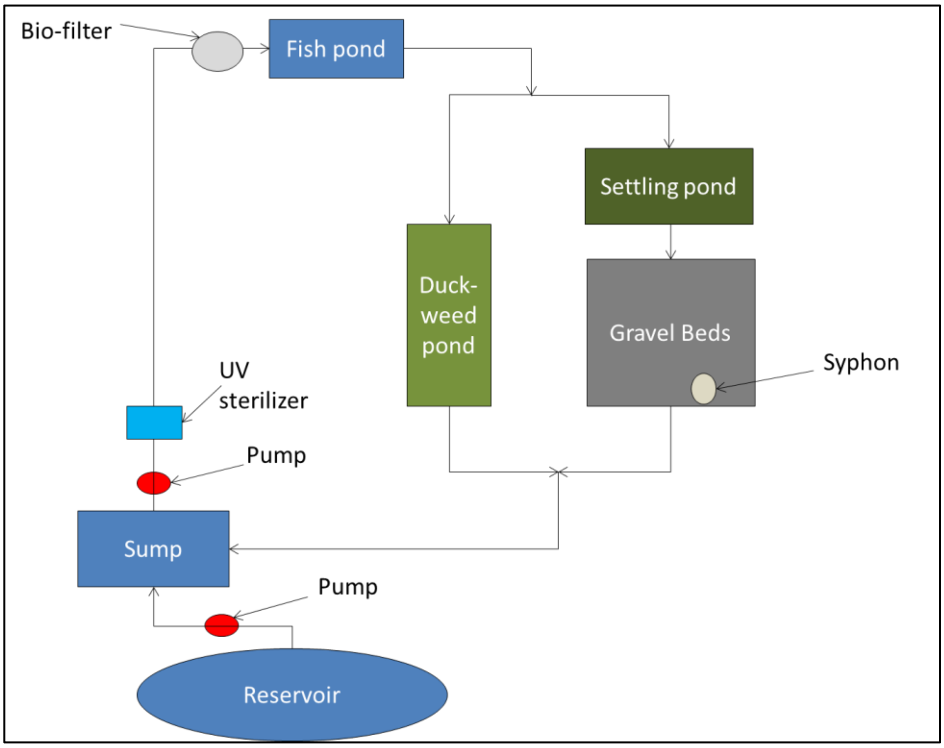

Figure 12: Schematic diagram of the components and layout of the aquaponics system

Figure 13 indicates the first section of the ponds that were constructed to accommodate the fish. Similar size fish were grouped together in separate ponds (**Figure 13a**). The 500 L green water tanks (Jojo-tanks) act as the bio-filters before water is pumped back into the fish ponds after being recirculated through the entire system (**Figure 13b**). The bio-filters in the Jojo-tanks consist of tiny polystyrene balls (bacteria accumulate on the balls) (**Figure 13c**). The section indicated in **Figure 13** is now the area known as the hatchery.

Figure 13: Photographs of the original fish ponds (now the hatchery) that were built as part of the aquaculture system (Taken by I Botha, 27 July 2013)

Figure 14 groups together the other components of the system. **Figure 12** indicated that the water from the fish ponds either flows to the hydroponic gravel beds (via the settling pond to capture solids) or directly to the duckweed ponds. The flow of water is, where possible, by means of gravity to save the need for electricity.

Figure 14a and **b** show the first successful hydroponic gravel bed tunnel wherein different vegetables are being experimented with such as lettuce, spinach, beetroot, tomatoes, spring onions, water cress and herbs such as basil.

Figure 14c shows the original duckweed pond. Duckweed is grown as fish feed in nutrient rich water. When duckweed is cultivated in this manner, the nutritional value reaches 30 – 40% protein and 10 – 15% fibre (Gijzen and Khondker, 1997 **in** Tavares et al, 2008). The use of duckweed in the system contributes to a cost saving in fish feed and can be used for up to 30% fish food replacement while still enhancing growth rates. The water from the duckweed ponds are then circulated back, via the final sump, to the fish ponds.

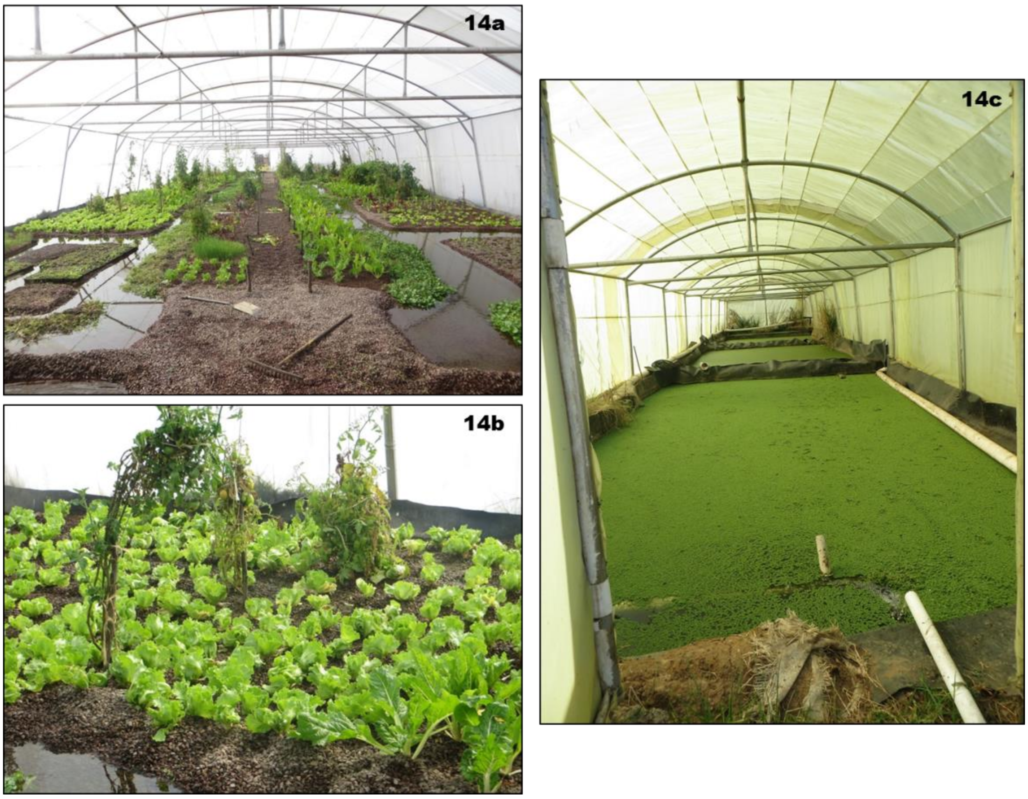

Figure 14: Photographs of one of the hydroponic gravel beds and the original duckweed ponds (Taken by I Botha, 7 June and 27 July 2013)

With increasing success the whole system was enlarged by constructing three new tunnels indicated in **Figure 15**. One tunnel serves as the aquaculture unit, one is for a hydroponic gravel bed and one for new duckweed ponds. The difference in this system is that only one large fish pond was constructed instead of smaller ponds (**Figure 15b**). A large settling pond (**Figure 15c**) was built outside of the fish tunnel wherein solids settle before the water is fed to the hydroponic gravel bed. The area indicated in the foreground of **Figure 15a** was being prepared for a second vegetable gravel bed tunnel.

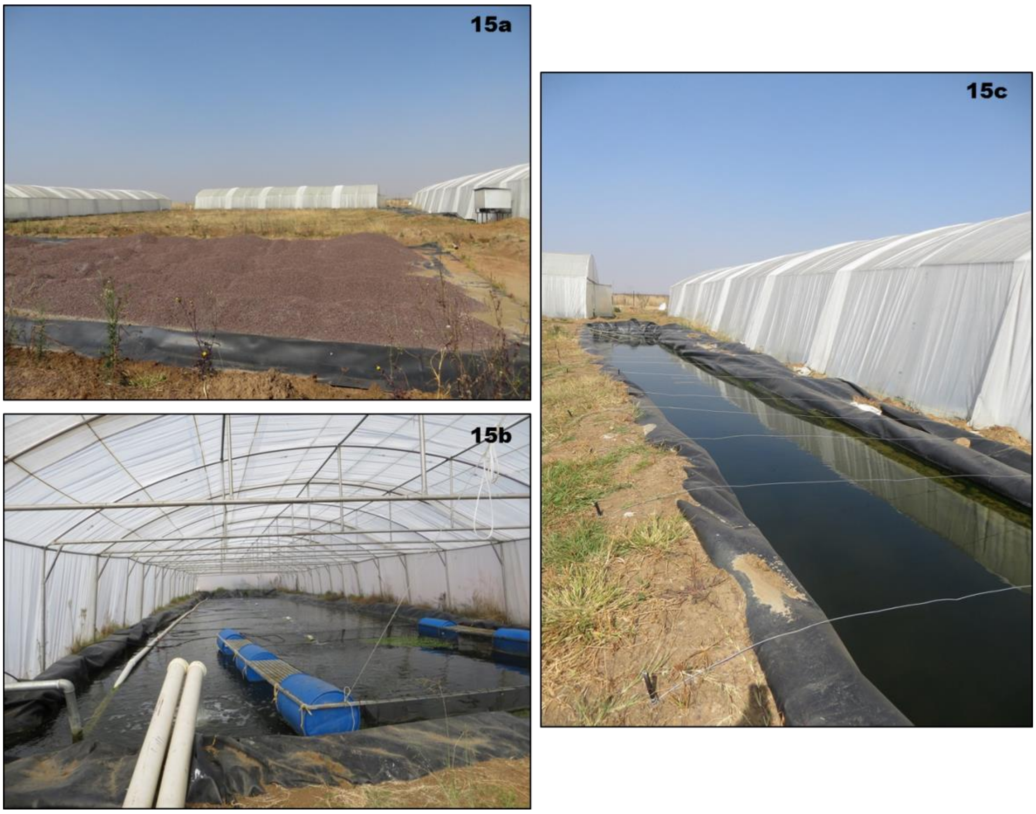

Figure 15: Photographs of the latest aquaponic extension area (Taken by I Botha, 7 June 2013)

Figure 16 groups together photos of the new hydroponic gravel bed (**Figure 16a**) and new duckweed ponds (**Figure 16b**). The progress of the additional gravel bed tunnel referred to in **Figure 15a** is indicated in **Figure 16c**. It should also be mentioned that there are ducks present at the site. The goal of having ducks in the system is to help with fertilization needs, especially during the colder winter months when the fish tend to eat less and therefore excrete less than in the summer months.

It is important to note that duckweed is actually also seen as a weed and an invasive species that is hard to control (Pond life, *s.a.*). It is, however, not formally declared as such in the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) Regulation 507 published on 19 July 2013, and therefore can safely be used for its full potential and purpose in the aquaponics system. It should though be contained on the site where aquaponics is practiced and not be allowed to spread into the natural environment and water systems.

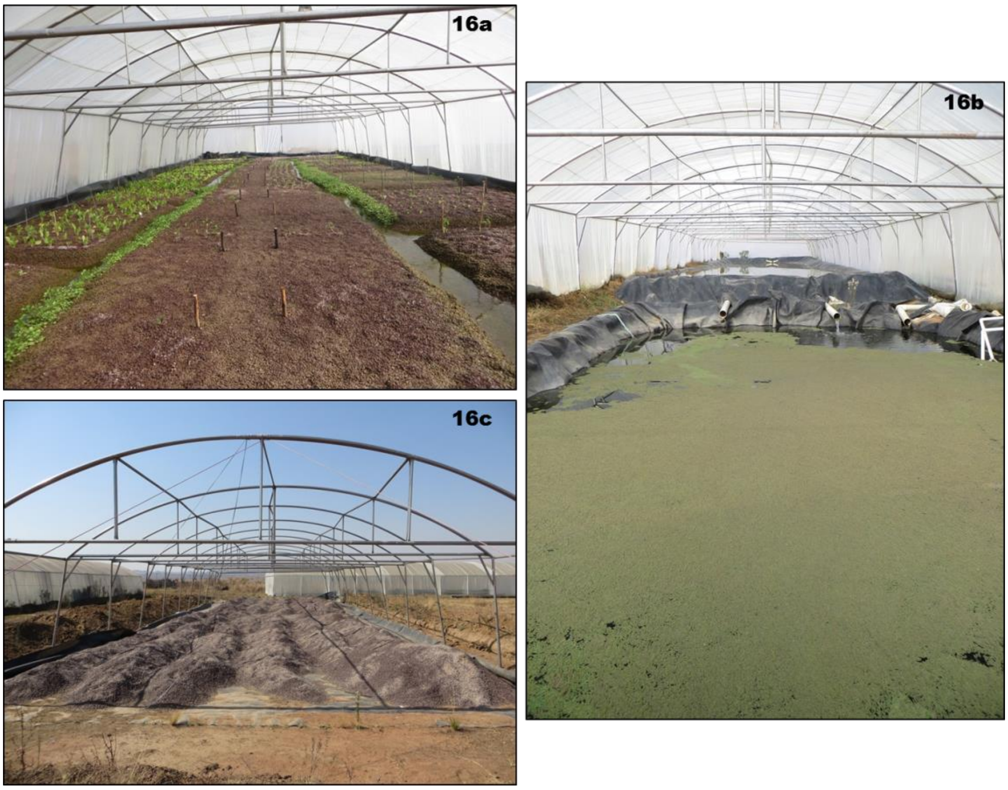

Figure 16: Photographs of the latest aquaponic extension area (Taken by I Botha, 7 June and 27 July 2013)

4.2.2. Mine rehabilitation sites

As mentioned in **Section 3.2.2**, five sites from three different mining groups were selected within a 20 km radius of the aquaponics site. To prove the *status quo* of rehabilitation practices as described by the *COM and CRA Guidelines for Rehabilitation of Mined Land*, surface coal mining rehabilitation practices were investigated at these sites. The reason for using sites within 20km from the aquaponics site is so that if aquaponics prove to be successful at the current experimental site, it could be considered for implementation at areas with similar site conditions. The qualitative and quantitative data that was obtained at the sites will be discussed in Chapter 5, **Section 5.1.1**.

CHAPTER 5 – RESULTS AND DISCUSSION

This chapter will focus on the results that were obtained as part of the research. The results and information will be discussed in detail to determine whether aquaponics could possibly be used as a post-mining land use on surface coal mining rehabilitated land. The content of this chapter will include tables with numeric values and comparative graphs (quantitative data) as well as other information specifically gathered as part of the research through interviews, verifications with literature and other sources (qualitative data). The approach will be to follow the data analysis process as presented in **Figure 8** and as described in **Section 3.4** in Chapter 3.

5.1. Step 1: Analysis of the rehabilitation practices and the aquaponics data

Section 3.4 indicated that Step 1 is twofold. The first part (**Section 5.1.1**) will entail the analysis of the information obtained for rehabilitation practices (qualitative and quantitative data) of the chosen mines. The second part (**Section 5.1.2**) will provide the analysis of the financial aspects of aquaponics data.

5.1.1. Analysis of rehabilitation practices and information obtained from the mines included in the study

The information obtained from the three mining companies' five sites will be presented and discussed, but due to the confidentiality agreement the mines will be assigned names as Mine A1 and A2, Mine B1 and B2 and Mine C. Each mine's information will therefore be discussed under the heading of that mine's assigned name. The order of the discussion will follow that of the structured open-ended questionnaire (**Annexure A**). Distinction will be made between qualitative data and quantitative data.

5.1.1.1. Mine A1 and Mine A2

The two mines form part of the same mining company, hence, distinguished by referring to these as Mine A1 and Mine A2, but collectively referred to as Mining Company A. The interview for this mining company was held on the 3rd of October 2013. At the time of discussion with the rehabilitation official, the mining group indicated that they conduct the rehabilitation of the mined areas themselves. They do not use a contractor to do the work. A farmer is, however, contracted to cut and bale the grasses when needed.

Mine A1 Qualitative data

Mine A1 is located some 15 km from Middelburg, within an area where mining and agricultural land uses are prevalent. The mine was used for agricultural purposes prior to mining and is therefore committed to productive rehabilitation. It is the mine's vision to sell the land back to the same farmer from whom they purchased the land to use it for agricultural practices post-mining.

The qualitative data and information gathered from Mine A1 during the site visit on the 3rd of October 2013 (through the questionnaire) is presented in **Table 6**.

Table 6: Rehabilitation data and information of Mine A1

Point to discuss	Result and discussion
Specific rehabilitation practices at the site:	The mined areas are rehabilitated to a grazing land capability standard. Thus, grazing standard grassland is re-established at the site. The specific detail about the rehabilitation practices are discussed in **Annexure B**.
Verify EMPR commitment to actual rehabilitation practices at the evaluated site (whether the mine is complying with what it is committed to do):	EMPR evaluated: *Mine A1 EMPR - Revision 2* dated September 2009, approved on 26 January 2010. Compliance with the EMPR was noticed. The closest applicable clear commitment states: "After rehabilitation the land can be used for agricultural purposes, mainly grazing but some sections would not have been disturbed and it can be used as arable land again." The aim of the mine is therefore to re-establish the mined areas to grazing land

Point to discuss	**Result and discussion**
	capability, and this is done.
Observations made during the site visit:	Areas where grassland has been re-established are well vegetated. The rehabilitation seems to be successful. Areas where problems occur were also noticed and the mine will conduct further maintenance on those areas to ensure that grassland is effectively re-established. Refer to **Table 8** for the species composition used in the rehabilitation process. Refer to **Annexure C**, **Figure A1**, for photographs taken at the site.
EMPR commitments compared with the pre-mining land use and land capability of the site:	The mining area includes some 280 ha. The pre-mining land capability of the mine site determined by a soil specialist indicated that 88.57% of the area (248.2 ha) consisted of arable land. Thus, 248.2 ha of arable land will be affected by mining. As the EMPR commitment is to re-establish a grazing land capability potential, it can be concluded that 248.2 ha of arable land capability will be lost for that land capability and land use class (e.g. cultivation of crops).
EMPR commitments and actual rehabilitation practices compared with the *status quo* of rehabilitation practices:	The EMPR commitment and rehabilitation practices on site therefore prove the *status quo* correct. Arable land that is mined is re-established to a grazing land capability for post-mining land use.
General response about their practices and whether that mine would consider establishing aquaponics as an end land use:	The mine will not consider aquaponics as they feel it is too technical. They would rather want to re-establish grazing land to a good potential so that they can easily sell the site and to be able to "move on". As they are a mining company, they do not want to be involved in any other activities. Their business is mining and they want to help the farmer re-gain agricultural land when mining is completed, since this was agricultural land (grazing and arable land) prior to mining. The agreed end land use is therefore grazing and will be implemented as such. The mine aim is to sell the land back to the farmer from whom the land was purchased.

A general observation that was made at Mine A1 is that there were rehabilitation areas that were ready for livestock grazing, but due to the nearby mining activities, no cattle could be allowed on the site. The defoliation practice that will therefore have to be undertaken is preferably grass cutting. Blasting activities have resulted in rocks being flung onto some of the rehabilitated area, increasing the risk for grass cutting, as rocks can damage the cutting equipment. Therefore, the only other alternative for defoliation of this piece of land is to burn the grass.

Mine A2 Qualitative data

Mine A2 is located some 5 km south from Emalahleni (previously Witbank) in an area dominated by mining land uses. The site visit was undertaken on the 11th of October 2013. The mine was also used for agricultural purposes prior to mining. Due to the site's close proximity to town, a few alternative post-mining land uses were suggested in the EMPR (e.g. infrastructure and housing). It was, however, decided to rather re-establish the site to grazing land since the adjacent surface coal mine was also rehabilitated to a grazing land standard (Mine C is the adjacent coal mine – refer to **Section 5.1.1.3**). It did, therefore, not make sense to the management group of Mine A2 to rehabilitate the site to any other land use, since the two areas are interlinked with each other.

Since Mine A1 and A2 are under the same management, rehabilitation is conducted in the same manner (refer to **Annexure B** for a description of the exact practices). The qualitative data for Mine A2 is presented in **Table 7**. No formal soil, land use and land capability study was conducted for the area, but according to the EMPR, the site was previously used for grazing purposes. Although the site is close to town and therefore ideally located for aquaponics, the same response about aquaponics was given as for Mine A1.

Table 7: Rehabilitation data and information of Mine A2

Point to discuss	Result and discussion
Specific rehabilitation practices at the site:	Grassland is re-established at the site to rehabilitate the land to a grazing land capability and land use standard. Similar practices are used as described for Mine A1. Refer to **Annexure B** for more detail.
Verify EMPR commitment to actual rehabilitation practices at the evaluated site (whether the mine is complying with what it is committed to do):	EMPR evaluated: *Revised Mine A2 EMPR* dated September 2008, approved on 2 April 2009. The mine is in compliance with the commitments in the EMPR, e.g. rehabilitating the site to a grazing land capability and land use. The EMPR suggested alternative land uses, but it states that the preferred option should remain agriculture, e.g. grazing, similar to the surrounding mines.
Observations made during	No formal seeding had been done at Mine A2 at the time of the site visit.

Point to discuss	Result and discussion
the site visit:	Grass grew naturally. More than 20% basal cover had been established at most of the areas. Seeding was, however, going to commence in the spring season of 2013, especially at bare areas. Fertilizer had already been applied. An additional point to mention is that this mine borrowed topsoil from undisturbed agricultural land (hence, arable land) adjacent to the mining area. Topsoil was taken in 50m strips, while leaving 25m strips in between. A grader then levelled the 25m by grading the soil over the 50m strips where soil was borrowed from. The whole area will be returned to grazing to fit in with the final land uses from the adjacent mines. Thus, the mine used the topsoil on adjacent pieces of land to ensure good quality rehabilitation on the mining land in order to blend in with the rest of the area. Refer to **Figure A2** in **Annexure C** for photographs of the areas subject for final rehabilitation at Mine A2.
EMPR commitments compared with the pre-mining land use and land capability of the site:	The total area of the Mine A2 mining right comprises 13.67 ha, but the actual mine is quite small, comprising only 3.5 ha. Due to the small area, it was probably not deemed necessary by the mine to conduct a thorough soil study, and the mine application was approved based on information provided. The pre-mining land use and land capability according to the EMPR was grazing. The land where topsoil is being borrowed from for rehabilitation at this mine had to be of arable potential considering the fact that the soil on the non-mining areas is deep enough to allow soil removal. Thus, a few hectares of adjacent arable land will be affected by mining close to this site by using the topsoil from that area. This mine is, however, only a small piece of land compared to the bigger picture which includes adjacent mines. As the EMPR commitment is to re-establish a grazing land capability potential, similar to the pre-mining land use, it can be concluded that the mine is re-establishing the pre-mining land use and land capability on the 3.5 ha mining area, but a possible loss in arable land capability will occur due to the borrowing of topsoil on the adjacent unmined areas.
EMPR commitments and actual rehabilitation	The EMPR commitment and rehabilitation practices at Mine A2 also prove the *status quo* correct. Although the actual mining area is being re-

Point to discuss	Result and discussion
practices compared with the *status quo* of rehabilitation practices:	established to the pre-mining land use, other areas that were most likely of arable potential are being impacted on by borrowing topsoil from those areas to have enough soil on mined out areas. Thus, rehabilitation can then be successful for a grazing land capability over the mining areas, but arable land on the adjacent areas are compromised to become grazing land once rehabilitation is completed. In addition to this, the adjacent surface coal mine (Mine C) was also rehabilitated to a grazing standard leaving no arable land after mining.
General response about their practices and whether that mine would consider establishing aquaponics as an end land use:	This is viewed in the same light as at Mine A1 although this site is located very close to town. As stated in **Table 7**, the company will not consider aquaponics due to its technical nature. The agreed end land use as indicated in the EMPR is grazing land which will be implemented.

<u>Mine A1 and Mine A2 Quantitative data and results</u>

The second part of the information gathering process was to determine the estimated costs to rehabilitate mining land to a grazing capability standard, hence, the quantitative data that had to be gathered and that was provided by the rehabilitation official.

As mentioned, Mining Company A conducts the rehabilitation practices at the mines themselves. The exact methodology of how rehabilitation is conducted as well as the calculations of the costs associated with the steps in the process at these sites is described in order of performance in a table in **Annexure B**. The total costs (as calculated and presented in **Annexure B**) for each step in the process are included in **Table 8**.

