A Techno-Economic Feasibility Study into Aquaponics in South Africa

by
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Declaration

By submitting this thesis/dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

The purpose of this study is to investigate the techno-economic feasibility of operating an aquaponics farm in South Africa. Aquaculture is the fastest-growing type of food production in the world, yet South Africa is lagging behind international efforts to boost the industry.

An independent academic feasibility study on small scale aquaponics farms in South Africa has not been performed before, causing current and prospective farmers to be uncertain about the prospects of the venture.

The study is approached by investigating the aquaculture and aquaponics industry and gathering the relevant information. By investigating other models used to represent aquaculture or aquaponics systems, the required information is gathered in order to build a unique model for the purpose of determining the feasibility of the case study farms.

The model is modified to represent each of the case study farms. The results show that the majority of the farms are not economically viable. A sensitivity analysis provides some insight on how varying certain parameters can affect the performance of the systems.

Using the information gathered in the case studies and research, a near-ideal system is specified in order to establish whether this improved system can be viable whilst taking into account the constraints placed upon aquaponics ventures in South Africa.

The study suggests some recommendations for current and prospective farmers that might improve their chances of succeeding with an aquaponics venture.

The study finds that currently aquaponics in South Africa is hindered by a number of constraints that result in it being a high-risk venture with meagre returns on investment. However, the study shows that if an aquaponics system were designed, built and managed correctly, it could theoretically be an economically viable venture.

The investigation has, in a logical method, provided insight into the viability of operating an aquaponics farm in South Africa.

Opsomming

Die doel van hierdie studie is om die lewensvatbaarheid van akwaponika in Suid-Afrika te ondersoek. Akwakultuur is die tipe voedselproduksie wat die vinnigste groei in die wêreld, maar Suid-Afrika hou nie tred met die internasionale poging om akwakultuur te ontwikkel nie.

‘n Onafhanklike lewensvatbaarheid studie oor kleinskaal akwaponika plase in Suid-Afrika is nog nooit onderneem nie. Dit veroorsaak dat huidige en voornemende akwaponika boere onseker is oor die uitkomste van hulle ondernemings.

Die studie is benader deur die akwaponika en akwakultuur bedrywe te ondersoek, en die relevante inligting te versamel. Deur ander modelle wat gebruik word om akwakultuur en akwaponika sisteme te verteenwoordig te ondersoek, is die nodige inligting versamel om ‘n unieke model te bou wat gebruik word om die lewensvatbaarheid van die gevallestudies te bepaal.

Die model is aangepas om elkeen van die gevallestudies te verteenwoordig. Die resultate wys dat die meerderheid van die gevallestudie plase nie ekonomies lewensvatbaar is nie. ‘n Sensitiwiteitsanaliese gee insig oor hoe spesifieke parameters die prestasie van die sisteme affekteer.

Deur die inligting wat versamel is tydens die gevallestudies en navorsing te gebruik, kan ‘n sisteem gespesifiseer word om te bevestig of hierdie verbeterde sisteem lewensvatbaar kan wees terwyl dit die beperkings waaronder akwaponika sisteme in Suid Afrika geplaas word in ag neem.

Die studie verskaf ‘n paar aanbevelings vir huidige en voornemende boere. Hierdie aanbevelings kan die kanse van sukses van die ondernemings verbeter.

Die studie het gevind dat akwaponika in Suid-Afrika deur ‘n aantal beperkings benadeel word, wat lei tot ‘n situasie waar dit ‘n hoë-risiko onderneming is, met lae opbrengste op die belegging. Maar, die studie wys ook dat as ‘n sisteem korrek ontwerp, bou en bestuur word, dit teoreties ‘n ekonomies lewensvatbare onderneming kan wees.

Die studie het op ‘n logiese wyse insig gegee oor die haalbaarheid van akwaponika in Suid-Afrika.

Contents

Glossary

Aquaculture: The cultivation of aquatic organisms.

Aquaponics: The symbiotic cultivation of plants grown using hydroponics, and aquatic organisms in a recirculating environment.

Hydroponic: The cultivation of plants in a nutrient solution as opposed to soil.

***Oreochromis mossambicus*:** A species of tilapia indigenous to southern Africa.

Recirculating aquaculture system: An aquaculture method that recirculates and re-uses the water in the system.

Sustainable: Capable of being maintained at a steady production level without exhausting natural resources or having a significant effect on the environment.

Techno-economic evaluation: Evaluation of the technical and economic aspects of a project, as well as the relations between the two, to assist research guidance and planning for an organization.

Tilapia: The name given to parts of the species of cichlid fish from the tilapiine cichlid tribe. They are omnivorous sub-tropical fish that are farmed globally.

Trophic level: The level that an organism occupies on the food chain.

Abbreviations

DO: Dissolved oxygen

FAO: Food and agriculture organization of the United Nations

FCR: Feed conversion rate (kg dry feed consumed per kg wet biomass gained)

IRR: Internal rate of return

NFT: Nutrient film technique

NPV: Net present value

RAS: Recirculating aquaculture system

TAN: Total ammonia nitrogen

USA: United States of America

UVI: University of the Virgin Isles

VBA: Visual basic for applications

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1.1 Introduction

The study investigates the feasibility of aquaponics in South Africa. There are a number of aquaponics farms in operation in the Garden Route area, and these farms will be used as case studies for verification purposes.

The produce from the aquaponics systems' aquaculture component are fish, namely tilapia (*Oreochromis mossambicus*), and vegetables and herbs from the hydroponic component of the system. At present, there is no established market, distribution or selling point for tilapia. There is said to be a considerable market for tilapia in South Africa, yet most producers experience great difficulty in selling it (L Ter Morshuizen 2010, pers. comm., 27 Feb). The species of fish is relatively unknown amongst the South African population.

A method of predicting the future prospects or trends of an industry could be to look at the trends that occur in other countries. In the USA, tilapia has risen from almost nowhere to being the fifth most popular aquatic organism consumed by humans (Nicholls 2007) (Appendix A). This has occurred over the past decade. South Africa is lagging behind international efforts to boost aquaculture (Peters 2007), which might imply that a booming increase in tilapia production and demand will occur in the future, with adequate market development.

Global production of all species of tilapia is anticipated to increase from 1.5 million tons in 2003 to 2.5 million tons by 2010, with a sales value of more than R35 billion (FAO 2006).

From a technical perspective, aquaponics is a sustainable food production method. If it were economically viable, a successful aquaponics farm would provide jobs for the surrounding population on the farm itself, as well as in tasks up- and downstream in the supply chain of the farming operation. This has the potential to uplift the surrounding community.

1.2 Background

Integrated aquaculture is a practice in which the by-products of one organism are recycled to become the inputs for another. Recirculating integrated aquaculture systems make maximum use of the resources within the systems, and minimise the release of harmful effluent into the environment.

Aquaculture is viewed as a means to provide high-quality protein for the global population (El-Gayar, Leung 2001).This is essential, as the global fish stocks are being depleted by the increased demand for seafood and by unsustainable fishing practices; Figures 1 and 2 shows the percentage of under-fished, fully fished, and overfished fisheries over time.