The same rehabilitation practices and costs apply to these two sites (Mine A1 and Mine A2) which could in turn, still be subject to variation determined by fertilization needs of the soil. In general the costs are based on the same principals. The quantitative data for the two sites can therefore be concluded to be similar, but the total costs remain an estimation based on 2013 rates.

Table 8: Mine A1 and A2 - Estimated costs for 1 ha rehabilitation to grazing land capability and land use post-mining (2013)

Step in the process	Estimated Rand cost per ha (excl. VAT)
Replacement of topsoil (300mm of topsoil):	R48,000.00
Levelling of topsoil:	R1,424.00
Total topsoil replacement costs:	**R49,424.00**
Removal of rocks:	R1,840.00
Ripping of soils:	R1,440.00
Disc of soils:	R7,200.00
Spread lime:	R3,084.00
Spread fertilizer 1 (Superphosphate) – prior to seeding:	R2,646.00
Spread fertilizer 2 (KCl 50%) – prior to seeding:	R3,129.25
Spread fertilizer 3 (KAN 28%) with seeding:	R2,833.50
Spread fertilizer (2:4:3) with during second season (spring):	R3,523.80
Seeding of soil:	R4,293.20
Rolling of seed:	R1,440.00
Building of contours:	R1,440.00
Cutting and bailing of grass:	None if contractor takes the grass
TOTAL ESTIMATED REHABILITATION COSTS AT MINE A1/ha (including replacement of topsoil)	**R82,293.75**
TOTAL ESTIMATED REHABILITATION COSTS AT MINE A1/ha (excluding replacement of topsoil)	**R32,869.75**
Potential income from selling grass bales (per ha per year)	
100% grass bales sold:	R2,500.00
50% bales sold:	R1,250.00
Farmer / contractor who cuts and bales (service for free) takes all the bales:	-

<u>Conclusions for Mine A1 and A2</u>

From the site visits and the photographs, the study indicated that Mining Company A really tries to adhere to all the operational commitments in the applicable EMPRs in order to re-establish good quality rehabilitation in the form of grazing land.

Keeping Mine A1's location and the pre-mining land use in mind, and the fact that they have agreed with the farmer who was the directly affected party to re-establish a good quality grazing land for his benefit, it can be concluded that they are establishing a productive post-mining land use. However, a percentage of arable land will be lost due to mining.

Mine A2 on the other hand is ideally located to investigate an alternative of establishing aquaponics at the site, since it is so close to town. Even though their pre-mining land use was grazing, they are borrowing topsoil from unmined areas within their mining right boundaries to enhance the rehabilitation of the site and to ensure that a grazing standard can be re-established. By doing this, they are impacting on other areas where it is most probable that the pre-disturbed land capability is arable land, due to sufficient thickness of soils (which enables the borrowing of the materials).

5.1.1.2. Mine B1 and Mine B2

Mine B1 and Mine B2 are, as with Mine A1 and A2, also two sites under the same management within a single mining company (referred collectively as Mining Company B). Both of these mines are perfectly located (within close proximity to Middelburg town) for consideration of an alternative post-mining land use such as aquaponics. The interview and site visits were conducted on the 11th of September 2013 (interview and Mine B2 site visit) and on the 20th of December 2013 (Mine B1 site visit). The environmental manager with whom the interview was held is in charge of both sites.

This Mining Company works differently in terms of rehabilitation of their sites. They appoint a contractor to do all the work related to final rehabilitation of the sites. Topsoil is usually replaced and levelled before the contractor starts working on the site. A discount price by the contractor has to be included in the costs since 80% of the grass bales that are cut are allocated to the contractor himself. The environmental manager's response about considering aquaponics as an alternative post-mining land use was tested, and proved to be quite positive about the option.

Mine B1 Qualitative data

Table 9 includes the qualitative data gathered for Mine B1. This pre-mining land use was a Eucalyptus plantation, but the actual classified land capability as determined by a soil scientist could not be verified since those sections of the EMPRs were not made available.

Table 9: Rehabilitation data and information of Mine B1

Question / Point to discuss	Result and discussion
Specific rehabilitation practices at the site:	Grassland is re-established, e.g. grazing land use and capability. Final rehabilitation is conducted by a contractor (usually with a farming related background). The way the costs are allocated is included in **Table 11**.
Verify EMPR commitment to actual rehabilitation practices at the evaluated site (whether the mine is complying with what it is committed to do):	EMPRs evaluated: *Mine B1 EMPR* - dated 1995, and the EMPR Amendment, dated 1999. Compliance with the EMPR was noticed in the sense that grassland / grazing land is re-established. However, the EMPR Closure Objective stated that the mine will return the mined areas to arable land. The practice on site is however that grassland / grazing land capability, is re-established where applicable.
Observations made during the site visit:	Grassland of a grazing standard is being re-established on mined areas. Two sites with 3 - 4 year old rehabilitation were visited as well as the site that was rehabilitated in October 2013. Refer to the photographs of this site in **Annexure C**, **Figure B1**.
EMPR commitments compared with the pre-mining land use and land capability of the site (if available):	The actual pre-mining land capability and land use determined by soil characteristics could not be verified as no soil assessment was seen or could be found in the EMPRs provided. The entire mining area was part of a Eucalyptus plantation. A pre-mining aerial photo of the site verified this. The pre-mining site was, however, according to the EMPR, degraded due to illegal dumping and soil removal that took place. The EMPR stated that the land capability will be improved by the systematic stripping of the exotic growth and the rehabilitation of the mined out areas. The total area covered by the mine includes some 878 ha, of which at least 600 ha will be mined.
EMPR commitments and actual rehabilitation	The overall EMPR commitment stating the establishment of rehabilitating to grazing standards prove the *status quo* correct, although no

Question / Point to discuss	Result and discussion
practices compared with the *status quo* of rehabilitation practices:	verification could be made on the actual pre-mining land capability as classified by a soil scientist. The closure objectives, however, mentioned the re-establishment of arable land should be conducted.
General response about their practices and whether that mine would consider trying aquaponics as an end land use:	The Environmental Manager was formerly employed by a government department. From a regulatory point of view he feels that something like Aquaponics could contribute positively to sustainability. He mentioned that if aquaponics is considered as a post-mining land use, it should be included in the mine's Social and Labour Plan, as it could contribute to the uplifting of a community, and to keep a town lively after mining. He feels positive about something like this. He also raised a question of how this could contribute for a mine to obtain a closure certificate, since this is still a big topic in the mining industry. He thought that if explored, aquaponics could contribute to this.

Mine B2 Qualitative data

The information in **Table 10** pertains to the qualitative data gathered for Mine B2.

Table 10: Rehabilitation data and information of Mine B2

Question / Point to discuss	Result and discussion
Specific rehabilitation practices at the site:	Grassland suitable for grazing is re-established at Mine B2 resulting in a grazing land use and land capability. The same principles apply for the final rehabilitation as for Mine B1 (refer to **Table 9**). The costs for rehabilitation at Mine B2 are included in **Table 12**.
Verify EMPR commitment to actual rehabilitation practices at the evaluated site (whether the mine is complying with what it is committed to do):	EMPR evaluated: *Mine B2 EMP - Revised February 2010*, approved on 14 April 2010. The EMP stated that the mine will rehabilitate the area with natural indigenous plants to reduce risk of erosion and that grazing land will be established. Compliance in terms of this commitment in the EMP was noticed.
Observations made during the site visit:	Mine B2 can be seen from the road. The Environmental Manager said that an area of Mine B2 had to be re-seeded during the previous season, since the establishment of the vegetation was not successful. No other

Question / Point to discuss	Result and discussion
	specific information was given about the area, but the photographs are included in **Annexure C**, **Figure B2**. Interpretations were made based on observations. Overall, it was seen that the grasses have established.
EMPR commitments compared with the pre-mining land use and land capability of the site (if available):	The mining right area comprises 425.95 ha. A pre-mining land capability assessment (conducted as part of the Pedological study) indicated that 33.57 ha (7.88%) of the area consisted of arable land, but the majority of the area, 317.39% (74.51%) was grazing land. At this mine, 33.57 ha of arable land will be affected by mining as only a grazing land capability will be re-established at this site.
EMPR commitments and actual rehabilitation practices compared with the *status quo* of rehabilitation practices:	Majority of the area consisted of grazing land capability prior to mining, which will be re-established after mining. However, the arable land on the site will also be re-established to a grazing land capability standard and not to the original arable standard, hence, proving the *status quo* correct.
General response about their practices and whether that mine would consider trying aquaponics as an end land use:	The same applies as was given in **Table 9**. The Environmental Manager felt that Aquaponics could potentially contribute to sustainability and upliftment of a community. Hence, it should be included in the mine's Social and Labour Plan.

Mine B1 and Mine B2 Quantitative data

Costs to rehabilitate the sites to grazing standard were obtained. As stated previously, the mine group appoints a contractor to conduct the final rehabilitation for them. The contractor only provides one total cost for the mine per hectare based on a list of criteria that is provided by the Mining Company for the tender process. **Tables 11** and **12** include the list of criteria (as provided by the mine to the contractor) on which the total costs to rehabilitate the site is based, as well as the total cost as charged by the contractor to rehabilitate each hectare of land.

The costs for replacement of topsoil were provided in terms of what the distance of the topsoil dumps are in relation to the rehabilitation site. An average distance of 1 – 2 km was used to determine the final costs for topsoil replacement plus an additional amount for topsoil levelling as provided by the company. These costs are also based on a wet rate, hence, including diesel costs.

It is, however, not the responsibility of the appointed contractor who conducts the final rehabilitation (liming, fertilization and seeding) to replace the topsoil. It is uncertain whether the building of contours is included in the contractor's price. It was included in the original tender document (and hence, listed in **Table 11** and **12**), but the price quoted for final rehabilitation per hectare is quite low compared to the other mining companies and could therefore lead to uncertainty.

Table 11: Mine B1 - Estimated costs for 1 ha rehabilitation to grazing land capability and land use post-mining (2013)

Description as provided by the Mining Company to the contractor for the tender process	Rand cost per ha (excl. VAT)
Removal of small rocks over top soiled areas:	
Purchase of dolomitic lime and transport to site: 74 tons of lime	
Spread dolomitic lime at 2.2 tons per hectare:	
Purchase of 2:3:2 fertiliser and transport to site: 30kg per ha	
Spread 300 kg 2:3:2 fertiliser per hectare:	
Rip topsoil and plant 3kg Smuts finger grass (*Digitaria eriantha*), 2kg Love grass (Oulands) (*Eragrostis curvula*) and 5kg Teff (*Eragrostis tef*) per hectare.	
Cut and bale (late January / Mid February 2014)	
Purchase of LAN (28) and transport to site:	
Spread 600 kg LAN (28) per hectare as topdressing after each short cutting:	
Price discount if 80% of the bales is given to contractor	
Site establishment (if possible) – including development of contour lines on a rehabilitated area where needed:	
TOTAL ESTIMATED REHABILITATION COSTS AT MINE B1/ha (excluding replacement of topsoil)	**R15,557.00**
Replacement and levelling of topsoil (300mm of topsoil)	R137,370.00
TOTAL ESTIMATED REHABILITATION COSTS AT MINE B1/ha (including replacement of topsoil)	**R152,927.00**
Potential income from selling of grass bales (only 20% of what is produced, but mostly given to a community nearby):	-

Table 12: Mine B2 - Estimated costs for 1 ha rehabilitation to grazing land capability and land use post-mining (2013)

Description as provided by the Mining Company to the contractor for the tender process	Rand cost per ha (excl. VAT)
Removal of small rocks over top soiled areas:	
Purchase of dolomitic lime and transport to site: 29 tons of lime	
Spread dolomitic lime at 2.5 tons per hectare:	
Purchase of 2:3:2 fertiliser and transport to site: 5 tons	
Spread 400 kg 2:3:2 fertiliser per hectare:	
Rip topsoil and plant 3kg Smuts finger grass (*Digitaria eriantha*), 2kg Love grass (Oulands) (*Eragrostis curvula*) and 5kg Teff (*Eragrostis tef*) per hectare.	
Cut and bale (late January / Mid February 2014)	
Purchase of LAN (28) and transport to site:	
Spread 250 kg LAN (28) per hectare as topdressing after each short cutting:	
Price discount if 80% of the bales is given to contractor	
Site establishment (if possible) – including development of contour lines on a rehabilitated area where needed:	
TOTAL ESTIMATED REHABILITATION COSTS AT MINE B2/ha (excluding replacement of topsoil)	**R13,472.13**
Replacement and levelling of topsoil (500mm of topsoil)	R228,950.00
TOTAL ESTIMATED REHABILITATION COSTS AT MINE B2/ha (including replacement of topsoil)	**R242,422.13**
Potential income from selling of grass bales (only 20% of what is produced, but mostly given to a community nearby):	-

As seen, the contractor provides the service with a discount rate if 80% of the grass bales are for the use of the contractor himself. The other 20% bales are usually given to a nearby community. Therefore, the mines in general do not rely on any potential income generated through selling of grass bales.

Conclusions for Mine B1 and B2

The rehabilitation costs, excluding topsoil replacement, at Mining Company B are much less than what was calculated for Mining Company A. This could be due to less seeds used per hectare, and the application of less fertilizer and lime than applied at Mining Company A.

One area where costs are significantly higher is when the topsoil replacement price for Mine B2 is included in the rehabilitation costs. 500 mm of topsoil should be replaced at Mine B2 as per EMP commitment, and the cost was calculated accordingly.

As per discussion with the Environmental Manager of Mine B1 and B2, a part of the rehabilitation area at Mine B2 had to be re-seeded during the second season due to poor grass establishment. This could be due to various reasons, e.g. if the fertilizers were not allocated correctly as per the fertilization needs of the soil, and less amounts of seeds used per hectare in comparison with the amounts used at Mine A1. This could also explain the patches seen in the rehabilitated sites (**Annexure C**, **Figure B2c**) where grasses did not seem to re-establish thoroughly.

Mines B1 and B2 are both located on ideal locations to practice aquaponics. The Environmental Manager thought that aquaponics as an end land use is a good idea and something that could help the mines to achieve closure certificates as aquaponics could have potential benefits for nearby communities. Although the sites are rehabilitated to a grazing land standard, alternative end land uses can (and should) still be explored to ensure that the land could be at its most productive after mining.

5.1.1.3. Mine C

Mine C is part of a large mining group. A very brief interview was held with the person responsible for the rehabilitation of this site. This site is located adjacent to Mine A2.

Mine C is a very large mine divided into six different sections. Three of the six sections fall within the 20 km radius of the study area. One of these three sections, however, consists only of underground mining, whereas the other two sections consist of both underground mining and surface mining practices. Hence, only these two sections will be included in the study.

Mine C Qualitative data

Qualitative data for Mine C was gathered through the EMP as well as the brief discussion held with the person responsible for rehabilitation of the site. Mining has been completed at the original mining area (section relevant for inclusion in the study). The area is therefore subject to final rehabilitation. The other section included is the one directly adjacent to Mine A2 (mentioned earlier).

Table 13: Rehabilitation data and information of Mine C

Question / Point to discuss	Result and discussion
Specific rehabilitation practices at the site:	The idea is to replace 600 mm so that there is a better chance to have arable potential land post-mining. Grassland is established as part of rehabilitation.
Verify EMPR commitment to actual rehabilitation practices at the evaluated site (whether the mine is complying with what it is committed to do):	EMPR evaluated: *Mine C EMPR* - dated 2000, approved on 25 February 2003. According to the EMPR, if more than 600 mm topsoil is replaced arable land capability can be achieved. If less is replaced, then grazing land capability will be achieved. The EMPR states that there is enough topsoil available to rehabilitate the pre-mining land capabilities (by replacing an excess of 600 mm topsoil), but that it is inevitable that degradation will take place, especially in the ramp and void areas as well as where soil pollution occurred. The mine therefore aims to replace at least 600 mm of topsoil, which is the border line between arable and grazing land capability, but by doing this, they aim to re-establish the pre-mining land capability.
Observations made during the site visit:	Grazing land was re-established (as seen from the site visit done at Mine A2). Therefore, the rehabilitation at Mine A2 also aims to blend in with the rehabilitation observed at Mine C to form one continuous landscape. Refer to **Annexure C**, **Figure C**, for photographs of the rehabilitation practices at this site.
EMPR commitments compared with the pre-mining land use and land capability of the site (if available):	The two applicable mining areas included in the study from Mine C together comprise some 9036 ha. A combination of surface and underground mining were undertaken at both sites. The classified land capability prior to mining was 22.13% (2000 ha) arable land and 72.63% (6563 ha) grazing land. Thus, 2000 ha of arable land will be affected by

Question / Point to discuss	Result and discussion
	mining. As the EMPR commitment is to re-establish a potential arable land capability where possible (by replacing 600 mm of topsoil), pasture grass species are planted to initiate the re-establishment of the land.
EMPR commitments and actual rehabilitation practices compared with the *status quo* of rehabilitation practices:	The commitment in the EMPR is to re-establish the pre-mining land use and capability. This is done by aiming to replace a minimum of 600 mm of topsoil on mined out land. The EMPR does, however, recognize that land degradation will occur in certain areas (e.g. ramps and voids, and areas with soil pollution) where this aim will not be achieved.
General response about their practices and whether that mine would consider trying aquaponics as an end land use:	Rehabilitation is done to a grazing land standard, but 600 mm of topsoil is replaced at areas where arable land needs to be re-established. The mine group is open to alternatives if it could help them to obtain closure certificates.

The mine aims to re-establish the pre-mining land use and capability by replacing 600 mm of topsoil (the minimum requirement to re-establish arable land). It is understood though that 600 mm will not guarantee that arable land capability will be achieved, since soil compaction still occurs while the soil needs to settle. In addition to this, erosion also occurs reducing the amount of topsoil present.

Mine C Quantitative data

This mine group uses a different seed mix consisting of 4 grass species for their rehabilitation, which are accounted for in the final rehabilitation costs. The Kweek grass species (*Cynodon dactylon*) was seen at Mine A1 and A2 where it established naturally. According to the Mine C EMPR, some of the species that will be established after mining (Kweek grass and Love grass) were naturally present in the majority of the area prior to mining.

Table 14: Mine C - Estimated costs for 1 ha rehabilitation to grazing land capability and land use post-mining (2013)

NR	Description	Unit	R/unit 2013	TOTAL 2013 / ha
1	Topsoil replacement (including levelling) costs @ 600mm	m^3	R37.00	R220,000.00

NR	Description	Unit	R/unit 2013	TOTAL 2013 / ha
Final rehabilitation:				
2	Rip	ha	R 1 687.49	R 1 687.49
3	Disc (6 times)	ha	R 829.16	R 4 974.95
4	Removal of rocks (7.5 m^3/ha)	m³	R 792.17	R 5 941.24
5	Spread lime	ha	R 455.51	R 455.51
6	Spread fertilizer (new areas)	ha	R 334.17	R 334.17
7	Harrow	ha	R 327.55	R 327.55
8	Seeding	ha	R 496.43	R 496.43
9	Rolling	ha	R 330.08	R 330.08
10	Fertilizer Maintenance	ha	R 369.59	R 369.59
11	Cut pasture	ha	R 511.54	R 511.54
12	Rake pasture	ha	R 385.66	R 385.66
13	Transport bales (25 bales per ha)	bales	R 16.58	R 414.43
14	Bale of windrows	ha	R 674.09	R 674.09
15	Build contours (1250 m^3/ha)	m³	R 3.41	R 4 262.50
16	Dolomitic lime (6000kg/ha)	kg	R 0.43	R 2 567.40
17	Fertiliser 8.2.3(32) (600kg/ha)	kg	R 7.16	R 4 298.58
18	Fertiliser 2.3.4(30) (750kg/ha)	kg	R 7.82	R 5 865.75
19	Smutsvinger (15kg/ha)	kg	R 116.73	R 1 750.98
20	Eragrostit teff (20kg/ha)	kg	R 24.35	R 487.08
21	Bermuda Kweek (5kg/ha)	kg	R 120.77	R 603.85
22	Love grass (Oulands) (13kg/ha)	kg	R 99.33	R 1 291.29
Total Rehabilitation costs (excluding topsoil replacement) per hectare				**R 38 030.14**
Total Rehabilitation costs including topsoil replacement per hectare				**R 260 030.14**

The topsoil replacement rate is very high, since this mine group tries to replace 600 mm of topsoil compared to some of the others' 300 mm minimum standard of topsoil. It is thus clear that replacement of a greater depth of topsoil significantly increases the rehabilitation costs per hectare.

Conclusions for Mine C

The calculated final rehabilitation costs, excluding topsoil replacement, for Mine C is very similar to those calculated for Mining Company A. This mining company, however, uses four grass species for their rehabilitation and grass composition as opposed to the other two mining companies' three species.

5.1.1.4. Comparison of rehabilitation costs

The quantitative data that was collected for the mines are graphically presented on **Figure 17**. The difference in price for total rehabilitation costs (including topsoil replacement and levelling) can greatly be related to the depth of topsoil that is replaced. The inclusion of these tariffs in this study are important to form a holistic view and perspective of final rehabilitation costs for mines and the land capability to expect of post-mining land if different depths of topsoil is replaced.

Different approaches on mines lead to different rehabilitation costs. It is clear that Mine Company A has a much lower estimated topsoil replacement cost than the other two companies, especially when directly compared to Mine B1 who also replaces 300 mm of topsoil thickness. Since the costs for topsoil replacement are too different to compare directly with each other, another comparison was included on the graph that only focuses on the final rehabilitation costs excluding topsoil replacement costs. Similar practices are followed and can therefore be compared more directly, but still with circumspect since different amounts of lime, fertilizer and seeds are used at each mine.

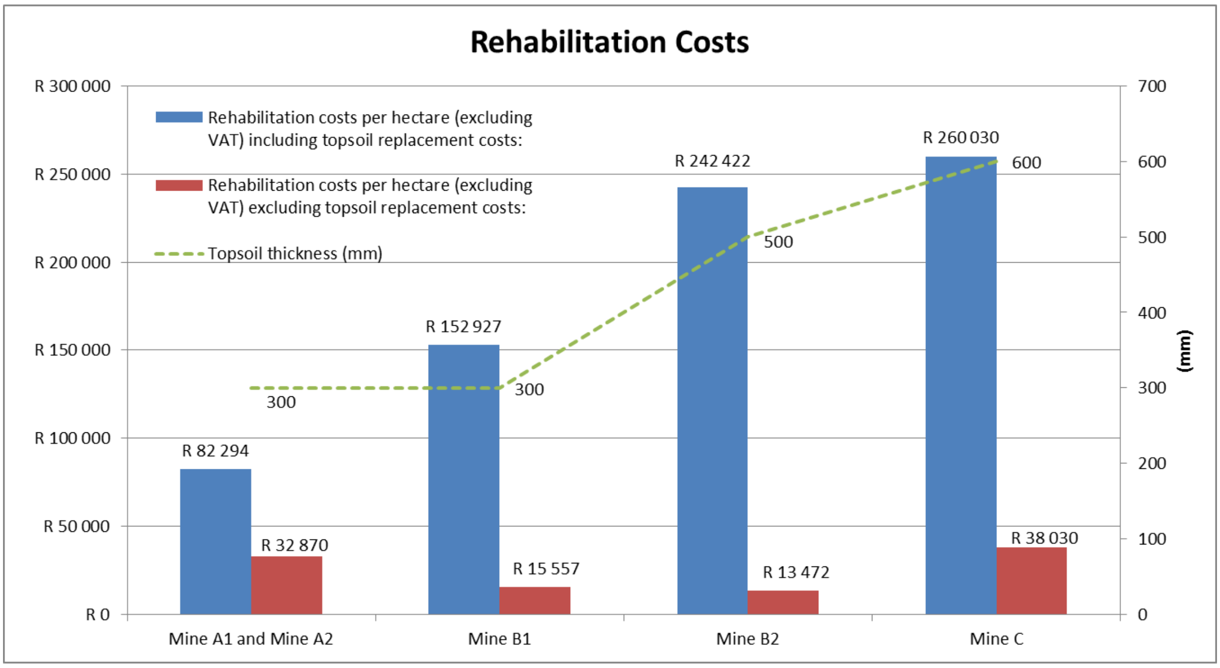

Figure 17: Summary of rehabilitation costs to re-establish grazing land at the mines included in the study

It is suggested that to achieve successful rehabilitation of grazing land capability standard for post-mining land, the rehabilitation costs excluding topsoil replacement reflected within Mining Company A and C is a more realistic amount to budget for. Fertilizer maintenance costs are the only relevant costs that are applicable after establishment, but all the above prices include a maintenance cost for second or third year rehabilitation areas, or for areas where the first grass cutting was conducted.

In terms of operational costs, the only other applicable cost if rehabilitation seeding was successful (except for fertilizer maintenance), is grass cutting and baling or, if not possible, burning. Burning is usually a last option if cutting and baling cannot be conducted. The costs for cutting and baling were either included in the respective tables (**Table 8**, **11**, **12** and **14**) or as mentioned under Mining Company A, an agreement with a farmer or contractor is reached so that he cuts and bales the grass for no cost, in return for the grass.

It can therefore be assumed that the costs presented on **Figure 17** do not only include the costs to establish grazing land as part of mine rehabilitation, but the costs also include the follow up operational and maintenance costs relevant for the rehabilitated sites.

5.1.1.5. Potential income that can be generated from mine rehabilitated grazing land

The current rehabilitation practices of mines could lead to three possible options to generate potential income from the rehabilitated mine land. The options are indicated in **Table 15**.

Table 15: Options to generate income on the type of mine rehabilitated land investigated in this study

Options	Favourability by mining companies
Option 1: Cutting and baling of grass.	Most favourable – current practice at all mines included in study.

Options	Favourability by mining companies
Option 2: Lease rehabilitated land to farmer.	Depends on the size of the mine and whether rehabilitated land can be fenced off with separate entry points. Also depends on quality of rehabilitation. This will, however, eliminate the maintenance responsibility of the mine on the vegetation and fertilization of the land as this becomes the lessee's responsibility.
Option 3: Cattle production (meat or dairy)	Least favourable as mining companies do not want to venture into other types of business. If this is ventured into, it could form part of a community initiative. However, none of the mines investigated disclosed that they owned cattle or are participating in such venture or community initiative.

From **Table 15** and the qualitative data that was gathered from the mines, it is clear that Option 1 is conducted at all the sites. Therefore, this is the most likely way that a mine will initially aim to generate an income on mine rehabilitated land. However, most of the contracts established for cutting and selling of grass usually include an agreement with the contractor (usually a farmer) that the majority of the grass forms part of the "payment". Thus, in most cases income is not physically generated, but a discount is rather assigned for the services rendered.

The income that can potentially be generated at the mines studied for cutting and baling of grass were estimated as follows in **Table 16** (extracted from **Tables 8**, **11**, **12** and **14**):

Table 16: Option 1: Potential income generated from mine rehabilitated sites that form part of the current practices at the mines investigated

Possible income to be generated from:	Mine A1 and A2	Mine B1 and B2	Mine C
Scenario at each mine / mining company:	Refer to **Annexure B** and **Table 8**. Farmer cuts grass at no cost and takes 100% of grass bales, or farmer charges cutting and baling as a cost but takes 50% of bales. The other 50% is then	None – contractor gives discount if 80% of the bales are taken for own use. The other 20% is given to nearby communities. Refer to **Tables 11** and **12**.	Cutting and baling of grass as well as transport of grass is included in the rehabilitation costs (**Table 14**).

Possible income to be generated from:	Mine A1 and A2	Mine B1 and B2	Mine C
	purchased by him.		
Potential income from selling grass bales (per ha) based on the current scenarios:	Grass bales sold @ R250.00 per bale. Approximately 10 bales per hectare of land. Thus: 100% sold: R2,500.00 50% sold: R1,250.00	-	-

The current scenarios at the mines investigated indicate that the mines do not rely on an income from the rehabilitated land. It remains a liability for them to maintain until it can be declared as suitable grazing land that could be leased to a farmer (or whichever favourable contract is drawn up between the farmer and the mine). Most rehabilitated areas are not yet suitable for livestock to graze on as mining is usually still in progress within close proximity to the rehabilitated sites. Thus, until mining has ceased in certain areas and the sites are no longer subject to any potential dangerous activities, cutting and baling of grass will be the main focus and the only possible way of generating an income from the rehabilitated grazing land.

This brings us to Option 2: Lease rehabilitated land to farmer. The grazing potential of rehabilitated land is usually determined by an agricultural specialist who rates the carrying capacity of land in terms of the Mature Livestock Unit (MLU) value (Du Plessis, 2013, pers. comm. 10 December). Mr Du Plessis, who is a rehabilitation official at a mining company (not included in this study), mentioned that mines in general aim to re-establish a 2 - 3 MLU. This means that 2 to 3 hectares of veld can support one mature cattle unit. Once rehabilitated land is confirmed as established with an acceptable MLU value, the land can be leased to a farmer or community if the area can be fenced off from other mining activities and declared safe from any dangerous activities. Income can thus be generated from the lease. **Table 17** overview summarizes the mines' current practices in relation to Option 2.

From **Table 17** it is clear that none of the mining companies investigated in the study currently leases rehabilitated land to generate an income. Mine A1 is the only site that disclosed that they recently allowed grazing activities, but this is under the supervision of the farmer who owns the cattle. He does not lease the land from the mine, but in exchange he maintains the land used for grazing by his cattle (Rehabilitation Official, Mining Company A, 2013, pers. comm. 20 December).

Table 17: Option 2: Potential income generated from mine rehabilitated sites if leased

Possible income to be generated from:	**Mine A1 and A2**	**Mine B1 and B2**	**Mine C**
Scenario at each mine / mining company:	Mine A1 recently ceased mining activities (end November 2013). Some of the older rehabilitation areas are now used directly for grazing by the nearby farmer's cattle. No activities at Mine A2.	No other activities than **Option 1** (**Table 17**).	Did not disclose if any land is leased to farmers for grazing. Therefore, assumed that **Option 1** (as stipulated in their costs in **Table 14**) is the only activity.
Potential income from lease of land:	The agreement in place is that the farmer maintains the rehabilitated land (fertilizer and erosion maintenance) for the use of the land. Thus, no lease income generated.	-	-

The last option pertaining to the current scenarios and re-establishment of grazing land, is as stated in Option 3 (refer to **Table 15**), livestock (mainly cattle) production if mines buy their own livestock to produce meat or dairy. This can also only be done once the land is declared safe and the MLU is of an acceptable standard for grazing. The latter were not considered to date by the mines included in the study and will most likely not be considered by any of them unless it forms part of some sort of community initiative project. The possible income that can be generated directly from grazing activities on the rehabilitated land in terms of cattle production (meat and dairy) will therefore not be assessed as part of this study, since it does not form part of the current practices of the mines investigated.

To conclude, the only current reliable option to generate an income from mine rehabilitated land that can be considered as part of this study is cutting and baling of grass (Option 1). This option pertains to the current rehabilitation practices at mines which forms the focus of this study. The possibility of leasing the rehabilitated land if declared as sufficient grazing land (Option 2) can also be considered as a possible income that can be generated, but certain conditions usually form part of the contract, e.g. the maintenance of the land becomes the responsibility of the lessee. Option 3 is not considered as a possible income for mines as part of this study, since none of the mines indicated that they own or wish to own their own livestock and will therefore always revert back to Option 1 or Option 2. Option 3 also does not form part of the focus of this study, and can be assessed by embarking on a separate study to determine the possible income that can be generated from mining land if cattle production (meat or dairy) is attempted.

5.1.2. Analysis of aquaponics data and information obtained from the experimental site

The general information gathered for the experimental site was discussed in parts of Chapter 3 and 4. A schematic diagram of the how the components of the system, as part of a RAS design, fit into each other was given in **Figure 12** in **Section 4.2.1.2**. This section will focus on the basic estimated capital costs as well as predicted cash flow scenarios calculated using the Blenkinsop model (2013, pers. comm. 27 July). The model was designed for an aquaponic system based on the design of the system at the experimental site.

Blenkinsop based his financial model design on a similar sequence to that prescribed by Rakocy and Hargreaves 1993a (as cited **in** Lapere, 2010) to determine the feasibility of an aquaponics venture. This sequence was also confirmed by an industry professional (G Lawrence) interviewed by Lapere (2010) in his study. This sequence is as follows:

1) Calculate the system requirements to complement the growth projections of the relevant fish species.
2) Calculate the capital costs to implement the size of system calculated in point 1.
3) Calculate and predict the operational costs for the required system.
4) Project the potential sales of the produce.
5) Combine the information in points 1 – 4 to predict the financial viability of the planned system.

Note that some assumptions that are relevant for the study had to be made to focus the study and to eliminate too many variables that could have an influence on costs. Unless otherwise stated, estimates are based on those numbers (in 2013 Rands) obtained by the operator of the current experimental site, Mr Blenkinsop (2013, pers. comm. 27 July and 10 December). The basic assumptions are as follows:

- Land size: Although the experimental site comprises 4 hectares of land, only 1 hectare of land will be used for the scenarios to enable comparison with 1 hectare of grazing land.
- The costs related to land and earth works were excluded from the capital costs since it is assumed that if aquaponics is established as a post-mining land use, then these costs will not be relevant to capital costs. The reasoning behind this is that the land will belong to the mine and that the earth works will have to take place as part of final rehabilitation, thus, this cost can be included as landscaping costs that forms part of the original rehabilitation process.
- The costs for water supply and reticulation is based on R25.00 per m^3 and Piping was calculated at R20.00 per m^3. Power supply costs will vary, depending on location of the site and the availability of electricity supply in the area. The electrical costs are related to wiring of the system. The Blenkinsop model assumes the electrical wiring cost to be around R18 750.00 for every 1000 m^3 of water in the system. Pumps and blowers were included as per **Tables 18**, **20** and **22**.
- Security and fencing costs were based on securing the current experimental site. This will remain similar, depending on the size of the area. Containers and sheds are necessary as “office space” for refrigerators and freezers and for packaging

work space. The floor size of the containers and sheds were assumed to be in the order of 1000 m^2. Two ablution units were deemed sufficient.

- The information pertaining to the tunnels (R135.00 per m^2) and dam liners (R40.00 per m^2) are straight forward. Gravel is placed at a depth of 300 mm in the vegetable tunnels and the costs included are done accordingly (R250.00 per m^3). The Multi parameter meter and the Ozone / UV unit are for water quality control. Net is placed over all the ponds. The costs included for the sludge collectors (structures collecting solids prior to circulating the water to the gravel beds) was calculated to be in the order of R66.67 per m^3 including labour costs.
- Building labour costs can be calculated based on approximately R30 000.00 for every 1000 m^3 of water in the system. Other assumptions were that tools required for the system (even if increasing the system) can be budgeted for at a once off price of R40 000.00, but this could vary according to the needs of the system.
- One light delivery vehicle should be available to service the system and also to deliver produce to clients. It was assumed that one vehicle for every 5000 m^3 of water in the system should be sufficient.
- The cash flow scenarios do not take into account the possible risks that the system is exposed to (e.g. climatic catastrophes such as hail damage, floods, pests or alternatively theft that could negatively influence the produce). The contingency costs should be sufficient to cover some of these expenses should any of these risks occur during the building period that could have a direct influence on the capital costs.
- The income depicted is generated by farming with the two tilapia fish species as described in **Section 2.2.1.4** as well as a variety of vegetables as described in **Section 4.2.1.2**.
- Note that the costs, based on 2013 Rands, are not absolute, but only an indication of what can be expected when an aquaponics venture is established based on the experimental site's design.

5.1.2.1. Basic capital costs of an aquaponic system similar to the one at the experimental site

The estimated capital costs of the system will be formulated based on a layout similar to the one at the experimental site as given in **Figure 12**. Three scenarios will be evaluated for the aquaponics system to test feasibility and profitability in different scales or sizes of the suggested design.

Scenario 1: Similar to the size of the system at the experimental site

The first of the scenarios investigated is one exactly similar to the experimental site's design. **Table 18** contains the information that the components were scaled against to calculate the capital costs as included in the Blenkinsop model. The model was slightly adjusted in this study to ensure all relevant factors were included, such as inflation costs on labour and fish feed.

Scenario 1 consists of a 1800 m^3 system volume wherein fish are stocked at 20 kg / m^3. The estimated grow-out time was set as 15 months until an acceptable 300 – 500 g mass per fish had been reached. This will equate to a 2400 kg production of fish per month and a maximum fish mass of 36 000 kg in the system. The water circulation and power requirements based on this system size are included in **Table 18**. A construction time of 1 month was allowed as included in the Blenkinsop model. Once operational, vegetable production will start at month 5 and fish production will be ready from month 16 onwards when the maximum fish mass has been reached in the system.

Table 18: Components that Scenario 1 is based on and against which the costs were scaled

Scenario 1:	Number	Units
Land	1	ha
Fish		
System volume (fish ponds)	1800	m^3
Fish density in ponds	20	kg/m^3
Grow-out time (thus, fish production)	15	months
Maximum fish mass	36000	kg

Scenario 1:	**Number**	**Units**
Monthly production	2400	kg
Water circulation and power		
System water circulation rate	300	m^3/hr
Pumps required @100m^3 / pump	3	units
Power requirement for pumping	6.48	KW
Spare breakdown pumps	2	units
Blowers circulation rate	518.4	m^3/hr
Blowers required	3	units
Power Requirement for blowers	3.6	KW
Spare breakdown blowers	2	units
Tunnels		
Fish and Duckweed Tunnels (@ 500m^2 / tunnel)	2	units
Gravel bed Tunnels (@ 300m^2 / tunnel)	3	units
Construction and production time frames		
Building Period:	1	month
Vegetable production from month:	5	months
Fish production from month:	16	months
Incremental build up to full production (per month)	4.2%	

Although the experimental site comprises 4 hectares of land, the system could easily fit onto 1 hectare of land since the tunnels only comprise 1900 m^2 of land. Thus, only 1 hectare of land was included in **Table 18**, and as indicated in the assumptions, only 1 hectare of land will be evaluated for aquaponics. In fact, a larger system could easily fit onto 1 hectare of land and that will be explored in Scenarios 2 and 3.

This system comprises three (3) vegetable tunnels and two (2) tunnels for fish and duckweed production (one (1) tunnel each). A hatchery was also built where the fingerlings are kept. The component ratio, which means "…matching the volume of fish tank water to volume of hydroponic media…" (Diver, 2010:3), that was used to design this system was a 1:2 ratio as seen in **Figure 12**. This means that for every fish tank there are 2 vegetable tunnels. The scenario was just slightly changed by including a duckweed production system to supplement fish feed. Thus, instead of 2 vegetable tunnels present for every fish tunnel, there is 1 vegetable and 1 duckweed tunnel. Due to the fact that the vegetable tunnels (300 m^2) are slightly smaller than the fish ponds and duckweed tunnels (500 m^2), and due to the fact that the hatchery component is also present, two additional vegetable tunnels could fit into the system.

Table 19 comprises the estimated capital costs to build the system described in Scenario 1. The costs were calculated using the Blenkinsop model and scaled according to the information given in **Table 18**.

Table 19: Capital costs to build Scenario 1 (based on 2013 costs)

No.	Capital Costs	Number	Units	Unit cost	Budget total
1	Land	1	Ha	R 0.00	R 0.00
2	Fish and Duckweed Tunnels	1000	m^2	R 135.00	R 135 000.00
3	Gravel bed Tunnels	900	m^2	R 135.00	R 121 500.00
4	Earth Works	1	unit	R 0.00	R 0.00
5	Water Supply and reticulation	1800	m^3	R 25.00	R 45 000.00
6	Security – fencing	1	unit	R 0.00	R 100 000.00
7	Container + Sheds	2	unit	R 115 000.00	R 230 000.00
8	Ablutions	2	unit	R 10 000.00	R 20 000.00
9	Power Supply	1	unit	R 150 000.00	R 150 000.00
10	Ponds Dam liner	2068	m^2	R 40.00	R 69 120.00
11	Sludge Collectors lined	90	m^3	R 66.67	R 6 000.00
12	Piping Systems	1800	m^3	R 20.00	R 36 000.00
13	Tools	1	unit	R 40 000.00	R 40 000.00
14	Blowers	5	unit	R 9 000.00	R 45 000.00
15	Gravel	270	m^3	R 250.00	R 67 500.00
16	Gravel bed dam liner	900	unit	R 40.00	R 36 000.00
17	Pumps	5	unit	R 10 000.00	R 50 000.00
18	Electrical	2	unit	R 18 750.00	R 33 750.00
19	Multi parameter meter	1	unit	R 20 000.00	R 20 000.00
20	Hatchery	1	unit	R 150 000.00	R 150 000.00
21	Ozone / UV	1	unit	R 35 000.00	R 35 000.00
22	Building Labour	2	unit	R 30 000.00	R 54 000.00
23	Netting	2	unit	R 3 750.00	R 6 750.00
24	Light delivery vehicle	1	unit	R 200 000.00	R 200 000.00
Total (excluding VAT)					**R 1 650 620.00**
Contingency					10.00%
Grand Total (excluding VAT)					**R 1 815 682.00**

<u>Conclusion for Scenario 1's capital costs</u>

To build a system similar to the one located at the experimental site will have a total capital cost of approximately R 1 650 620.00 (excluding VAT), but with an added contingency of 10%, one should budget for approximately R 1 815 682.00 (excluding VAT).

Scenario 2: System size to fill half a hectare of land

By increasing the system volume, one can easily build more tunnels or greenhouses to increase both fish and vegetable production. Due to high capital costs a conservative approach will be followed. Scenario 2 will therefore only look at 3 times the size of Scenario 1, therefore consisting of a 5400 m^3 system volume. This equates to four (4) fish and duckweed tunnels (2 of each) and eight (8) vegetable tunnels, comprising approximately 4400 m^2 of tunnels. The original size of containers and sheds of approximately 1000 m^2 as per Scenario 1 remains sufficient. Hence, a total area of approximately 5400 m^2 will be used for production, which is just over a half a hectare of land.

Table 20: Components that Scenario 2 is based on and against which the costs were scaled

Scenario 2:	Number	Units
Land	1	ha
Fish		
System volume (fish ponds)	5400	m^3
Fish density in ponds	20	kg/m^3
Grow-out time	15	months
Maximum fish mass	108000	kg
Monthly production	7200	kg
Water circulation and power		
System water circulation rate	900	m^3/hr
Pumps required @100m^3 / pump	9	units
Power requirement for pumping	19.44	KW
Spare breakdown pumps	6	units
Blowers circulation rate	1555.2	m^3/hr
Blowers required	9	units
Power Requirement for blowers	10.8	KW
Spare breakdown blowers	6	units
Tunnels		
Fish and Duckweed Tunnels (@ 500m^2 / tunnel)	4	units
Gravel bed Tunnels (@ 300m^2 / tunnel)	8	units
Construction and production time frames		
Building Period	1	month
Vegetable production from month:	5	months
Fish production from month:	15	months
Incremental build up to full production (per month)	4.2%	

It is expected that the capital costs will increase significantly with a larger system, but this size system will have the ability to produce 7200 kg of fish per month together with 8 tunnels' vegetable produce. The same assumptions apply to Scenario 2 as was described for Scenario 1.

Table 21: Capital costs to build Scenario 2 (based on 2013 costs)

No.	Capital Costs	Number	Units	Unit cost	Budget total
1	Land	1	Ha	R 0.00	R 0.00
2	Fish and Duckweed Tunnels	2000	m^2	R 135.00	R 270 000.00
3	Gravel bed Tunnels	2400	m^2	R 135.00	R 324 000.00
4	Earth Works	1	unit	R 0.00	R 0.00
5	Water Supply and reticulation	5400	m^3	R 25.00	R 135 000.00
6	Security – fencing	1	unit	R 0.00	R 100 000.00
7	Container + Sheds	2	unit	R 115 000.00	R 230 000.00
8	Ablutions	2	unit	R 10 000.00	R 20 000.00
9	Power Supply	1	unit	R 150 000.00	R 150 000.00
10	Ponds Dam liner	4136	m^2	R 40.00	R 207 360.00
11	Sludge Collectors lined	270	m^3	R 66.67	R 18 000.00
12	Piping Systems	5400	m^3	R 20.00	R 108 000.00
13	Tools	1	unit	R 40 000.00	R 40 000.00
14	Blowers	15	unit	R 9 000.00	R 135 000.00
15	Gravel	720	m^3	R 250.00	R 180 000.00
16	Gravel bed dam liner	2400	unit	R 40.00	R 96 000.00
17	Pumps	15	unit	R 10 000.00	R 150 000.00
18	Electrical	5	unit	R 18 750.00	R 101 250.00
19	Multi parameter meter	3	unit	R 20 000.00	R 60 000.00
20	Hatchery	3	unit	R 150 000.00	R 450 000.00
21	Ozone / UV	3	unit	R 35 000.00	R 105 000.00
22	Building Labour	5	unit	R 30 000.00	R 162 000.00
23	Netting	5	unit	R 3 750.00	R 20 250.00
24	Light delivery vehicle	2	unit	R 200 000.00	R 400 000.00
Total					**R 3 461 860.00**
Contingency					10.00%
Grand Total					**R 3 808 046.00**

<u>Conclusion for Scenario 2's capital costs</u>

Scenario 2 is basically three times the size of Scenario 1. Yet, it only fills approximately half a hectare and has the potential to produce 7200 kg fish per month, including vegetable produce from 8 tunnels. The total capital cost for this size system can be expected in the order of R 3 461 860.00 (excluding VAT), or R 3 808 046.00 (excluding VAT) if a contingency of 10% is added as seen in **Table 21**.

Scenario 3: System size to fill one hectare of land

The maximum size system suggested that can fit onto 1 hectare of land is similar to 5 times the experimental site's layout. This will equate to a 9000 m^3 system volume, comprising of six (6) fish and duckweed tunnels (3 tunnels for each equating to a total of 3000 m^2) and twelve (12) gravel bed tunnels for hydroponics (with a total of 3600 m^2), equating to a total tunnel area of 6600 m^2 plus an additional 1000 m^2 for the sheds and container area that will still remain sufficient for this size venture. The total built area will equate to approximately 7600 m^2 (76% of the allocated area). This size system will have the ability to produce 12 000 kg fish per month.

Table 22: Components that Scenario 3 is based on and against which the costs were scaled

Scenario 3:	**Number**	**Units**
Land	1	ha
Fish		
System volume (fish ponds)	9000	m^3
Fish density in ponds	20	kg/m^3
Grow-out time	15	months
Maximum fish mass	180000	kg
Monthly production	12000	kg
Water circulation and power		
System water circulation rate	1500	m^3/hr
Pumps required @100m^3 / pump	15	units
Power requirement for pumping	32.4	KW
Spare breakdown pumps	10	units
Blowers circulation rate	2592	m^3/hr
Blowers required	15	units
Power Requirement for blowers	18	KW
Spare breakdown blowers	10	units
Tunnels		
Fish and Duckweed Tunnels (@ 500m^2 / tunnel)	6	units
Gravel bed Tunnels (@ 300m^2 / tunnel)	12	units
Construction and production time frames		
Build Period	1	month
Veg production from month	5	months

Scenario 3:	**Number**	**Units**
Fish production	15	months
Incremental build up to full production (per month)	4.2%	

The capital costs will again show a significant increase with a larger system as shown in **Table 22**. The same assumptions as described for Scenario 1 also apply to Scenario 3.

Table 23: Capital costs to build Scenario 3 (based on 2013 costs)

No.	**Capital Costs**	**Number**	**Units**	**Unit cost**	**Budget total**
1	Land	1	Ha	R 0.00	R 0.00
2	Fish and Duckweed Tunnels	3000	m^2	R 135.00	R 405 000.00
3	Gravel bed Tunnels	3600	m^2	R 135.00	R 486 000.00
4	Earth Works	1	unit	R 0.00	R 0.00
5	Water Supply and reticulation	9000	m^3	R 25.00	R 225 000.00
6	Security – fencing	1	unit	R 0.00	R 100 000.00
7	Container + Sheds	2	unit	R 115 000.00	R 230 000.00
8	Ablutions	2	unit	R 10 000.00	R 20 000.00
9	Power Supply	1	unit	R 150 000.00	R 150 000.00
10	Ponds Dam liner	6204	m^2	R 40.00	R 345 600.00
11	Sludge Collectors lined	450	m^3	R 66.67	R 30 000.00
12	Piping Systems	9000	m^3	R 20.00	R 180 000.00
13	Tools	1	unit	R 40 000.00	R 40 000.00
14	Blowers	25	unit	R 9 000.00	R 225 000.00
15	Gravel	1080	m^3	R 250.00	R 270 000.00
16	Gravel bed dam liner	3600	unit	R 40.00	R 144 000.00
17	Pumps	25	unit	R 10 000.00	R 250 000.00
18	Electrical	9	unit	R 18 750.00	R 168 750.00
19	Multi parameter meter	5	unit	R 20 000.00	R 100 000.00
20	Hatchery	5	unit	R 150 000.00	R 750 000.00
21	Ozone / UV	5	unit	R 35 000.00	R 175 000.00
22	Building Labour	9	unit	R 30 000.00	R 270 000.00
23	Netting	9	unit	R 3 750.00	R 33 750.00
24	Light delivery vehicle	2	unit	R 200 000.00	R 400 000.00
Total					**R 4 998 100.00**
Contingency					10.00%
Grand Total					**R 5 497 910.00**

Conclusion for Scenario 3's capital costs

Scenario 3, comprising of approximately 5 times the size of Scenario 1, can still fit onto 1 hectare of land comfortably, but is also the maximum size scenario suggested that should be considered on 1 hectare of land if spaces between buildings, electrical wiring and power supply are taken into consideration. The total capital costs is also much higher than the other two scenarios, with a total of R 4 998 100.00 (excluding VAT), or with contingency a grand total of R 5 497 910.00 (excluding VAT) as shown in **Table 23**.

5.1.2.2. Comparison of aquaponics capital costs

The calculated estimated capital costs to establish an aquaponics system based on the experimental site's design and scaled to different sizes as discussed in **Section 5.1.2.1** is presented on **Figure 18**.

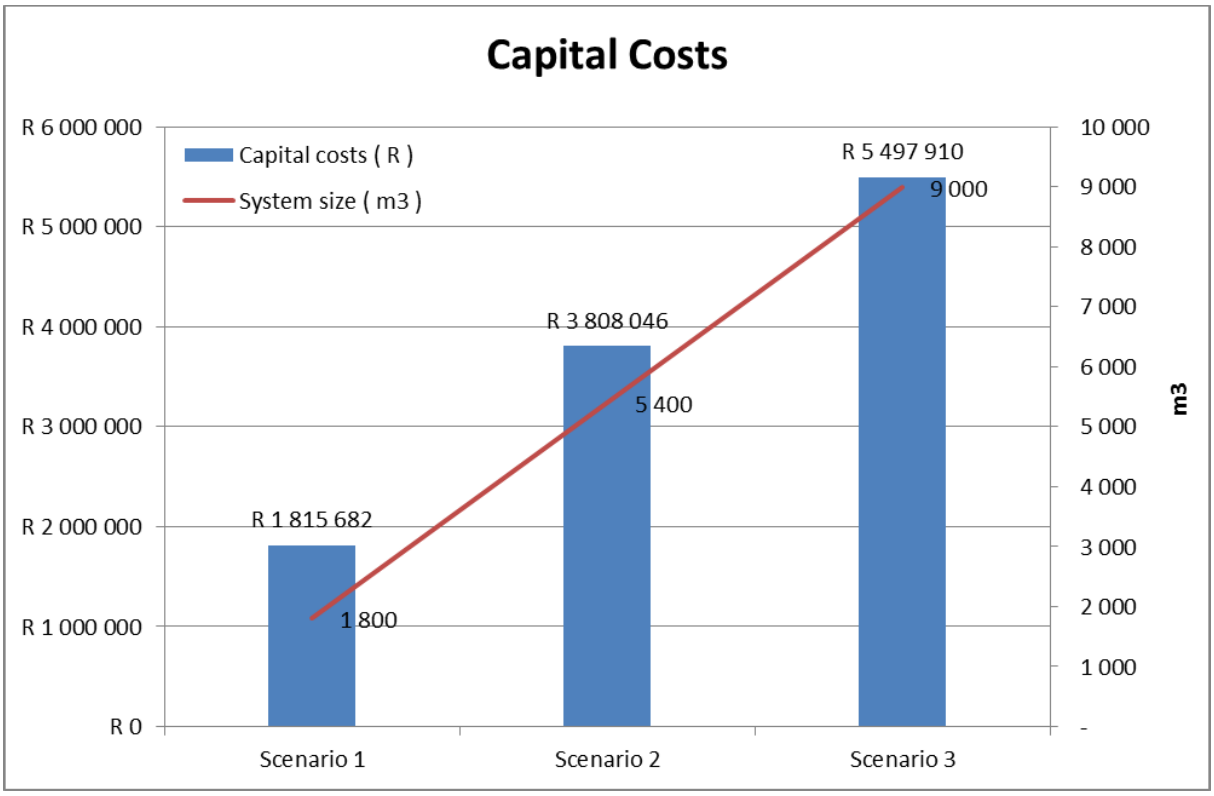

Figure 18: Comparison of capital costs of the three scenarios

It is expected that the capital cost increases as the system size increases. Only 1 hectare of land is included in this study in order to make the comparison more direct with grazing land. Larger sizes of aquaponic systems could most probably also be considered, but with that the practicality and feasibility of the exercise will also have to be investigated prior to building such a large system.

Smaller aquaponics systems can also be considered, such as the small scale scenarios that were investigated by Lapere (2010) located in the Sedgefield / Knysna area. The capital costs for the six farms he investigated and other related information are provided in **Table 24**.

From Lapere's study (2010) it is evident that the type of material used, whether heating is used or not, and other factors all play a profound role in the capital costs for an aquaponic system. Therefore, it must be stated again, that all costs included for aquaponics as calculated by the Blenkinsop model should still be treated with circumspect and remains only an estimation. All costs will vary where different scenarios, designs or materials are used.

Due to high capital costs of establishing an aquaponics system, one can only decide if it is a feasible option to consider as a post-mining land use once the potential income that can be generated from it is calculated as well as the expected return on investment. The potential income that can be generated will therefore play a significant role in deciding whether it will be worthwhile to spend such an amount of money to establish aquaponics. From Lapere's study (2010) he concluded that small scale aquaponics was a high-risk venture that showed small returns on investment. However, if the design and the setup are done correctly together with improved management of the operations, then aquaponics could theoretically be economically feasible.

Table 24: Comparison between the case study farms investigated by Lapere (2010:56)

Parameter		Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Capital Cost		R100 000	R250 000	R250 000	R200 000	R150 000	R60 000
Ponds	Volume	55 m^3	112 m^3	88 m^3	28 m^3	15 m^3	12 m^3
Hydroponics	Construction	Brick and concrete	Wood and plastic	Wood and plastic	PVC-halfpipe	Wood and guttering	PVC-halfpipe
	Method	Gravel medium	Gravel medium	Raft	Gravel medium	NFT	Gravel medium
Filtration	Solids capture	Sand filter	Settling tank	Net filter	None	None	None
	Bio-filtration	Gravel medium	Bio-filter tanks	Gravel and air pump- powered bio-filters	Gravel medium	Bio-filter tanks	Gravel medium
Performance	Aquaculture component	Good	Good	Good	Bad	Good	Bad
	Hydroponics component	Very good	Very good	Very bad	Very good	Good	Very bad
Produce	Fish	Bad	Bad (predicted)	Bad	Very bad	Good	Bad
	Plants	Very good	Good	Very bad	Very good	Very good	Bad
	Other	N/a	Spirulina (construction underway)	N/a	Chickens	Algae	N/a
Heating	Method	Solar and fire-powered boiler	Fire-powered boiler	Heat pump	Heat pump	Heat pump	None

*Note that this information in **Table 24** contains 2010 data.

5.1.2.3. Potential income that can be generated from aquaponics

The potential income that can be generated with the three different aquaponics scenarios were calculated using the Blenkinsop model. The operation was split into months to formulate a five year cash flow forecast. The following assumptions should be kept in mind:

- The Central Bank (South African Reserve Bank) rate that was used (where applicable) was 10.50%. However, for a post-mining scenario the whole capital cost amount will most probably be budgeted for and paid as a whole when construction is complete. For the purpose of the study, this was the assumption that was made and the calculations were done accordingly.
- The South African Producer Price Index (PPI) was based on a 5% annual increase.
- The South African Consumer Price Index (CPI) was based on a 6.2% annual increase.
- A power inflation rate was based on a 1.16% annual increase.
- The amortisation of the assets will take place over a 5 year period with a linear amortisation type. A predicted forecast for only 5 years was therefore included in the study.
- The model stated that the tax rate used was 28% (where applicable), with a discount rate - nominal before tax of 16.90%, and a discount rate - nominal after tax of 12.17%.
- It was assumed that vegetables were planted in Month 2 (to produce by Month 5) and that fish were also added to the system in Month 2 (to start selling fish by Month 16). Hence, feed cost for fish were also included from Month 2. A rate of R9.00 per kg fish food was used (with an added PPI value per month) since it is assumed that 30 - 40% of the fish diet will consist of duckweed that is produced by the system. A feed conversion ratio (FCR) of 1.2 was therefore used to calculate the fish feed (pellet) costs.
- The labour costs were calculated based on 1 labourer for every 600 m^3 in the system. Throughout all 3 scenarios only 1 supervisor and 1 admin or marketing person were deemed necessary.

- The costs pertaining to vehicles were assumed to be 1 vehicle for every 5000 m^3 in the system. Therefore, for a larger system, more than 1 vehicle will have to be purchased and vehicle costs will be included accordingly in the cash flow scenario.
- Maintenance on the system was included from Month 6 onwards. The costs were calculated using the compound capital value and adding 0.15% as well as the PPI value increase per month.
- The revenue from fish sales were based on R32.00 per kg and the revenue from vegetable sales were based on R3800.00 per tunnel per month (conservative approach) with an added value of CPI per month.

The first step to help determine feasibility of the three scenarios is by viewing the cash flow scenarios and whether a positive or a negative cash flow will be generated (Lapere, 2010). As example of the cash flow sheets as calculated for Scenario 3 can be viewed in **Annexure D**. A summary of the findings for each scenario's net cash flow with a forecast of 5 years was included in this section.

Other financial indicators that can help determine the feasibility of each scenario are the estimated Net Present Value (NPV) and Internal Rate of Return (IRR) (based on the 2013 rates). Both of these indicators were calculated and are also included in this section. Brief definitions of these indicators, as well as an example of how the NPV was calculated, are shown in **Annexure E**.

The NPV is based on the principle that your money is worth more now than later on in the future (Goodstein, 2011, Maths is fun, *s.a*). For example, R100.00 is more today than it would be one year from now. In short, to calculate the NPV, one would have to calculate the Present Value (PV) of the investment as well as the PV of the incomes it would generate in the years to come, using a fixed discount or interest rate. One would then calculate the sum of the NPV by adding the initial investment and the present values of the expected income over the allocated time period to determine the NPV (refer to **Annexure E**).

The reasoning behind the inclusion of the NPV, is that a positive NPV indicates a good investment that could be considered, whereas a negative NPV indicates a bad investment and hence, should rather not be considered if a return on investment is expected (Goodstein, 2011, Maths is fun, *s.a.*, Lapere, 2010).

In addition to this, the IRR is also used as an indicator as it is seen as a good way to judge an investment. It is the interest rate or the discount rate that makes the NPV zero, or to make it simple, it is the rate at which an investment breaks even (Maths is fun, *s.a.*, Lapere, 2010). If, for example, the investment shows an IRR of 10%, it will mean that the investment would earn 10% as return. An IRR will help the decision maker to accept an investment if exceeding the required return.

Scenario 1:

Table 25: Scenario 1 - Net cash flow for 5 years (Year 1 based on 2013 rates)

Year 1	Year 2	Year 3	Year 4	Year 5
R -479 105.14	R -32 794.22	R 171 605.52	R 117 772.63	R 11 863.41

As one can see, the cash flow of Year 1 is a high negative value, remaining negative in Year 2. Year 3 shows the best cash flow for the 5 years, since it decreases again in Year 4 with an additional significant decrease in Year 5. This could be attributed to high operational and maintenance costs that increase significantly with inflation over the period of 5 years. If the five years' cash flow are added together, then the accumulated cash flow adds up to R-210 657.79.

Table 26: Scenario 1 - NPV and IRR

NPV	R -2 073 601.93
IRR	-46.48%

The calculated NPV (based on the provided 16.80% discount rate) indicates a very low negative value showing that this would not be a good investment if Scenario 1 is built. The IRR also shows a very low negative value, thus indicating that his investment will not earn a return, but will only cost money to continue operation.

Scenario 2:

Table 27: Scenario 2 - Net cash flow for 5 years (Year 1 based on 2013 rates)

Year 1	Year 2	Year 3	Year 4	Year 5
R -1 008 610.90	R 483 454.95	R 1 166 289.42	R 1 122 811.22	R 997 034.79

Scenario 2 also shows a negative cash flow in Year 1, but grows positive from Year 2 onwards. The maximum cash flow is in Year 3, where-after the income declines again as per Scenario 1 from Year 4 onwards. The accumulated cash flow for the five years equate to R 2 760 979.48.

Table 28: Scenario 2 - NPV and IRR

NPV	R -2 529 053.76
IRR	-6.73%

The NPV in Scenario 2 (calculated using the provided 16.80% discount rate) also indicates an extremely low negative value. The IRR is also negative, but is better than for Scenario 1. This scenario still indicates that the investment will only cost money to operate with no return expected, and hence, does not seem like a feasible venture.

Scenario 3:

Table 29: Scenario 3 - Net cash flow for 5 years (Year 1 based on 2013 rates)

Year 1	Year 2	Year 3	Year 4	Year 5
R -1 495 459.78	R 1 046 238.78	R 2 236 293.27	R 2 207 896.86	R 2 067 277.88

The cash flow for Scenario 3 seems a bit better compared to that of Scenario 1 and 2. Similar to the other two scenarios, Year 3 indicates the highest cash flow, decreasing in the following years. The accumulated cash flow for the five years adds up to R 6 062 247.00.

Table 30: Scenario 3 - NPV and IRR

NPV	R -2 482 482.94
IRR	2.26%

As per the other two scenarios, the NPV (based on the 16.80% discount rate) remains a low negative value. The first impression would therefore be that this is also not a viable investment to consider. The IRR, however, show a positive value indicating that this investment would earn a return of 2.26%. Thus, compared to Scenario 1 and 2, this is the most feasible option to consider, but the NPV is still a very low negative number.

<u>Conclusions for the potential income to be generated</u>

The information included in the above section and **Tables 25** to **30** is summarised in **Figures 19** and **20** to ease the comparison.

High capital costs can be expected if similar systems to the one occurring at the experimental site are planned to be built. From the net cash flow and the IRR, Scenario 1 does not seem like a financially feasible option for future income to be generated. Not only is the accumulated cash flow over the five year period a negative value, but the NPV (based on the 16.90% discount rate) is also a very low negative value. In addition to that, the IRR also indicates a negative percentage value of -46.48%. It will therefore not be advisable to build a system as small as Scenario 1 if a positive return on investment is expected.

Scenario 2 seems to be a better alternative than Scenario 1. The initial capital costs are slightly less than double the costs for Scenario 1, but the size of Scenario 2 is 3 times the size of Scenario 1. The NPV (16.90% discount rate used) remains extremely low (negative value) and in addition to this, the IRR for Scenario 2 is also a negative value of -6.73%. As a result it is also not advisable to consider building this type of system without changing the design and layout to improve cost effectiveness.

Even though Scenario 3 indicated the highest capital costs, it equates to 5 times the size of Scenario 1. Although the NPV (based on the 16.90% discount rate) is a very low negative value, the IRR for Scenario 3 indicated a positive percentage with a value of 2.26%.

It is evident that high capital costs, inflation rates and operational and maintenance costs all play a profound role in the profitability of an aquaponics system. From the net cash flow calculations and if the IRR specifically is considered for the three different scenarios it can be concluded that Lapere's study (2010) proving that small scale aquaponic ventures is not necessarily economically viable is also applicable to the smaller Scenario 1 and 2. Thus, it seems that Scenario 3 is the most feasible option to consider when aquaponics is planned based on the experimental design if the IRR is specifically taken into account. This is also the largest system that will fit comfortably on a 1 hectare size land that can be considered if aquaponics will be established as a post-mining land use. All three scenarios indicated positive cash flow scenarios from Year 2 or 3 onwards, with a decrease from Year 4 onwards due to high inflation costs. It is evident that system performance and cash flow generated is highly sensitive to operational costs and associated increases (as also confirmed by Lapere, 2010).

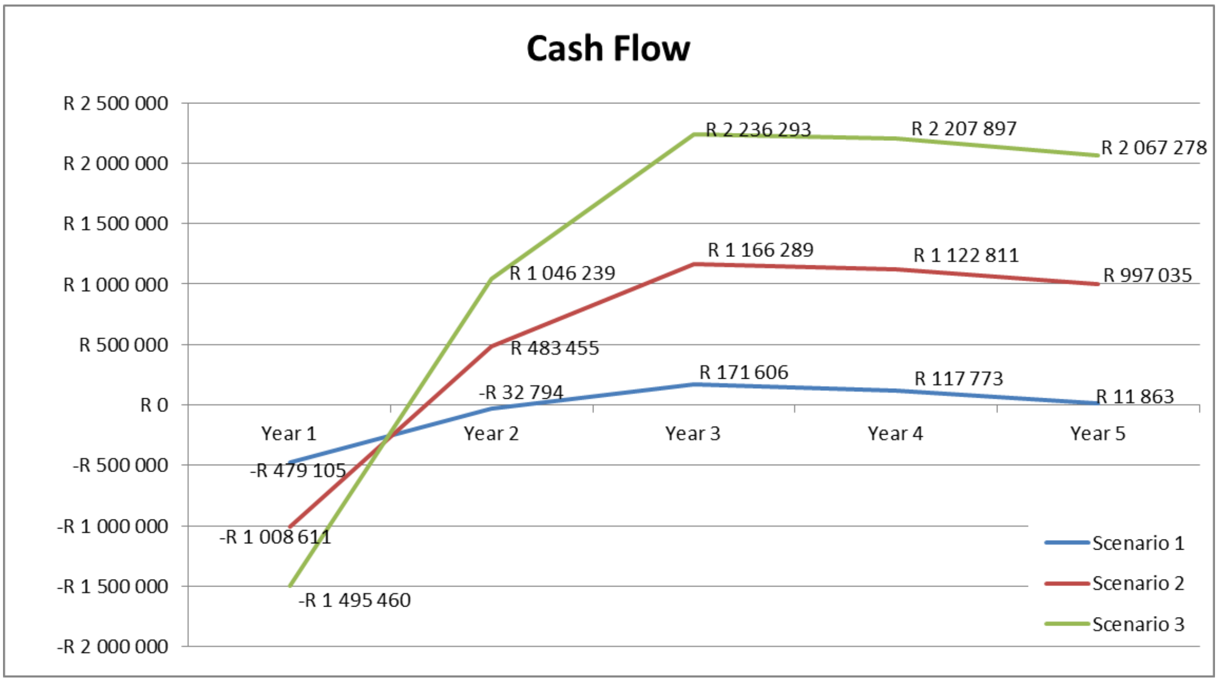

Figure 19: Five year cash flow for the three scenarios (Year 1 based on 2013 rates)

It must be emphasized that the approach followed in the Blenkinsop model is rather conservative, using a very high discount rate (or interest rate) of 16.90% to calculate the NPV. The revenue to be obtained from vegetable produce was also conservative based on R3800.00 per tunnel. A different approach could therefore also be followed as some farmers even claim to make up to R8000.00 per month revenue from vegetable produce (Blenkinsop, 2013, pers. comm. 10 December).

When considering the NPV alone, all three scenarios have very low negative NPVs. This is an indication that the investments do not look like something to consider from a financial perspective. The NPV will, however, be changed if the interest or discount rate used (16.90%) is lowered. The NPV and IRR will also change if the revenue for vegetables is increased. This will be investigated as part of a sensitivity analysis in **Section 5.1.2.4**.

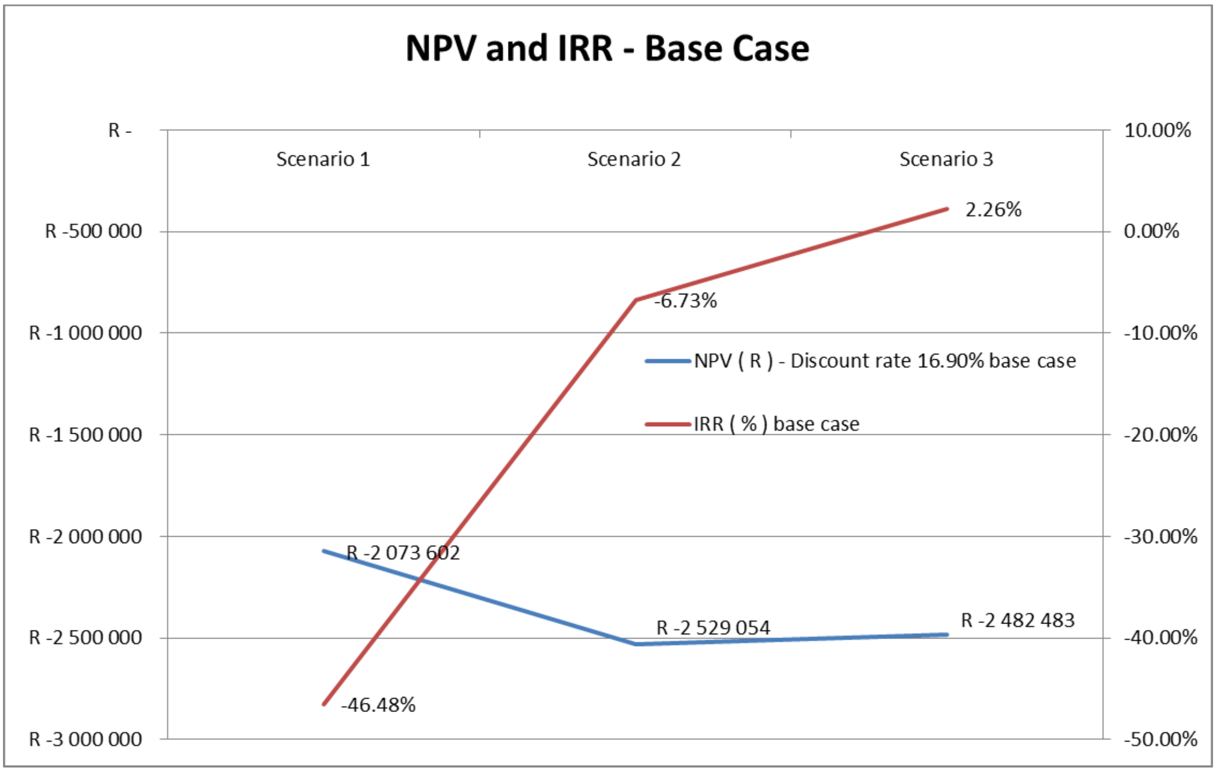

Figure 20: The calculated NPV and IRR for the three scenarios

5.1.2.4. Sensitivity analysis

A sensitivity analysis is usually conducted as part of an economic feasibility study to understand what effect the changing of a certain parameter would have on the financial indicators that measure a proposed venture's performance (Lapere, 2010:77). Although the change of many parameters, such as capital costs or difference in operational costs, could create a difference in the outcome of the economic feasibility, only two parameters were changed as part of this study, namely the discount rate (or interest rate) used to determine the NPV and the revenue for vegetable production. Capital and operational costs were not changed as the scenarios are based on the experimental site's layout. Hence, any changes to the layout of the system will influence the entire picture. Therefore, only economic factors and influences were changed.

The first sensitivity analysis was to change the discount / interest rate used to calculate the NPV from 16.90% in the base scenarios (**Section 5.1.2.3**) to 10.50%. This is similar to the stated interest rate of the South African Reserve Bank (included in assumption in **Section 5.1.2.3**). Goodstein (2011) explained that if a higher discount rate is used to calculate the NPV, the benefits obtained in future years will be less. The sensitivity analysis will test the lower discount / interest rate in order to see if the investment can become more attractive.

The results are shown on **Figure 21**. The NPV's for all three scenarios improved, but remain very low negative values. In fact, the NPV's will only become positive for any of the three scenarios if the discount / interest rate is lower than the IRR, since the IRR is the rate at which the NPV equals zero.

The next parameter that was changed was the revenue that can be generated from the vegetable produce. The Blenkinsop model used a conservative value (R3800.00) based on the experimental site's scenario. As mentioned previously, farmers claim to receive up to R8000.00 per tunnel (Blenkinsop, 2013, pers. comm. 10 December). Therefore, two tests were done, namely if the revenue is increased to R5000.00 per tunnel for vegetable produce (**Figure 22**) and also if the revenue is increased to R8000.00 per tunnel (**Figure 23**). The two figures indicate these tests compared to that of the original base scenarios (**Section 5.1.2.3**). The associated NPV were also calculated for the increased revenues using a 16.90% and a 10.50% discount / interest rate, as well as the IRR (based on increased revenues).

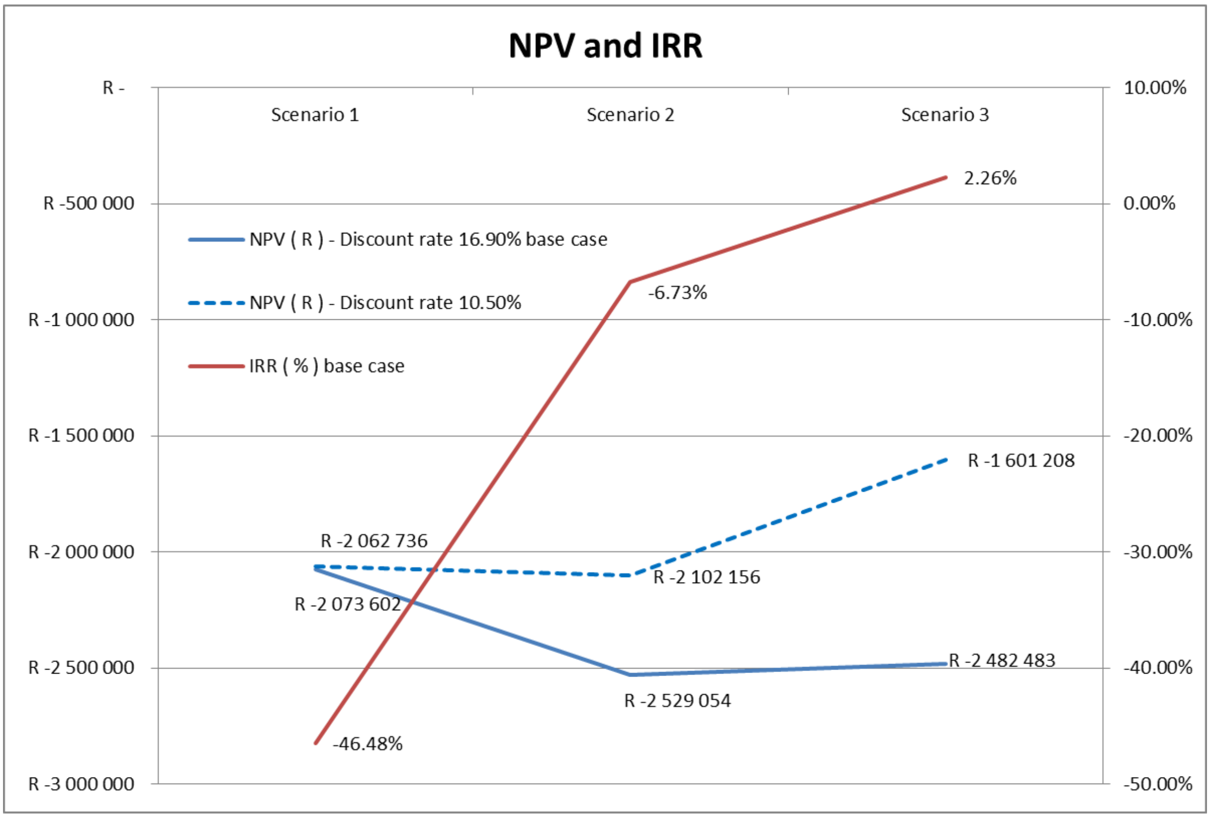

Figure 21: Base scenarios NPV (with 16.90% discount / interest rate) and IRR compared to NPV with 10.50% discount / interest rate

The following is concluded from the graphs in **Figure 22**: If R5000.00 revenue is received for vegetable produce sold, the NPV will remain negative for all three scenarios with both discount / interest rates used. The IRR will remain negative for Scenario 1 and 2, although an increase is seen. The best increase is the IRR value for Scenario 3 with a return of 5.58% to be expected.

The graphs in **Figure 23** indicate that if R8000.00 revenue is received for the vegetable produce sold, then the situation changes. The NPV based on the 16.90% discount / interest rate results in negative values, although much better than for the base scenarios. But when a discount / interest rate of 10.50% is applied, then the NPV for Scenario 3 indicates a positive value of R 570 145.79 and an IRR of 13.20%. Scenario 2's NPV remains negative, but the IRR also increased to 6.09%.

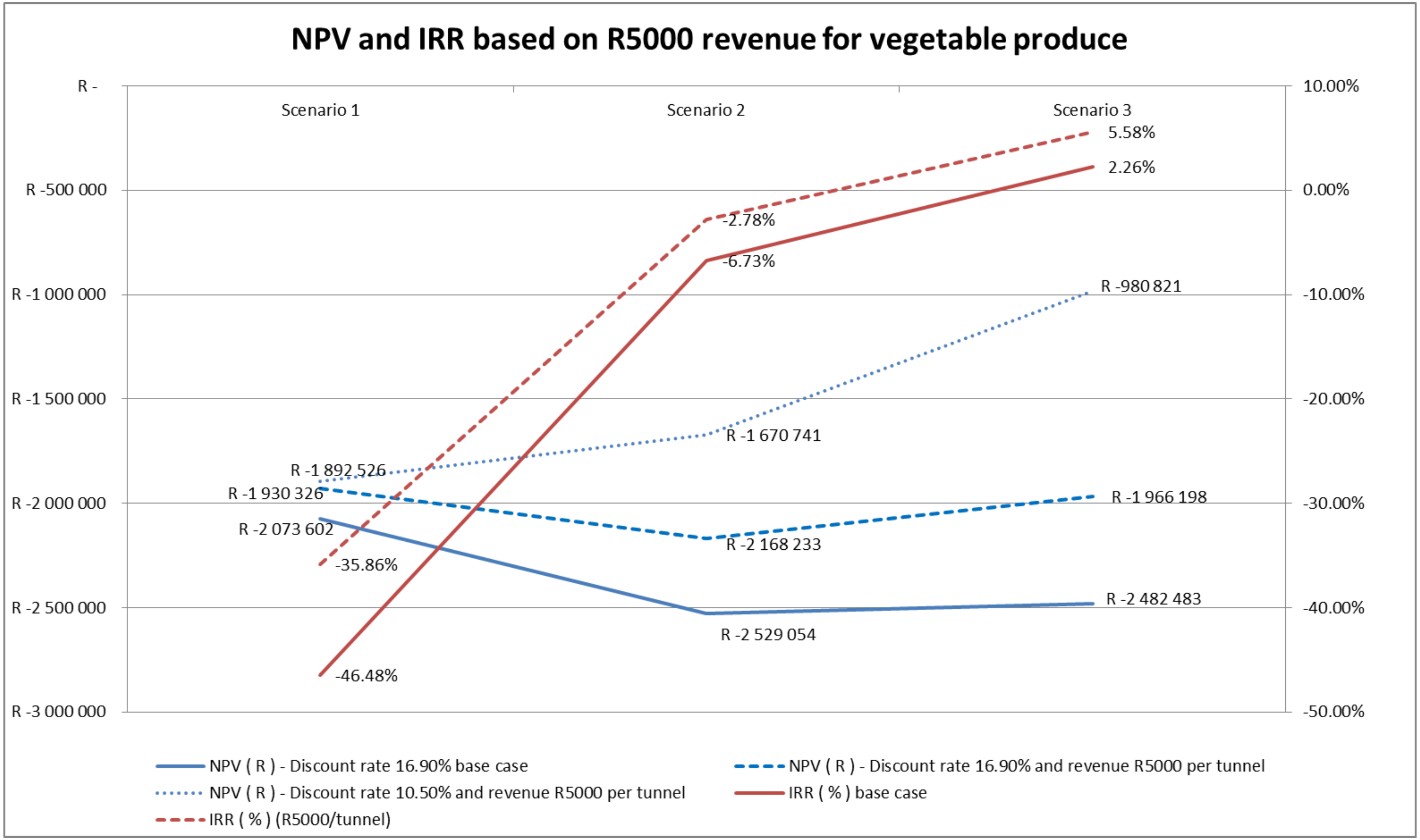

Figure 22: NPV and IRR calculated for R5000 revenue received for vegetable produce and different discount /interest rates

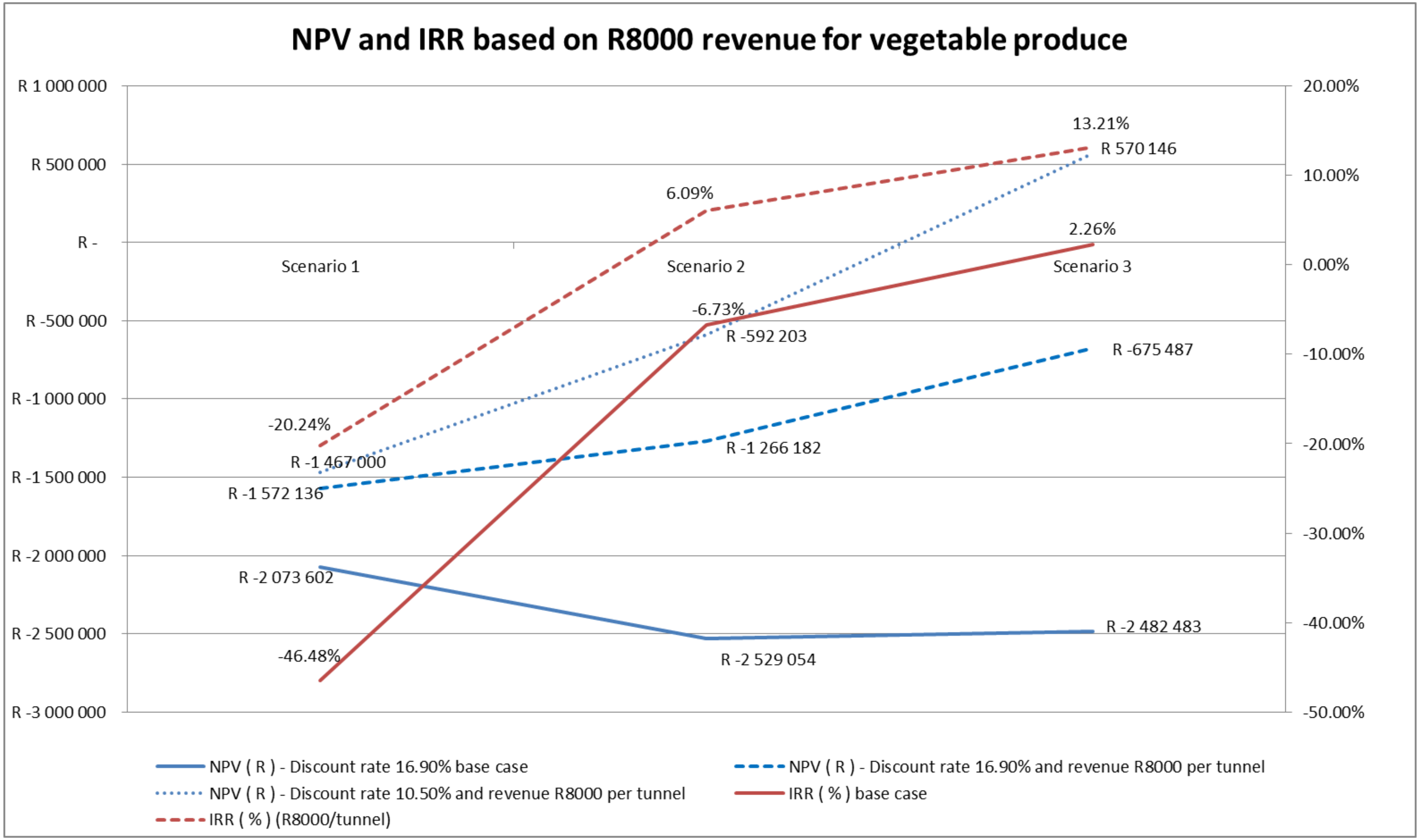

Figure 23: NPV and IRR calculated for R8000 revenue received for vegetable produce and different discount /interest rates

From this analysis one can conclude that a lower discount / interest rate as well as higher revenue received from produce sold will positively influence the economic feasibility of the proposed type of venture.

It can therefore also be concluded that the original base financial calculations as provided with the allocated interest rates in the Blenkinsop model were done from a worst case scenario perspective. However, two parameters had to change to generate a positive NPV, namely the discount / interest rate from which the NPV is calculated as well as the revenue received from vegetable produce had to be increased to the best possible scenario.

The sensitivity analysis, therefore, indicated that higher revenue received from produce sold will most definitely have a positive influence and should be investigated. This does not necessarily have to be vegetable produce, but could also be other products in the system. Studies conducted by the University of Hawaii on the research of the profitability and sustainability of commercial scale aquaponics that was done in Hawaii (Tokunaga, Tamaru, Ako and Leung, 2013) indicated an IRR for aquaponics of 27% and 100% of the farms showed gross profits. Those farms investigated were, however, smaller scale systems similar to the farms used in Lapere’s study. Thus, aquaponics has proven to be profitable internationally, and hence, as Lapere (2010) stated, it can theoretically be economically viable.

The following suggestions can help to improve the feasibility of aquaponics as a post-mining land use, especially from an economic perspective:

- Improved management of the aquaponics system, specifically the aquaculture component, could enhance productivity of the system. Instead of having one large fish pond with all the fish (adult males and females as well as fingerlings), smaller sections or ponds should be considered to better manage the system. Fingerlings can also be sold as a product instead of only selling fillets. The inputs of an aquaculture specialist will be advantageous.
- The climatic conditions of the region hinder the productivity of tilapia farming. If other fish species could be used, such as trout, which is more tolerant to colder

conditions and which has an established market for selling the fish, it will most definitely have a positive effect on the feasibility.

- Due to the colder winter climatic conditions, greenhouses are necessary to produce vegetables, therefore increasing the capital costs. It should, however, also be noted that greenhouses could allow the production of vegetables throughout the year instead of only during the warmer seasons.
- The use of renewable energy will reduce power costs and the associated inflation that could contribute to a cost saving on operational costs. The capital costs will, however, increase. Maintenance of these structures will also have to be considered.
- On this point, if gravity principles are used that could be constructed as part of the mine rehabilitation process, power needs and costs could be reduced in total. This could also lower the operational costs.
- Duckweed in the system is a positive addition since it lowers the cost on fish feed. However, it is not sold as a product and therefore hinders the opportunity of creating larger revenue that could be obtained from vegetable produce. If duckweed is eliminated, the price for fish feed will be increased, but so also the total income due to vegetable revenue. Perhaps the system should attempt to decrease the duckweed production units and rather add more vegetable units. The sensitivity analysis also proved to result in a positive NPV if the revenue obtained from vegetables is increased.
- It is suggested to include another product to the system, e.g. farming with chickens. This will add two products, namely meat and eggs. The chicken droppings can also be utilized in the system as additional fertilizer.
- To eliminate some of the capital costs, studies can be conducted to consider using mine infrastructure instead of building new infrastructure for the aquaculture component. Infrastructure such as redundant pollution control dams or slurry dams can be converted into fish ponds. Reducing capital costs could most likely make the venture more economically feasible.
- Operate aquaponics in combination with other land uses such as grazing.

5.2. Step 2: Financial comparison of the alternatives

This section aims to compare the analyses in Step 1 of the two proposed post-mining end land use options. To keep the study comparable and simple, 1 hectare of land was utilized to directly compare capital or re-establishment costs for the two alternatives as well as the potential income to be generated from the different land uses. The practicality of the two different land use options is actually not directly comparable for 1 hectare of land due to the following reasons:

- Aquaponics can be a business on its own that can be conducted on a small piece of land and that can generate income, create jobs as well as produce food in a sustainable manner.
- To re-establish grazing land is the most practical solution for mines at this stage as a post-mining land use, since it is a low maintenance option and the land can be utilized for farming purposes, hence made practical again. However, typical grazing land will not consist of only 1 hectare of land. Thus, more than 1 hectare would usually be rehabilitated to a grazing standard and will be utilized for that reason. One can actually therefore not only look at 1 hectare of grazing land re-establishment to be exact with the comparison of the two alternatives.

It should also be considered that a surface coal mine could consist of many hectares of land. If aquaponics is chosen as a post-mining land use, it will most likely only be implemented on a smaller area of the site. The rest of the site will then still have to be rehabilitated, most likely to a grazing standard. It is therefore advisable to note that aquaponics can be considered as an end land use option, in combination with another land use such as grazing (or even arable land if the rehabilitation standard is conducted to the necessary specifications).

5.2.1. Comparison of capital and re-establishment costs of the two post-mining land use alternatives

If a mine considers building an aquaponics system, the first question would be what they can expect it to cost. It is evident that capital costs to set up an aquaponics system on 1 hectare of land are much higher compared to re-establishing grazing land on 1 hectare of land. The costs are reflected in **Section 5.1.1.1 - 5.1.1.4** (**Table 8**, **11**, **12** and **14** and **Figure 17**), **Section 5.1.1.1** and **5.1.2.2** (**Tables 19**, **21** and **23** and **Figure 18**).

5.2.2. Comparison of potential income of the two post-mining land use alternatives

A mine would need a good reason to establish an aquaponic system with such high capital costs rather than just rehabilitating the site to a grazing land standard. Therefore, the predicted cash flows for the three scenarios of aquaponics were calculated in **Section 5.1.2.3**. However, the NPV and IRR of all three scenarios did not seem to be positive (except the IRR for Scenario 3) which reflect that implementing the aquaponics systems as post-mining land uses could become a costly exercise with limited (or no) return on investment if based on the experimental site's design and operational methods. From Lapere's study (2010) he did, however, mention that in theory aquaponics systems should and could be economically viable, and that the correct designs and better operational methods could contribute to feasibility. Studies undertaken by the University of Hawaii also indicated that aquaponics is a highly profitable venture with many other benefits (Tokunaga *et al*, 2013). One can therefore not deem it not feasible based only on this exercise.

If compared to the five mines' current practices of re-establishing grazing land, the possible income generated as current state of affairs indicated small incomes (if any) from the rehabilitated land. Instead, the land costs the mines money to maintain. The product from the land at this stage is grass that is baled, but instead of selling the grass the contract agreements usually favour the contractor in return for a discount on the work performed. The remaining grass bales are usually given to a nearby community.

From that point of view, it can be noted that the potential income generated from an aquaponics venture could definitely be more favourable and attractive than what is currently the case at the mines that were studied, and with better planning, designs and management, this could be enhanced as predicted by the sensitivity analysis (**Section 5.1.2.4**).

The potential incomes from the two alternatives are reflected in **Section 5.1.1.5** (**Tables 15**, **16** and **17**) and **Section 5.1.2.3** (**Tables 25 – 30** and **Figures 19** and **20**).

If a mine decides what to establish on mine rehabilitated land purely based on economic information, then Scenario 3 for aquaponics would be the most favourable. However, as mentioned, this is for 1 hectare of land, and hence, the remaining land will then still most likely be rehabilitated to a grazing or arable standard.

5.2.3. Potential feasibility from a financial perspective

To determine the full potential income that can be generated from grazing land as a post-mining land use, one must keep in mind that there were three options considered as per **Table 17** in **Section 5.1.1.5**, but only the current scenario (Option 1) as conducted by mines (at least at those included in this study) was evaluated. Option 3, which entails cattle production (meat and dairy) would most definitely show the most favourable potential income to be generated, but for the purpose of this study, only the current practices were evaluated.

In comparison with the current rehabilitation practices, namely cutting and baling of grass, it is clear that an aquaponics system based on Scenario 3 could generate an income and a positive return on investment on rehabilitated mine land, whereas the current practices of the five mines hardly bring in any income. The NPV of Scenario 3, however, remained a very low negative number, labelling it as not a good investment to consider from a financial perspective if the base scenario's current discount / interest rate is used (16.90%) and if revenue to be expected from vegetable remain as low as R3800.00 per tunnel. With a lower discount rate (10.50%), and higher revenue from vegetables, the venture looks attractive.

Aquaponics based on the experimental design and financial model information can thus also be rated, as stated by Lapere (2010), as a high-risk venture with small returns on investment. But in comparison with the current rehabilitation practices and incomes generated at the mines, it can be considered as a competitive post-mining land use to implement in combination with grazing or arable land on the remaining mined land.

5.3. Discuss the benefits of the two alternative land uses in terms of sustainability criteria

Step 1 and Step 2 evaluated the financial, and hence, economic information of the two proposed post-mining land uses. It is clear from the foregoing analysis that the feasibility of aquaponics as a post-mining land use alternative to current practices cannot be justified on straight economic terms and would not present an attractive option to the cost-conscious coal mining industry.

The first and most important aim for a mining company's rehabilitation practices is to re-establish a sustainable post-mining land use (COM and CRA, 2007) which is practical (MPRDA, 2002). Mines are also aware of the fact that they impact on land and contribute to environmental degradation, specifically with the reduction of arable land which could contribute to food security issues. By re-establishing grazing land, one cannot regard it as not being sustainable since it enhances the return to a natural grassland environment (although not similar to a pristine condition of vegetation as described in **Table 4**) and contributes to food production by means of meat and dairy produce. However, the loss of arable land and land suitable to plant vegetables and crops is a problem that can be addressed to some extent by implementing aquaponics as an alternative post-mining land use.

Economic viability is only one component of sustainability. Although a full sustainability cost accounting exercise is beyond the scope of this thesis, the following matrix (**Table 31**) was developed to provide an initial comparison and discussion of the benefits and possible constraints when considering the implementation of the two post-mining land use alternatives. The matrix was structured to look at selected readily available sustainability criteria and certain related sub-criteria and requirements.

To ease the reading of the matrix, a robot colour coding system was used to compare the benefits and possible constraints of the two land use alternatives. In terms of the colours, green was assigned if the one alternative seemed to provide a greater benefit than the other which was then coded red. Orange was used if the benefits are balanced and basically the same.

As mentioned before, the two land uses cannot be directly compared for the reasons given under Step 2 (**Section 5.2**). In addition to those reasons, it must be emphasized that the one alternative (aquaponics) is water dependent, whereas the other can go without water for months given that the rainy season provides adequate moisture for grazing land.

The matrix suggested 27 indicators that could be viewed as a benefit or a possible constraint for the establishment of the two land uses. From the 27 indicators, aquaponics had shown the greater benefit for 14 of the indicators. 9 of the indicators showed that the benefit would be similar, and 4 indicators favoured the grazing alternative.

As described in the literature review in Chapter 2, **Section 2.2.2** and **2.2.3**, the matrix shows benefits that confirm the statement that aquaponics is an environmentally friendly method of food production. It could contribute positively to the environmental component as well as the social component, even though the economic criteria as calculated in this study did not prove to be positive if based on the experimental site's operation. That could possibly be overcome if further studies are done to continue improving the designs and to lessen operational costs of the systems as proposed by Lapere (2010). In addition to this, higher revenue from vegetables or other produce could change the whole picture completely in terms of economics as shown in the sensitivity analysis (**Section 5.1.2.4**).

Table 31: Sustainability matrix to assess the potential benefits and constraints of the two land use alternatives

CRITERIA	SUB-CRITERIA TO ASSESS	INDICATORS	ALTERNATIVE LAND USES	
			Grazing	Aquaponics
Economic	Economic or financial feasibility	Capital Costs to establish land use:	Low in comparison with Aquaponics.	High in comparison with grazing land.
		Potential income to be generated:	Low if the current practices evaluated are considered, namely cutting and baling of grass.	Higher in comparison with the current cutting and baling of grass. However, the type of system should be carefully scrutinized and preferably Scenario 3 should be implemented if based only on the experimental site's design.
	Produce	Contribution to local, regional and national revenue:	Meat and dairy as well as other products such as leather and even wool could be considered.	Produce per hectare is high. Vegetables, e.g. lettuce, tomatoes, cucumbers, beetroot, peppers and a variety of herbs as well as fish. In addition, chickens (including eggs) or ducks can also form part of the produce. Other produce include duckweed and at some farms algae.
Environment	Sustainable food production	Impacts on environment and in the light of agricultural production methods:	Positive impact as natural grassland is re-established on mine disturbed land. However, the grassland is not similar to the pristine condition (refer to **Table 1)** for species used). Another positive impact is when animals are allowed to graze on the land since it helps with defoliation of the grasses. The excretion of the animals fertilizes the land, hence contributes to restoration of land.	Positive impact if done on mine disturbed land. This is also positive if compared to conventional agricultural methods. The production is done in an organic manner as no fertilizer is used and the waste from the one system becomes the nutrients for the other system. Produce per hectare is high, especially protein produced per hectare.

CRITERIA	SUB-CRITERIA TO ASSESS	INDICATORS	ALTERNATIVE LAND USES	
			Grazing	Aquaponics
Environment	Land Capability	Rehabilitation Standard with limited (low levels) irreparable surface disturbance:	Sufficient amounts of topsoil of certain quality are required. If available, the desired land capability could be achieved, e.g. grazing land.	No topsoil needed. However, material such as gravel needs to be imported to site. Where implemented, the output of food production per hectare will be high.
		Rehabilitation Standard where major, irreparable, surface disturbance has occurred:	Sufficient amounts of topsoil of certain quality are required. If NOT available, the desired land capability would not be achieved, e.g. arable or grazing land.	No topsoil needed. However, material such as gravel needs to be imported to site, but it would help to make the land productive again and could result in a high productivity of food per hectare.
		Topography:	Shape disturbed mining land to natural topography which is suitable as part of mine rehabilitation process.	Shape disturbed land to desired state for aquaponics as part of mine rehabilitation process.
		Stress on natural systems:	By utilising post-mining land as grazing land, one can remove the stress on other more pristine areas and rather focus on using the already impacted land for this purpose.	By practicing aquaponics, one could utilise marginal or low productive land to be productive again for food production and eliminate using pristine land for the same purpose. Fish farming also helps to relieve the natural water sources from being fished and to keep the ecosystems intact.
	Climatic conditions	Temperature:	Suitable to establish grasslands.	Temperature is not necessarily suitable throughout the year. Greenhouse production is therefore proposed, especially if tilapia is used. Greenhouses help to control and regulate the temperatures for higher production targets throughout the year for a variety of products.

CRITERIA	SUB-CRITERIA TO ASSESS	INDICATORS	ALTERNATIVE LAND USES	
			Grazing	**Aquaponics**
Environment	Climatic conditions	Rainfall requirements:	Natural rainfall sufficient (average 750 mm/a), no irrigation needed.	Not directly reliant on rainwater for the system. Rainfall necessary for resources used such as reservoir. Design system so that predicted rainfall is sufficient.
		Wind:	No influence.	Could damage greenhouses.
		Hail:	Could damage if hail occurs at the beginning of the season when the plants are small.	Greenhouses will protect the plantations and fish, but hail could damage greenhouses.
		Frost:	Natural occurrence during winter months and will therefore not always be detrimental to grassland. However, in some cases, the vegetation could die and if it was sparsely distributed, it could have an impact on the site as grasses could be hindered to re-establish.	Greenhouses protect, but if temperature is too low and no heat is added, fish and vegetables could die.
		Summer:	Perfect conditions.	Perfect conditions.
		Winter:	Still suitable.	Suitable, but extreme cold could have a negative influence on productivity. However, greenhouses will reduce the impact and hence, production can continue throughout the whole year, resulting in high yields of products.
	Water requirements	Resource needed on site:	None needed for the re-establishment of grassland, except for natural rains.	River / Dam / Groundwater / Water treatment plant.

CRITERIA	SUB-CRITERIA TO ASSESS	INDICATORS	ALTERNATIVE LAND USES	
			Grazing	**Aquaponics**
Environment	Water requirements	Volumes	No irrigation.	Depends on system size (e.g. 9000m^3). Initially the whole volume will be needed, but thereafter water will be topped up as needed, but to a small extent since the water circulates in the system. This will then contribute to a highly productive system with different products. Water availability in the identified study area in the Mpumalanga Highveld (20km radius of the aquaponics site) should suffice.
		Quality:	Rain water sufficient.	Fish and vegetables require specific qualities (pH, salt, etc.) – see **Table 3**. However, this could add to sustainability, as the operator or mining company will have to ensure that the water quality used (and that will be most probably obtained from the mining area) is of sufficient standard, thus enhancing the quality of the post-mining land.
	Environmental Authorisation	National Environmental Management Act, 1998 (Act No 108 of 1998) (NEMA) authorisation – including the associated Environmental Impact Assessment Regulations of 18 June 2010, Regulations Numbers 543, 544, 545 and 546:	Needed prior to mining as part of initial mining application and authorisation. No additional authorisation needed from NEMA for rehabilitation process to grazing land standard.	Except for the authorisation for mining activities as part of the mining process, an additional listed activity in terms of the NEMA regulations will have to be applied for to establish an aquaponics system. This could, however, be compiled into one application prior to any activities. The application will state that the site will be rehabilitated to use for an aquaponics system. Thus, only one authorisation process could be undertaken. This could contribute positively to sustainability and

CRITERIA	SUB-CRITERIA TO ASSESS	INDICATORS	ALTERNATIVE LAND USES	
			Grazing	Aquaponics
Environment	Environmental Authorisation			could enhance the authorisation to be approved.
		MPRDA authorisation:	Prior to mining as part of initial mining application and authorisation. A Closure Plan will have to be submitted to the DMR to approve the proposed post-mining land use.	In the case of a new mine, the intent to implement an aquaponics system after mining could contribute favourably to a mining company. The Closure Plan will have to be submitted to the DMR wherein aquaponics will be described as a post-mining land use and hence, where it will be subject for authorisation. This could possibly contribute positively for a mining company to obtain a Closure Certificate after mining is completed.
		National Water Act, 1998 (Act No. 36 of 1998) (NWA) – Water Use Licence (WUL) application in terms of Section 21 of the Act:	No WUL necessary to re-establish grazing land, unless if the land will be irrigated.	Depending on water volumes needed, this activity might trigger the need for a WUL.
Social	Post-mining land use	Discussed at a Public Participation meeting?	Usually mentioned and included in the EMPs.	Not yet trialled at a rehabilitated mine site.
	Post-mining job creation	Contribution to job creation:	When grass cutting and baling is still conducted, then it contributes to a job for a contractor or farmer and associated personnel. When a farmer takes the land over as grazing land for livestock, then the farmer and his workforce benefits from the land.	Aquaponics is labelled as rather labour intensive. Labourers, a supervisor and administration staff could be employed. It must be mentioned that due to the technical nature of aquaponics, especially the aquaculture component, it is advisable that an aquaculturerest be involved in the projects. This could create work for more specialised people than

CRITERIA	SUB-CRITERIA TO ASSESS	INDICATORS	ALTERNATIVE LAND USES	
			Grazing	Aquaponics
Social				just labourers.
	Post-mining job creation	Nearby communities:	If grazing land is handed over to a farmer, then a nearby community will not necessary benefit from the land unless if employed by the farmer.	Local labour could be employed at the venture. It could also be started as a community initiative but with the help of a non-profit organisation.
	Food security	Local and regional:	When meat is produced then it satisfies the local and regional markets.	By implementing aquaponics it could contribute to local and regional food security. It could also lessen food miles by importing less food from elsewhere and using local produce. Production output per hectare could also be high with different types of produce that could satisfy needs of all sorts (e.g. nutrients and protein).
	Food security	Community benefits:	Unless if the land is given to a local community to utilise as grazing land for their stock, they will not directly benefit from this as red meat is an expensive protein to buy.	Communities could benefit from aquaponics as fish is a cheaper protein alternative than red meat. Vegetables produced locally could also be more affordable. If communities are involved, it could also be a food source for their own consumption.
		Urban sustainability:	Farming closer to towns including production of meat and dairy could contribute positively to urban sustainability.	Producing vegetables and fish within close proximity to town can contribute positively to urban sustainability by eliminating food miles and resulting in food security. This is even more favourable if high yields of products per hectare are produced.

Section 2.2.1 (**2.2.1.2** and **2.2.1.3**) of Chapter 2 mentioned that the aquaculture industry is growing rapidly worldwide, and South Africa is also slowly catching up with these trends. If aquaculture in South Africa, and specifically tilapia farming, indicates growth similar to international trends, conditions would also become more profitable for aquaponic systems. Research in Hawaii has proved the profitability and sustainability of commercial scale aquaponics (Tokunaga *et al*, 2013). The climatic conditions are, however, more favourable and fish is seen as a primary source of protein with a well-established market. Aquaponics has therefore been proven to be profitable and economically viable, where practised on a commercial scale with access to established markets. It can, therefore be concluded that, in future aquaponics could provide a sustainable post-mining land use alternative and could result in many benefits for a mine who decides to implement it.

5.4. Step 4: Concluding the feasibility of aquaponics as post-mining land use

If an economically viable design and operational method can be determined, then aquaponics could theoretically be considered as a sustainable post-mining land use. This argument can also be supported by answering the three sub-questions formulated to better answer the main research question at the outset of this study. The first sub-question is as follows:

1) Can aquaponics be a practical (reasonable / useful / workable / user friendly / applicable / sensible) post-mining land use?

To answer sub-question No. 1, it can be seen as a practical land use based on observations made at the experimental site and what was understood from the relevant literature review. It is reasonable and useful since it produces different types of food sources. If well established, then aquaponics can be seen as workable and user friendly, although inputs from aquaculture specialists could greatly improve the systems' productivity. Aquaponics could be greatly applicable and sensible as a post-mining land use, since it can make degraded land productive again.

The second sub-question is as follows:

2) Is it possible (attainable / achievable) to implement aquaponics on post-mining land taking note of the specific site conditions?

Environmental impacts associated with surface coal mining that can be expected on rehabilitated land were discussed in Chapter 2, **Section 2.1.1** and **2.1.2**. Land degradation was seen as the reasoning for proposing aquaponics as an alternative post-mining land use, since the quality of land needed to practice aquaponics does not have to be of a good standard. In addition, no soil is needed for vegetable production, and hence, aquaponics will not contribute to loss or erosion of soils. This makes aquaponics a very favourable alternative especially at older mines or areas where topsoil is not sufficient for decent quality grazing land rehabilitation.

The most common constraint that could hinder the implementation of aquaponics is poor water quality or decant of acid water on the land area proposed for aquaponics. Large volumes of water are initially needed. The positive in this is that once water is in the system, it is recirculated and only topped up as necessary. However, if an area where poor water quality or decant exists is considered for an aquaponics venture, then clean water will most likely have to be imported from elsewhere, or a water treatment system will have to be built to ensure sufficient good quality water is available for the activity. Polluted water will also have to be diverted away from the system, since it could have adverse effects on the vegetables and fish. As indicated in **Table 3**, tilapia are quite tolerant of high salinity water and a relatively wide range of pH (also stated by the Argentine Beef Packers, 2010), but these water qualities would not necessarily be suitable for the vegetables in the system. Although tilapia is tolerant of high salinity in water, it has proven to negatively affect the growth rate of the fish (Roderick, 2011).

The other constraint and impact associated with surface coal mined land is the possibility of the occurrence of spontaneous combustion. Cracks or sinkholes could form on the rehabilitated areas that could expose spontaneous combustion from underlying spoils. This is, however, not a common phenomenon and is more the exception than the rule at rehabilitated surface coal mines. If spontaneous combustion is however detected at a site, then aquaponics should not be considered on that piece of land.

The third and last sub-question is:

3) Can aquaponics be viable (sustainable / worthwhile) on post-mining land?

This question can be answered by referring back to the sustainability matrix in **Table 31**. From the environmental and social perspectives it can most definitely be seen as a viable option to consider due to the benefits it offers. A possible constraint that will have to be kept in mind if implementation is considered in the Mpumalanga Highveld from the environmental perspective is that climatic conditions could influence the productivity of the system, especially if a species such as tilapia is produced, as they prefer warmer climates. Greenhouses most certainly help to eliminate the problems in terms of cold temperate winter seasons. The infrastructure could, however, be damaged by hail storms or strong winds. Other factors if post-mining land is considered were discussed as part of sub-question 2.

Producing food closer to towns could have positive benefits in terms of food miles, hence lessening the carbon footprint of transporting food. This also contributes to sustainability proving the ventures to be worthwhile, especially when implemented close to towns.

Environmental authorisation will have to be obtained from various government departments to implement aquaponics on post-mining land. This process could hinder the immediate establishment of aquaponics as authorisation will have to be obtained prior to implementation. If not applied as part of the initial environmental authorisations prior to mining activities, this could involve additional costs in terms of compiling authorisation applications and conducting the necessary studies on the land proposed for the ventures. On the contrary, if authorisation is applied for prior to mining and approved, the process of implementation can continue immediately after mining. If the DMR approves aquaponics as a post-mining land use, the capital costs could possibly even be funded through the rehabilitation trust funds that are payable by mines that ensure rehabilitation after mining.

From the social perspective, aquaponics could most definitely be seen as viable, sustainable and worthwhile to consider. Not only could it alleviate poverty through job creation, but having more affordable food closer to communities, especially low cost protein food such as fish, could improve the health and well-being of people. The only negative point that can be mentioned is that aquaponics could be seen rather technical in nature, referring to the aquaculture component. The argument is based on the fact that the aquaculture component could be improved if more expert knowledge is applied, that may not to be found in a rural community. It could therefore be an incentive for a mining company to consider giving out bursaries to a top scholar from such a community to study aquaculture and thereby improve the education levels and hence, possibly the living standards of such individuals.

It is also suggested that the help of a Non-Profit Organization (NPO) should be found to help initiate and operate the system if established. This will take pressure off the mining company as this is not their core business. If a mine is willing to fund the project, an NPO can run it in conjunction with a community and train the latter to eventually take over as a whole. If a mining company operates a system by themselves, aquaponics could, however, contribute to generate an income from mine rehabilitated land that is larger than what is currently the case at the sites studied for a similar size area. The income could contribute to maintenance of the land and also pay salaries to the people involved in the project.

It is evident that aquaponics should especially be considered as a post-mining land use in areas closer to towns and where communities or large populations reside. It is most suitable as a post-mining land use on areas where excessive topsoil losses have occurred and where grazing land cannot adequately be re-established. Small areas of land are sufficient for the implementation of aquaponics, and therefore it can also be practiced in combination with other land uses such as grazing land. In addition, it does not always have to be practiced for commercial purposes, but it could also be practiced for sustaining a local community and providing them with the necessary nutrients for a healthy balanced diet.

CHAPTER 6 – RECOMMENDATIONS AND CONCLUSIONS

Vast areas of good quality arable land are being lost due to surface coal mining practices in the Mpumalanga Highveld region of South Africa. South Africa is still predominantly dependent on coal as the main energy source, which is a fact unlikely to change within the next 20 years. The dilemma of this truth is that most of the coal resources are located beneath highly productive arable land. These resources are mostly too shallow to allow underground mining, and therefore are extracted via surface mining methods. This results in many environmental impacts with irreversible effects, such as the loss of valuable topsoil. Without sufficient topsoil, arable land is permanently lost to agriculture and replaced with grazing land after mining.

South Africa is already facing a food security crisis. The South African government is aware of the food security crisis and high levels of poverty that need to be alleviated. Therefore, the focus is leaning towards establishing a more diversified "green economy" which is highlighted at national level. This is evident by the development of the 2030 NDP, which addresses environmental sustainability, as well as the South African Green Accord (Siphuma, 2013). Agricultural land was identified as a key focus that could help achieve these set goals.

Reducing the areas available for food production to make room for mining will prevent the country from reaching the goal of increasing agricultural output in the future. Mines therefore need to take land rehabilitation very seriously if they want to contribute positively to the national need by improving agricultural productivity on post-mining land. Environmental managers, consultants and authorities involved in the surface coal mining sector need to understand the opportunities and constraints associated with all feasible rehabilitation alternatives to ensure that our coal mining activities better align with the sustainable development challenges and ideals of South Africa.

This study was undertaken to better understand the feasibility of aquaponics as a suggested alternative post-mining land use for surface coal mines in the Mpumalanga Highveld region. The main driver for this study was to contribute to resolving the dilemma faced as described above (surface coal mines vs arable land resulting in a pending food security crisis). Not only can aquaponics help to turn mined land into productive land and help combat land degradation, but it could also contribute to securing food sources. It can either be practiced on a commercial scale with the potential to enhance the economy, or it could be practiced on small scale securing a local food source for a community. It could help alleviate poverty through job creation and, if on a sufficient scale, investor return whilst providing the necessary protein needs and nutrients supplied by fish and vegetables to society.

The study attempted to determine the feasibility, mainly from an economic and financial perspective based on the experimental site. Given the high capital costs to implement aquaponics, and mines' BATNEEC focus, it is unlikely that mining houses will willingly implement such systems. However, with appropriate incentives such as tax rebates or the possibility to more easily obtain closure certificates, mines might have an alternative outlook on this. By contributing towards the implementation of objectives of a local or regional area's IDP, mines could enhance their social licence to operate and reverse the negative image portrayed on them as destructive of productive land.

As a result of this study, aquaponics is recommended specifically for areas that cannot be rehabilitated according to the *status quo* of returning land to a grazing (or arable) land use due to severe degradation of the land. The study showed that aquaponics could not as a whole replace traditional rehabilitation approaches, but should rather be practiced in conjunction with other land uses such as grazing. The ideal locations in this context to practice aquaponics is on mines closer to towns or cities where people reside that could be employed to work on the aquaponics farms. Urban sustainability will also be enhanced as food will be available closer to towns. When mining ceases the communities could still have a livelihood with secured food sources and economic benefits. Mines could truly leave a proud legacy as they will contribute to sustainable food production.

REFERENCES

Aquaculture Association of South Africa. 2010. *Aquaculture Association of South Africa* [Online]. Available: http://www.aasa-aqua.co.za/ [Accessed: 9 August 2013].

Argentine Beef Packers. 2010. *USA - Amazing Tilapia tolerance in fish ponds* [Online]. Available: http://www.meattradenewsdaily.co.uk/news/060110/usa___amazing_tilapia_tolerance_in_fish_ponds.aspx [Accessed: 16 January 2014]

Blenkinsop, M. 2013. Personal Interview. 14 January, 7 June, 27 July, 19 November, 10 and 20 December. Middelburg.

Brand South Africa. *s.a*. *South Africa.info – South Africa's farming sectors* [Online]. Available: http://www.southafrica.info/business/economy/sectors/542547.htm#.UnoAn_mnqGW [Accessed: 6 November 2013].

Britz, P.J., Lee, B. and Botes, L. 2009. *AISA 2009 Aquaculture Benchmarking Survey: Primary Production and Markets.* AISA report produced by Enviro-Fish Africa (Pty) Ltd. 117p. Grahamstown, South Africa.

Chamber of Mines South Africa and Coaltech Research Association. 2007. *Guidelines for the rehabilitation of mined land.* Johannesburg: Chamber of Mines South Africa and Coaltech Research Association.

Cogho, V.E. 2012. Optimum Coal Mine: striving towards a 'zero effluent' mine. *Journal of the Southern African Institute of Mining and Metallurgy.* 112 (2): 119-126.

Creamer, T. 2013. *SA pushing ahead with carbon-capture plans despite global headwinds* [Online]. Available: http://www.polity.org.za/article/sa-pushing-ahead-with-carbon-capture-plans-despite-global-headwinds-2013-10-

03?utm_source=Creamer+Media+FDE+servic%E2%80%A6 [Accessed: 4 October 2013].

Department of Energy. *s.a.* [Online]. Available: http://www.energy.gov.za/files/coal_frame.html [Accessed: 27 December 2013].

Department of Environmental Affairs and Tourism. 2007. *South Africa Environment Outlook, A report on the state of the environment.* Pretoria: Government Printer.

Deneen, S. *s.a. Food miles* [Online]. Available: http://www.thedailygreen.com/living-green/definitions/Food-Miles [Accessed: 25 March 2013].

Diver, S. 2010. *Aquaponics – Integration of hydroponics with aquaculture.* Rinehart, L. (ed.) National Sustainable Agriculture Information Service [Online]. Available: http://www.extension.org/mediawiki/files/2/28/Hydroponics_with_Aquaculture.pdf [Accessed: 28 January 2013].

D'Souza, G., Miller, D., Semmens, K. and Smith, D. 2003. Mine water aquaculture as an economic development strategy: Linking coal mining, fish farming, water conservation and recreation. Unpublished paper delivered at the 2003 Aquaculture American Conference. 18 – 21 February, Louisville, KY.

Du Plessis, L. 2013. Personal Interview. 10 December. Middelburg.

Food and Agriculture Organization of the United Nations (FAO): Fisheries and Aquaculture Department. 2012. *The State of the World Fisheries and Aquaculture 2012* [Online]. Available: http://www.fao.org/docrep/016/i2727e/i2727e.pdf [Accessed: 9 August 2013].

Ghose, M.K. 2001. Management of topsoil for geo-environmental reclamation of coal mining areas. *Environmental Geology.* 40 (11-12): 1405-1410.

Goodstein, E.S. 2011. *Economics and the Environment.* 6th Edition. USA: John Wiley & Sons, Inc.

Hoadley, M., Limpitlaw, D. and Weaver, A., 2002. Volume 1: *Mining, Minerals and Sustainable Development in Southern Africa: The report of the regional MMSD process.* Johannesburg: Creda.

Jaco-K Consulting cc. 2011. Basic Assessment Report in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), as amended, and the Environmental Impact Assessment Regulations, 2006: Establishment of an aqua culture facility on Portion 6 of the Farm Goedehoop 315 JS. Unpublished Report done for Sustainable Ecological Fisheries Supplies (Pty) Ltd.

Kolver, L. 2013. *SA to move towards a more diverse energy mix* [Online]. Available: http://www.engineeringnews.co.za/article/sa-to-move-towards-a-more-diverse-energy-mix-2013-10-10/rep_id:3182?utm_source=Creamer+Media+FDE+service%E2%80%A6 [Accessed: 21 November 2013].

Lapere, P. 2010. A Techno-Economic Feasibility Study into Aquaponics in South Africa. Unpublished Master's Degree thesis. Stellenbosch: University of Stellenbosch.

Maczkowiack, R.I., Smith, C.S., Slaughter, G.J., Mulligan, D.R. and Cameron, D.C. 2012. Grazing as a post-mining land use: A conceptual model of the risk factors. *Agricultural Systems*. 109: 76 - 89.

Maths is fun. 2012. [Online]. Available: http://www.mathsisfun.com/money/internal-rate-return.html [Accessed: 31 December 2013].

Mentis, M.T. 1999. Diagnosis of the rehabilitation of opencast coal mines on the Highveld of South Africa. *South African Journal of Science.* 95: 210 – 215.

Mentis, M.T. 2006. Restoring native grassland on land disturbed by coal mining on the Eastern Highveld of South Africa. *South African Journal of Science.* 102: 193 – 197.

Mentis, M. 2013. Correspondence. 8 July. Middelburg.

Miller, D. 2008. Using aquaculture as a post-mining land use in West Virgina. *Mine Water and the Environment.* 27: 122 – 126.

Miller, G.T. and Spoolman, S.E. 2012. *Living in the Environment. 17th Ed*. Canada: Brooks / Cole Cengage Learning.

Mine A1. 2009. Environmental Management Programme Report – Revision 2.. Unpublished Report.

Mine A2. 2008. Revised Environmental Management Programme Report. Unpublished Report.

Mine B1. 1995. Environmental Management Programme Report. Unpublished Report.

Mine B1. 1999. Environmental Management Programme Report Amendment. Unpublished Report.

Mine B2. 2010. Environmental Management Programme - Revised. Unpublished Report.

Mine C. 2000. Environmental Management Programme Report. Unpublished Report.

Mucina, L. and Rutherford, M.C. (eds.). 2006. *The Vegetation of South Africa, Lesotho and Swaziland - Strelitzia 19.* Pretoria: South African National Biodiversity Institute.

National Aquaculture Strategic Framework. *s.a*. *National Aquaculture Strategic Framework DRAFT.* [Online]. Available: http://www.aasa-aqua.co.za/site/wp-content/uploads/2010/12/National-Aquaculture-Strategic-Framework-NASF.pdf [Accessed 9 August 2013].

National Planning Commission. 2012. *National Development Plan 2030 - Our Future- make it work* [Online]. Available: http://www.npconline.co.za/pebble.asp?relid=25 [Accessed: 27December 2013].

O'Beirne, S., Napier, V. and Johnson, B. 2013. Why we have to learn to say 'No' to mining. Unpublished paper delivered at the 2013 International Association for Impact Assessment Conference. 16 – 18 September, Thaba 'Nchu.

Phillips, H., Uludag, S. and Chabedi, K. 2011*. Prevention and Control of Spontaneous Combustion. Best Practice Guidelines for Surface Coal Mines in South Africa.* Johannesburg: Coaltech Research Association

Pond life. *s.a.* [Online]. Available: http://www.pond-life.me.uk/plants/floating/lemna.php [Accessed 16 January 2014].

Popma, T.J. and Lovshin, L.L.1995. Worldwide Prospects for Commercial Production of Tilapia. Alabama: Auburn University: 1-42.

Population Reference Bureau. 2011. *2011 World Population Data Sheet*. Washington.

Population Reference Bureau. 2012. *Population and Economic Development 2012 Data Sheet*. Washington.

Republic of South Africa. 1998. *National Water Act 36 of 1998*. Pretoria: Government Printer.

Republic of South Africa. 1998. *National Environmental Management Act 107 of 1998*. Pretoria: Government Printer.

Republic of South Africa. 2002. *Mineral and Petroleum Resources Development Act 28 of 2002.* Pretoria: Government Printer.

Republic of South Africa. Department of Environmental Affairs. 2010. *National Environmental Management Act, 1998 (Act No. 107 of 1998) Environmental Impact Assessment Regulations*. Government Gazette no. 33306, 18 June.

Republic of South Africa. 2013. National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) Regulation 507. Gazette No. 33683, 19 July.

Roderick, E. 2011. *Salinity tolerance* [Online]. Available: http://www.thetilapiasite.co.za/articles_read.php?a_id=18 [Accessed 16 January 2014].

Siphuma, P. 2013. BP 327: Navigating Towards a Green Economy, in *South African Catholic Bishop's Conference*. Cape Town: Catholic Parliamentary Liaison Office: 1-4.

Skelton, P. 2001. *A complete guide to the freshwater fishes of Southern Africa.* 2*nd Ed*. Cape Town: Struik Publishers.

South African Government News Agency. 2013. *Food security a priority for Africa* [Online]. Available: http://www.sanews.gov.za/south-africa/food-security-priority-africa [Accessed: 27 December 2013].

South African National Biodiversity Institute. *s.a*. *Biodiversity GIS* [Online]. Available: http://bgis.sanbi.org/maptutorial/page_01.htm [Accessed: 14 May 2013].

South African Tilapia Farmers Association. 2013. *The Tilapia Site* [Online]. Available: http://www.thetilapiasite.co.za/ [Accessed: 9 August 2013].

Steenekamp, P. 2013. Vraag oor bo-grond, email to I. Botha [Online], 17 October. Available email: rehabgreen@ee-sa.com.

Tavares, F.d.A., Rodrigues, J.B.R., Fracalossi, D.M., Esquivel, J., and Roubach, R. 2008. Dried duckweed and commercial feed promote adequate growth performance of tilapia fingerlings. *Revista Biotemas*, 21(3): 91-97.

Tokunaga, K., Tamaru, C., Ako, H. and Leung, P. 2013. Commercial Scale Aquaponics: Profitability and Sustainability Preliminary Findings. Unpublished paper delivered at Aquaponics in Hawaii Conference. 25 May, Manoa.

World Bank Group. 2013. *Data – Gini Index* [Online]. Available: http://data.worldbank.org/indicator/SI.POV.GINI [Accessed: 21 November 2013].

World Coal Association (WCA). *s.a. Coal Mining* [Online]. Available: http://www.worldcoal.org/coal/coal-mining/ [Accessed: 24 September 2013].

ANNEXURE A - OPEN-ENDED QUESTIONNAIRE

Questionnaire (main questions and information to obtain):		**Info obtained?**
Question 1	Explain specific rehabilitation practices at the site.	
Question 2	EMPR Commitment to rehabilitation at evaluated site (verify in EMPR).	
Question 3	Do the actual rehabilitation practices correspond with the commitment in the EMPR (e.g. if committed to rehabilitate to grazing standard and that is the practice, then yes)?	
Question 4	Site visit to verify practices (take pictures if permitted).	
Question 5	Rehabilitation costs per ha (guided by Table 1 in Letter).	
Other specific questions:		**Info obtained?**
Question 6	Who does the rehabilitation?	
Question 7	How many times do they apply fertilizer in a year (or season)?	
Question 8	How many and what type of seeds are planted?	
Question 9 Question 10	How many months / years on average before grass is cut and baled? What happens to grasses once cut? Income generated from rehab land or from grass bales?	
Question 11	Thoughts on aquaponics as a post-mining land use option?	
COMMENTS:		

ANNEXURE B -
PROCESS TO CONDUCT REHABILITATION TO RECONSTRUCT GRAZING LAND

Process to conduct rehabilitation to reconstruct grazing land capability (as per Mine Company A)

Step in the process	Process description	Calculation of costs (2013 rates) per ha (Excluding VAT)
Replacement of topsoil:	Replacement of topsoil takes place on the levelled mine rehabilitated land. The reason why this practice is highlighted and the costs included is that this could be a potential cost saving if aquaponics is planned to be conducted. Topsoil is stripped when gravel beds and ponds are constructed. A minimum of 300mm of topsoil is replaced in order to re-establish grazing land.	Wet rate (includes diesel costs): R16 / m^3 to place 300 mm topsoil thickness per square metre (m^2). With this rate, replacement of topsoil accounts to: **R48 000** / ha.
Levelling of topsoil:	This practice is done with a grader. It takes approximately 4 hours to grade 1 ha of land.	The grader costs R356 / hour. Takes approximately 4 hours to grade 1 ha of land. Thus, levelling of soil by using a grader is calculated to cost: **R1424** / ha.
Removal of rocks:	The mine hires local labour to remove the rocks manually from the rehabilitated site. 4 labourers are enough to clear 1 ha of land in one day. The rocks are piled and a tractor is used to remove the rocks. The tractor takes the rocks to a mined out pit or to areas where erosion is a problem.	Local labour @ R100 per day. 4 labourers to clear 1 ha in one day. Thus, R400 per ha. The tractor costs R180 / hour. Could take one day to remove the rocks piled together from 1 ha. Thus, R1440 / ha per day for removal of rocks by tractor. The total costs for removal of rocks per ha equals R400 + R1440 = **R1840**.
Ripping of soils:	This is also done by a tractor. It takes approximately 8 hours	The tractor costs R180 / hour. One day or 8 hours per ha.

Step in the process	Process description	Calculation of costs (2013 rates) per ha (Excluding VAT)
	for the tractor to rip one ha of land.	Thus, total of **R1440** per ha.
Disc of soils, application of lime and fertilizer, seeding and rolling:	Disc of soils is done by tractor. Disc is done more than once. The procedure works as follows. 1) Rip the soils. 2) Disc the soils. 3) Spread lime (the volume as stipulated by the soil analysis). 4) Disc again. 5) Spread first fertilizer (usually Super phosphate - amount determined by soil analysis). 6) Disc again. 7) Spread next fertilizer (usually KAN - amount determined by soil analysis). 8) Disc again. 9) Wait for rain. 10) Disc again to loosen the soils. 11) Plant seeds. 12) Roll seeds. Rehabilitation is usually a success if the lime and fertilizer rations are applied correctly according to a soil analysis that was conducted. It would then usually not be necessary to apply additional fertilizer. In the beginning of the second season (first spring) some fertilizer (4:1:1 (33) or 2:4:3) will be applied.	The tractor costs R180 / hour. One day or 8 hours per ha. Thus, total of R1440 per ha for each disc of soil. Disc 4-5 times as explained. Thus, disc costs total: 5 x R1440 = **R7200**

Step in the process	Process description	Calculation of costs (2013 rates) per ha (Excluding VAT)
Spread lime and fertilizer (three separate processes):	Spread lime and fertilizer with tractor and 30t lime spreader. Costs for lime and fertilizers are shown separately. The amount of lime and fertilizer that need to be applied depends on the soil analysis and the prescribed rations that need to be applied to the soil. In this case, the costs to apply lime and fertilizer were based on the requirements of the soil of the specific site and as analysed at the time (20 June 2013). It is therefore possible that the costs could differ from other areas and prices may differ, depending on the service providers and market price.	Thus, R1440 per ha tractor costs for each time used. 6 ton of **lime** needed per ha for the soil analysed. 1 ton of lime = R199.00 (Calmasil Lime) Thus, 6 x R 199.00 = R1194.00 per ha Transport per ton = R75.00 Thus, 6 x R75.00 = R450.00 **Total costs for lime per ha**: R1194.00 (lime) + R450.00 (transport of lime) + R 1440.00 (tractor usage) = **R 3084.00** Costs of **fertilizer** determined for that site per ha (includes Superphosphate, KCl, KAN, 4:3:4 / 2:4:3, and transport of fertilizer): **Transport** per ton of fertilizer= R246.00 R246.00 per ton / 10 = R24.60 / 100kg Thus, 3 x R24.60 = R73.80 per 300kg Or 2 x R24.60 + (R24.60 / 2) = R61.50 per 250kg 300 kg **Superphosphate** needed per ha. R3774.00 per ton / 10 = R377.40 / 100kg. R377.40 x 3 = R1132.20 per 300kg / ha. **Total:** R1132.20 (Superphosphate) + R73.80 (transport of fertilizer) + R1440.00 (tractor) = **R2646.00**

Step in the process	Process description	Calculation of costs (2013 rates) per ha (Excluding VAT)
		250 kg **KCl (50%)** needed per ha. R6511.00 per ton / 10 = R651.10 / 100 kg (R325.55 / 50kg) Thus, R651.10 x 2 + R325.55 = R1627.75 **Total:** R1627.75 (KCl 50%) + R61.50 (transport of fertilizer) + R1440.00 (tractor) = **R3129.25** 300 kg **KAN (28%)** needed per ha with establishment of seeds. R4399.00 per ton / 10 = R439.90 / 100 kg R439.90 x 3 = R 1319.70 **Total:** R 1319.70 (KAN 28%) + R73.80 (transport of fertilizer) + R1440.00 (tractor) = **R2833.50** 300 kg **4:3:4 (33) / 2:4:3 (2:4:3 quoted below)** needed per ha for maintenance during the second season: R6700.00 per ton / 10 = R670.00 / 100 kg R670.00 x 3 = R 2010.00 **Total:** R 2010.00 (2:4:3) + R73.80 (transport of fertilizer) + R1440.00 (tractor) = **R3523.80**
Seeding of soil:	Three seeds are used at this site to re-establish grassland. These include: Teff (*Eragrostis Tef*) Love grass (Oulands) (*Eragrostis curvula*)	R1440 per ha tractor costs to sow seed mix. Seed prices from Agricol (2013). Teff: 12kg / ha @ R15.60 per kg = R187.20 / ha Love grass (Oulands): 7kg / ha @ R153.00 per kg = R1071.00/

Step in the process	**Process description**	**Calculation of costs (2013 rates) per ha (Excluding VAT)**
	Rhodes grass (*Chloris gayana*) The mix of ratio is determined by a specialist and provided for the site's specific needs.	ha Rhodes:11kg / ha @ R145.00 per kg = R1595.00 / ha Thus, R187.20 (Teff) + R1071.00 (Love grass) + R1595.00 (Rhodes) + R1440 (tractor) = **R4293.20**
Rolling of seeds into soil:	Done with a tractor. Same time and costs apply.	The tractor costs R180 / hour. One day or 8 hours per ha. Thus, total of **R1440** per ha.
Building of contours:	This is not always applicable on each hectare of land. A tipper and a grader are used to do this.	Grader and tractor used. Budgeted **R1440** per ha.
Cutting and bailing of grass:	Cut pasture, rake / bale grass, and transport of grass: All done by the farmer. The deal is that the farmer cuts the grass and gets 50% of the bales for himself. 1 ha of grazing land delivers approximately 10 bales. The other 50% is sold, but usually to the farmer himself. Transport of grass on farmers own costs.	Income generated: Sold to farmer for R250 / 350kg bale. Thus, obtain R2500 per ha for grasses if all are sold. But since only 50% of the bales are sold to the farmer, the income accounts to **R1250** per ha. However, in some cases the farmer cuts and bails for free if he can take all the grass bales, especially during a first season cutting when the bales consist mostly of Teff.

ANNEXURE C - REHABILITATION PHOTOGRAPHS

Mine A1

The photographs in **Figure A1** were taken on the day of the site visit at Mine A1 and prove the sites rehabilitation practices. **Figure A1a** is a fourth season rehabilitated area where the grasses have been thoroughly established. This is also evident in the Rhodes grass (*Chloris gayana*) and Love grass (Oulands) (*Eragrostis curvula*) grass present at the site. This site is ready for grazing, but due to the nearby mining activities as seen in the background, no cattle can be allowed on the site. The defoliation practice that will have to be undertaken is therefore grass cutting or burning. Blasting activities have resulted in rocks being flung onto this piece of land, making it risky for grass cutting, as the rocks can damage the cutting equipment. Therefore, the only other alternative for defoliation of this piece of land is to burn the grass. The area is, however, ideal for cows to graze now since it has been established sufficiently.

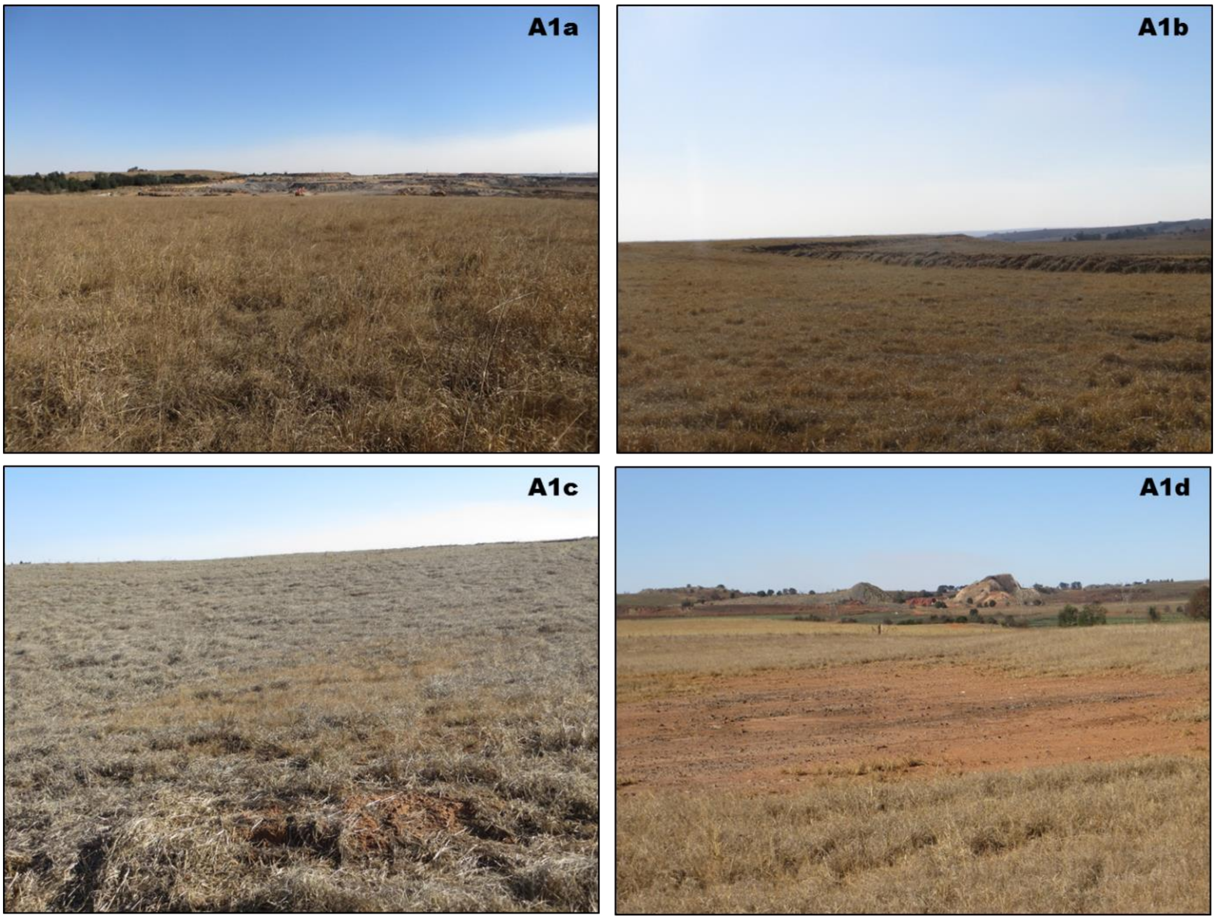

Figure A1: Mine A1's rehabilitation areas (Taken by I Botha, 3 October 2013)

Figure A1b is a third season rehabilitated area, easily distinguished by the presence of Love grass (Oulands) (*Eragrostis curvula*) (the yellow colour). There is a contour in the background that is built to prevent topsoil from being eroded away directly after placement during the first season's rain storm events. The contour will thus minimize and limit the movement of soil from one side to the other.

Figure A1c is a second season rehabilitated area. This is evident by the presence of Teff (*Eragrostis tef*) (the greyish colour) which is used to initially bind the soil and help establish the grasses. Teff being an annual grass will eventually die if not re-seeded. The yellow patch in the middle of the photo is where the Love grass (Oulands) is starting to establish and where the Teff has already died.

Figure A1d is an example in an area where soil has been washed away during a rainfall event, therefore a bare patch is present in the middle of the site. More topsoil will have to be replaced on this area and the patch will have to be re-seeded in order to fix the problem.

Mine A2

Figure A2 contains 4 photographs that were taken at Mine A2 to confirm the site's rehabilitation practices. **Figure A2a** shows the area where the site offices were located. Final rehabilitation will be conducted during this (2013 spring / summer) season. Fertilizers have been applied according to soil analysis results obtained. The first rain was being awaited before seeding could proceed.

Figure A2b indicates three different focus points. The foreground (less basal cover) is part of Mine A2's area. The final rehabilitation (seeding) still had to be done. The grasses present natural re-establishment in the area. No seeding has been done to date at the time of the site visit. The background where grasses are well established is the adjacent surface mine's rehabilitation area. Also note the contour that was built. Manual labour was brought to the site to remove alien vegetation, e.g. *Acacia mearnsii* (black wattle). The site where mining activities occurred was generally clear of black wattle, but a few small plants were noticed that will have to be removed prior to seeding of the area.

Figure A2: Mine A2's rehabilitation areas (Taken by I Botha, 11 October 2013)

Figure A2c shows an area where topsoil has been levelled and that is ready for fertilization and seeding. The red coloured soil (compared to **Figure A2b**) is proof of only topsoil being present. This is a part of the site where borrowed topsoil was replaced.

The area shown on **Figure A2d** is the mine's area towards the old ramp. The warehouse in the background is located next to the busy provincial road, close to town, making this a well located site for consideration of alternative post-mining land uses.

Mine B1

The site visit for Mine B1 was undertaken on the 20th of December 2013. Older rehabilitation sites (3 – 4 years) as well as the newly established 2013 rehabilitation (done in October) were seen. Photographs from the sites are included in **Figure B1**.

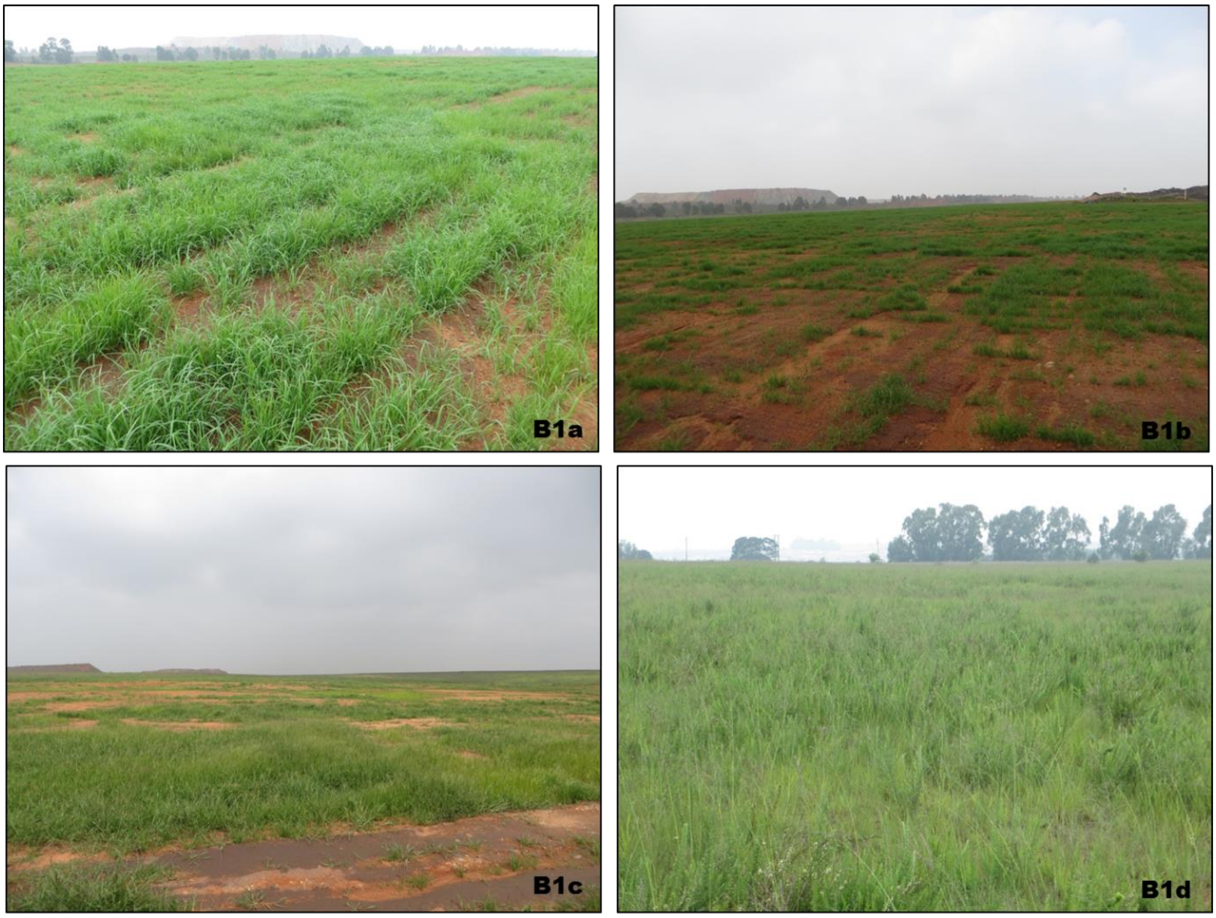

Figure B1: Mine B1's rehabilitation areas (Taken by I Botha, 20 December 2013)

Figure B1a is the newly established rehabilitation site that was planted in October 2013. Grasses are establishing quite well, except for some bare patches that were noticed as seen on **Figure B1b**. **Figure B1c** is a second season rehabilitation area, but as seen, some bare patches are also present at that site. **Figure B1d** is a 3rd to 4th season site and vegetation was seen to be well established. However, some other species were noticed that did not form part of the grass species mix that was used and should be present at the site. Maintenance of the site should therefore be considered.

Mine B2

Photographs were taken at Mine B2 and are included in **Figure B2**. As seen in **Figure B2a**, rehabilitation is still in progress at the site. Certain areas still need to be covered with topsoil and levelled before fertilization and seeding can take place. Topsoil and subsoil heaps can be seen in the background of **Figure B2b** nearby the high wall of the open pit. The forefront of **Figure B2b** is an area where grasses have been successfully re-established.

Figure B2: Mine B2's rehabilitation area (Taken by I Botha, 11 September 2013)

Figure B2c and **Figure B2d** also indicate an area where grasses were re-established, but a patch can be seen where it did not establish 100% (**Figure B2c**). The species composition used at Mine B1 and B2 is slightly different than what is used at Mine A1 and Mine A2. Instead of using Rhodes grass (*Chloris gayana*), Smuts finger grass (*Digitaria eriantha*) is used. The other two grasses, namely Love grass (Oulands) (*Eragrostis curvula*) and Teff (*Eragrostis tef*), remain the same as what is used at Mine A1 and A2.

Mine C

Figure C shows the pictures taken of rehabilitation done at Mine C in 2011.

Figure C: Mine C's rehabilitation area (Taken by Rehabilitation Officer, 10 January 2011)

Figure Ca indicated an area being prepared for final rehabilitation, with topsoil heaps seen in the background ready for levelling. **Figure Cb** shows a tractor in action preparing topsoil for fertilization and seeding. **Figure Cc** and **Cd** show areas where seeding was done and where grasses were starting to establish. Refer to **Figure A2b** to have a glimpse of the same area as it looked in October 2013 (described as the adjacent mine in the background of the photograph).

ANNEXURE D - CASH FLOW SHEETS

Example of Scenario 3

Scenario 3 (Year 1 based on 2013 rates):

				Year1											
				Month1	Month2	Month3	Month4	Month5	Month6	Month7	Month8	Month9	Month10	Month11	Month12
SA Central Bank Rate		10.50%													
SA PPI				0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%
Compound SA inflation PPI				1	1.004166667	1.008350694	1.012552156	1.016771123	1.021007669	1.025261868	1.029533792	1.033823517	1.038131115	1.042456661	1.04680023
SA CPI				0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%
Compound inflation SA CPI monthly				1	1.005166667	1.010360028	1.015580221	1.020827386	1.026101661	1.031403186	1.036732102	1.042088551	1.047472676	1.052884618	1.058324522
Compound inflation SA CPI annual															
Power Inflation				1	1	1	1	1	1	1.16	1.16	1.16	1.16	1.16	1.16
Financial Models Parameters															
Amortisation of Assets		5 years													
Amortisation type	linear														
Tax rate		28%													
Discount Rate (Nominal - before tax)		16.90%													
Discount Rate (Nominal - after tax)		12.17%													
Cashflow				1	2	3	4	5	6	7	8	9	10	11	12
Capital Costs				R 5 497 910.00											
Compound Capital				R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00
Mass of fish in system					12 000	24 000	36 000	48 000	60 000	72 000	84 000	96 000	108 000	120 000	132 000
Feed Cost		R 9.00	R/kg		R 8 676	R 17 424	R 26 245	R 35 140	R 44 108	R 53 150	R 62 266	R 71 458	R 80 725	R 90 068	R 99 488
FCR		1.20													
O&M Costs															
Labour					R 56 500	R 56 500	R 56 500	R 56 500	R 56 500	R 56 500	R 56 500	R 56 500	R 56 500	R 56 500	R 56 500
Power					R 3 193	R 3 193	R 3 193	R 6 387	R 9 580	R 14 817	R 18 521	R 22 226	R 25 930	R 29 634	R 33 339
Vehicles		R 2.50	7 000.00		R 17 590	R 17 681	R 17 773	R 17 864	R 17 957	R 18 050	R 18 143	R 18 237	R 18 331	R 18 425	R 18 521
Maintenance of system		0.15%	%/month						R 8 420	R 8 455	R 8 490	R 8 526	R 8 561	R 8 597	R 8 633
Total Costs				R 5 497 910.00	R 85 960	R 94 799	R 103 711	R 115 891	R 136 564	R 150 971	R 163 921	R 176 946	R 190 047	R 203 225	R 216 480
O&M Costs				R 0	R 85 960	R 94 799	R 103 711	R 115 891	R 136 564	R 150 971	R 163 921	R 176 946	R 190 047	R 203 225	R 216 480
Kg Fish sold								-	-	-	-	-	-	-	-
Tunnels in production								1	2	3	4	5	6	7	8
Revenue fish		R 32.00	R/kg	R 0				R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Vegetables	Revenue/tunnel/month/m2	R 3 800.00						R 3 879	R 7 798	R 11 758	R 15 758	R 19 800	R 23 882	R 28 007	R 32 173
Nett Cashflow				-R 5 497 910	-R 85 960	-R 94 799	-R 103 711	-R 112 012	-R 128 766	-R 139 213	-R 148 163	-R 157 146	-R 166 165	-R 175 218	-R 184 307
Cumulative Cashflow				-R 5 497 910	-R 5 583 870	-R 5 678 669	-R 5 782 380	-R 5 894 392	-R 6 023 158	-R 6 162 371	-R 6 310 534	-R 6 467 680	-R 6 633 845	-R 6 809 063	-R 6 993 370

				Year2											
				Month13	Month14	Month15	Month16	Month17	Month18	Month19	Month20	Month21	Month22	Month23	Month24
SA Central Bank Rate		10.50%													
SA PPI				0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%
Compound SA inflation PPI				1.051161898	1.055541739	1.05993983	1.064356246	1.068791063	1.073244359	1.077716211	1.082206695	1.08671589	1.091243873	1.095790722	1.100356517
SA CPI				0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%
Compound inflation SA CPI monthly				1.063792532	1.069288793	1.074813452	1.080366655	1.085948549	1.091559283	1.097199006	1.102867868	1.108566018	1.114293609	1.120050793	1.125837722
Compound inflation SA CPI annual				1.063792532											
Power Inflation				1.16	1.16	1.16	1.16	1.16	1.16	1.3456	1.3456	1.3456	1.3456	1.3456	1.3456
Financial Models Parameters															
Amortisation of Assets		5 years													
Amortisation type	linear														
Tax rate		28%													
Discount Rate (Nominal - before tax)		16.90%													
Discount Rate (Nominal - after tax)		12.17%													
Cashflow				13	14	15	16	17	18	19	20	21	22	23	24
Capital Costs															
Compound Capital				R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00
Mass of fish in system				144 000	156 000	168 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000
Feed Cost		R 9.00	R/kg	R 108 984	R 118 558	R 128 210	R 137 941	R 138 515	R 139 092	R 139 672	R 140 254	R 140 838	R 141 425	R 142 014	R 142 606
FCR		1.20													
O&M Costs															
Labour				R 60 104	R 60 104	R 60 104	R 60 104	R 60 104	R 60 104	R 60 104	R 60 104	R 60 104	R 60 104	R 60 104	R 60 104
Power				R 37 043	R 40 747	R 44 451	R 48 156	R 51 860	R 55 564	R 64 454	R 64 454	R 64 454	R 64 454	R 64 454	R 64 454
Vehicles		R 2.50	7 000.00	R 18 616	R 18 713	R 18 809	R 18 906	R 19 004	R 19 102	R 19 201	R 19 300	R 19 400	R 19 500	R 19 601	R 19 702
Maintenance of system		0.15%	%/month	R 8 669	R 8 705	R 8 741	R 8 778	R 8 814	R 8 851	R 8 888	R 8 925	R 8 962	R 8 999	R 9 037	R 9 074
Total Costs				R 233 417	R 246 827	R 260 316	R 273 884	R 278 298	R 282 714	R 292 320	R 293 038	R 293 759	R 294 483	R 295 211	R 295 942
O&M Costs				R 233 417	R 246 827	R 260 316	R 273 884	R 278 298	R 282 714	R 292 320	R 293 038	R 293 759	R 294 483	R 295 211	R 295 942
Kg Fish sold				-	-	-	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000
Tunnels in production				9	10	11	12	12	12	12	12	12	12	12	12
Revenue fish		R 32.00	R/kg	R 0	R 0	R 0	R 414 861	R 417 004	R 419 159	R 421 324	R 423 501	R 425 689	R 427 889	R 430 100	R 432 322
Vegetables	Revenue/tunnel/month/m2	R 3 800.00		R 36 382	R 40 633	R 44 927	R 49 265	R 49 519	R 49 775	R 50 032	R 50 291	R 50 551	R 50 812	R 51 074	R 51 338
Nett Cashflow				-R 197 035	-R 206 194	-R 215 389	R 190 241	R 188 226	R 186 220	R 179 037	R 180 754	R 182 481	R 184 217	R 185 963	R 187 718
Cumulative Cashflow				-R 7 190 405	-R 7 396 599	-R 7 611 988	-R 7 421 747	-R 7 233 521	-R 7 047 302	-R 6 868 265	-R 6 687 510	-R 6 505 029	-R 6 320 812	-R 6 134 849	-R 5 947 131

				Year3											
				Month25	Month26	Month27	Month28	Month29	Month30	Month31	Month32	Month33	Month34	Month35	Month36
SA Central Bank Rate	10.50%														
SA PPI				0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%
Compound SA inflation PPI				1.104941336	1.109545258	1.114168363	1.118810731	1.123472443	1.128153578	1.132854218	1.137574444	1.142314337	1.14707398	1.151853455	1.156652844
SA CPI				0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%
Compound inflation SA CPI monthly				1.13165455	1.137501432	1.143378523	1.149285979	1.155223956	1.161192613	1.167192109	1.173222601	1.179284251	1.18537722	1.191501669	1.197657761
Compound inflation SA CPI annual				1.13165455											
Power Inflation				1.3456	1.3456	1.3456	1.3456	1.3456	1.3456	1.560896	1.560896	1.560896	1.560896	1.560896	1.560896
Financial Models Parameters															
Amortisation of Assets		5 years													
Amortisation type	linear														
Tax rate	28%														
Discount Rate (Nominal - before tax)	16.90%														
Discount Rate (Nominal - after tax)	12.17%														
Cashflow				25	26	27	28	29	30	31	32	33	34	35	36
Capital Costs															
Compound Capital				R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00
Mass of fish in system				180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000
Feed Cost		R 9.00 R/kg		R 143 200	R 143 797	R 144 396	R 144 998	R 145 602	R 146 209	R 146 818	R 147 430	R 148 044	R 148 661	R 149 280	R 149 902
FCR		1.20													
O&M Costs															
Labour				R 68 017	R 68 017	R 68 017	R 68 017	R 68 017	R 68 017	R 68 017	R 68 017	R 68 017	R 68 017	R 68 017	R 68 017
Power				R 64 454	R 64 454	R 64 454	R 64 454	R 64 454	R 64 454	R 74 767	R 74 767	R 74 767	R 74 767	R 74 767	R 74 767
Vehicles		R 2.50	7 000.00	R 19 804	R 19 906	R 20 009	R 20 113	R 20 216	R 20 321	R 20 426	R 20 531	R 20 637	R 20 744	R 20 851	R 20 959
Maintenance of system		0.15% %/month		R 9 112	R 9 150	R 9 188	R 9 227	R 9 265	R 9 304	R 9 342	R 9 381	R 9 421	R 9 460	R 9 499	R 9 539
Total Costs				R 304 588	R 305 325	R 306 065	R 306 809	R 307 555	R 308 305	R 319 371	R 320 127	R 320 886	R 321 649	R 322 415	R 323 184
O&M Costs				R 304 588	R 305 325	R 306 065	R 306 809	R 307 555	R 308 305	R 319 371	R 320 127	R 320 886	R 321 649	R 322 415	R 323 184
Kg Fish sold				12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000
Tunnels in production				12	12	12	12	12	12	12	12	12	12	12	12
Revenue fish		R 32.00 R/kg		R 434 555	R 436 801	R 439 057	R 441 326	R 443 606	R 445 898	R 448 202	R 450 517	R 452 845	R 455 185	R 457 537	R 459 901
Vegetables	Revenue/tunnel/month/m2	R 3 800.00		R 51 603	R 51 870	R 52 138	R 52 407	R 52 678	R 52 950	R 53 224	R 53 499	R 53 775	R 54 053	R 54 332	R 54 613
Nett Cashflow				R 181 570	R 183 345	R 185 130	R 186 924	R 188 729	R 190 543	R 182 055	R 183 890	R 185 734	R 187 589	R 189 454	R 191 329
Cumulative Cashflow				-R 5 765 561	-R 5 582 215	-R 5 397 085	-R 5 210 161	-R 5 021 432	-R 4 830 889	-R 4 648 834	-R 4 464 944	-R 4 279 210	-R 4 091 621	-R 3 902 167	-R 3 710 838

				Year4											
				Month37	Month38	Month39	Month40	Month41	Month42	Month43	Month44	Month45	Month46	Month47	Month48
SA Central Bank Rate		10.50%													
SA PPI				0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%
Compound SA inflation PPI				1.161472231	1.166311699	1.171171331	1.176051212	1.180951425	1.185872056	1.190813189	1.195774911	1.200757307	1.205760462	1.210784464	1.215829399
SA CPI				0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%
Compound inflation SA CPI monthly				1.203845659	1.210065528	1.216317534	1.222601841	1.228918617	1.23526803	1.241650248	1.248065441	1.254513779	1.260995434	1.267510577	1.274059381
Compound inflation SA CPI annual				1.203845659											
Power Inflation				1.560896	1.560896	1.560896	1.560896	1.560896	1.560896	1.81063936	1.81063936	1.81063936	1.81063936	1.81063936	1.81063936
Financial Models Parameters															
Amortisation of Assets		5 years													
Amortisation type	linear														
Tax rate		28%													
Discount Rate (Nominal - before tax)		16.90%													
Discount Rate (Nominal - after tax)		12.17%													
Cashflow				37	38	39	40	41	42	43	44	45	46	47	48
Capital Costs															
Compound Capital				R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00
Mass of fish in system				180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000
Feed Cost		R 9.00 R/kg		R 150 527	R 151 154	R 151 784	R 152 416	R 153 051	R 153 689	R 154 329	R 154 972	R 155 618	R 156 267	R 156 918	R 157 571
FCR		1.20													
O&M Costs															
Labour				R 81 882	R 81 882	R 81 882	R 81 882	R 81 882	R 81 882	R 81 882	R 81 882	R 81 882	R 81 882	R 81 882	R 81 882
Power				R 74 767	R 74 767	R 74 767	R 74 767	R 74 767	R 74 767	R 86 730	R 86 730	R 86 730	R 86 730	R 86 730	R 86 730
Vehicles		R 2.50	7 000.00	R 21 067	R 21 176	R 21 286	R 21 396	R 21 506	R 21 617	R 21 729	R 21 841	R 21 954	R 22 067	R 22 181	R 22 296
Maintenance of system		0.15% %/month		R 9 579	R 9 618	R 9 658	R 9 699	R 9 739	R 9 780	R 9 820	R 9 861	R 9 902	R 9 944	R 9 985	R 10 027
Total Costs				R 337 822	R 338 598	R 339 377	R 340 160	R 340 946	R 341 735	R 354 491	R 355 287	R 356 087	R 356 890	R 357 696	R 358 507
O&M Costs				R 337 822	R 338 598	R 339 377	R 340 160	R 340 946	R 341 735	R 354 491	R 355 287	R 356 087	R 356 890	R 357 696	R 358 507
Kg Fish sold				12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000
Tunnels in production				12	12	12	12	12	12	12	12	12	12	12	12
Revenue fish		R 32.00 R/kg		R 462 277	R 464 665	R 467 066	R 469 479	R 471 905	R 474 343	R 476 794	R 479 257	R 481 733	R 484 222	R 486 724	R 489 239
Vegetables	Revenue/tunnel/month/m2	R 3 800.00		R 54 895	R 55 179	R 55 464	R 55 751	R 56 039	R 56 328	R 56 619	R 56 912	R 57 206	R 57 501	R 57 798	R 58 097
Nett Cashflow				R 179 350	R 181 246	R 183 153	R 185 070	R 186 997	R 188 936	R 178 922	R 180 882	R 182 852	R 184 834	R 186 826	R 188 829
Cumulative Cashflow				-R 3 531 488	-R 3 350 242	-R 3 167 089	-R 2 982 019	-R 2 795 022	-R 2 606 086	-R 2 427 164	-R 2 246 282	-R 2 063 430	-R 1 878 596	-R 1 691 770	-R 1 502 941

				Year5											
				Month49	Month50	Month51	Month52	Month53	Month54	Month55	Month56	Month57	Month58	Month59	Month60
SA Central Bank Rate	10.50%														
SA PPI				0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%	0.42%
Compound SA inflation PPI				1.220895355	1.225982419	1.231090679	1.236220224	1.241371141	1.246543521	1.251737452	1.256953025	1.262190329	1.267449456	1.272730495	1.278033539
SA CPI				0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%	0.52%
Compound inflation SA CPI monthly				1.280642022	1.287258672	1.293909509	1.300594708	1.307314447	1.314068905	1.320858261	1.327682695	1.334542389	1.341437525	1.348368285	1.355334855
Compound inflation SA CPI annual				1.280642022											
Power Inflation				1.81063936	1.81063936	1.81063936	1.81063936	1.81063936	1.81063936	2.100341658	2.100341658	2.100341658	2.100341658	2.100341658	2.100341658
Financial Models Parameters															
Amortisation of Assets		5 years													
Amortisation type	linear														
Tax rate	28%														
Discount Rate (Nominal - before tax)	16.90%														
Discount Rate (Nominal - after tax)	12.17%														
Cashflow				49	50	51	52	53	54	55	56	57	58	59	60
Capital Costs															
Compound Capital				R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00	R 5 497 910.00
Mass of fish in system				180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000	180 000
Feed Cost		R 9.00	R/kg	R 158 228	R 158 887	R 159 549	R 160 214	R 160 882	R 161 552	R 162 225	R 162 901	R 163 580	R 164 261	R 164 946	R 165 633
FCR		1.20													
O&M Costs															
Labour				R 104 862	R 104 862	R 104 862	R 104 862	R 104 862	R 104 862	R 104 862	R 104 862	R 104 862	R 104 862	R 104 862	R 104 862
Power				R 86 730	R 86 730	R 86 730	R 86 730	R 86 730	R 86 730	R 100 607	R 100 607	R 100 607	R 100 607	R 100 607	R 100 607
Vehicles		R 2.50	7 000.00	R 22 411	R 22 527	R 22 643	R 22 760	R 22 878	R 22 996	R 23 115	R 23 234	R 23 354	R 23 475	R 23 596	R 23 718
Maintenance of system		0.15%	%/month	R 10 069	R 10 111	R 10 153	R 10 195	R 10 237	R 10 280	R 10 323	R 10 366	R 10 409	R 10 452	R 10 496	R 10 540
Total Costs				R 382 300	R 383 117	R 383 937	R 384 761	R 385 589	R 386 420	R 401 132	R 401 970	R 402 812	R 403 658	R 404 507	R 405 360
O&M Costs				R 382 300	R 383 117	R 383 937	R 384 761	R 385 589	R 386 420	R 401 132	R 401 970	R 402 812	R 403 658	R 404 507	R 405 360
Kg Fish sold				12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000	12 000
Tunnels in production				12	12	12	12	12	12	12	12	12	12	12	12
Revenue fish		R 32.00	R/kg	R 491 767	R 494 307	R 496 861	R 499 428	R 502 009	R 504 602	R 507 210	R 509 830	R 512 464	R 515 112	R 517 773	R 520 449
Vegetables	Revenue/tunnel/month/m2	R 3 800.00		R 58 397	R 58 699	R 59 002	R 59 307	R 59 614	R 59 922	R 60 231	R 60 542	R 60 855	R 61 170	R 61 486	R 61 803
Nett Cashflow				R 167 864	R 169 890	R 171 926	R 173 974	R 176 033	R 178 104	R 166 309	R 168 402	R 170 507	R 172 624	R 174 752	R 176 892
Cumulative Cashflow				-R 1 335 077	-R 1 165 187	-R 993 261	-R 819 287	-R 643 253	-R 465 150	-R 298 841	-R 130 438	R 40 069	R 212 693	R 387 445	R 564 337

ANNEXURE E - NPV AND IRR CALCULATIONS

Calculation of Net Present Value (NPV)

The following explanation was taken from Goodstein (2011) and Maths is fun (*s.a.*):

1) Calculate the Present Value (PV) of the investment and the cash flows in the years to come. The formula is as follows:

   $PV = FV / (1 + r)^{T}$

   FV: Future Value; r: interest / discount rate: T: number of years

   Note that the initial investment will be a negative number since it is the amount that you will pay to invest.

2) To determine the NPV, add all the amounts together, e.g.:

   $NPV = [-FV / (1 + r)^{0}] + [FV / (1 + r)^{1}] + [FV / (1 + r)^{2}]$

3) An example as per aquaponics system Scenario 3:

   NPV = [R-5 497 910.00 / $(1 + 0.169)^{0}$] + [R -1 495 459.78 / $(1 + 0.169)^{1}$] + [R 1 046 238.78 / $(1 + 0.169)^{2}$] + [R 2 236 293.27 / $(1 + 0.169)^{3}$] + [R 2 207 896.86 / $(1 + 0.169)^{4}$] + [R 2 067 277.88 / $(1 + 0.169)^{5}$]

   THUS,

   NPV = R-5 497 910.00 + R-1 279 264.14 + R 765 599.76 + R 1 399 861.99 + R 1 182 281.07 + R 946 948.37 = R-2 482 482.94

Calculation of Internal Rate of Return (IRR)

4) The IRR is the interest or discount rate that makes the NPV zero. Commonly the guess and check method is used to determine this rate. E.g. if 2.26 % is used (r = 0.0226), then the NPV = 0, saying the investment would earn 2.26%.

ANNEXURE F - PEOPLE INTERVIEWED

Mike Blenkinsop

Mr Blenkinsop has a few ventures that he is involved in, but the most important for this study is that he is the Owner and Director of Sustainable Ecological Fisheries (SEFS) (Pty) Ltd. He is also involved in experiments for ESKOM regarding carbon capturing techniques using algae. Mr Blenkinsop is the one who suggested the study to evaluate aquaponics as a post-mining land use, since he feels it could contribute to Sustainable Development of redundant mining land. He initiated the experimental site and provided all the information he has gathered while trialling the system.

Piet Steenekamp

Mr Steenekamp is a soil specialist focussing on pre-mining soil studies for mining applications. He is experienced in the field and has ample knowledge on soils, land use and land capability and how mines should manage their soils and rehabilitate the area in order to ensure good quality rehabilitation.

Lourens du Plessis

Mr Du Plessis is a mine captain at one of the large coal mines in the Mpumalanga Highveld. He has many years of experience in mining with his special focus being rehabilitation of surface coal mining. Mr Du Plessis is also a part time dairy farmer. He therefore understands what outcome should be reached when mine land is rehabilitated in order to provide a good quality grazing standard.

Dr Mike Mentis

Dr Mentis is a soil specialist mainly focussing on mine rehabilitation. A brief telephone discussion was held with Dr Mentis to understand how he viewed the quality of rehabilitation land in the Mpumalanga Highveld. He also confirmed a few grazing quality indicators and what type of production (meat vs dairy) will be possible on the typical surface coal mining rehabilitation land.

Various mine officials

Due to the confidentiality agreement, the names of the officials that were interviewed cannot be mentioned. Brief references will be made according to the mines' assigned names in this dissertation.

Mine Group A

Mine Group A's official has many years of coal mining experience. Since his own family had a farm, he is passionate about farm land and therefore focuses on the rehabilitation of surface mine land. He understands the difference in quality of grazing land and hence, he aims to re-establish grazing land to a good standard so that the land can be given or sold back to a farmer without any problems.

Mine Group B

The Environmental Manager of the two mines from Group B was interviewed to gain the information required. He used to work for a government department prior to being appointed as an environmental manager at the group. Another official from this mine group, known as an environmental superintendent, also assisted in the information gathering process and was very helpful about the mine groups' practices.

Mine Group C

The person responsible for rehabilitation at Mine C was interviewed to understand the practices at that mining group and to gather the rehabilitation costs as part of this study. The responsible person is an agricultural engineer with many years of experience in environmental management of coal mines. He also grew up on a farm which helped him to understand what is needed to have successful rehabilitation of surface coal mines.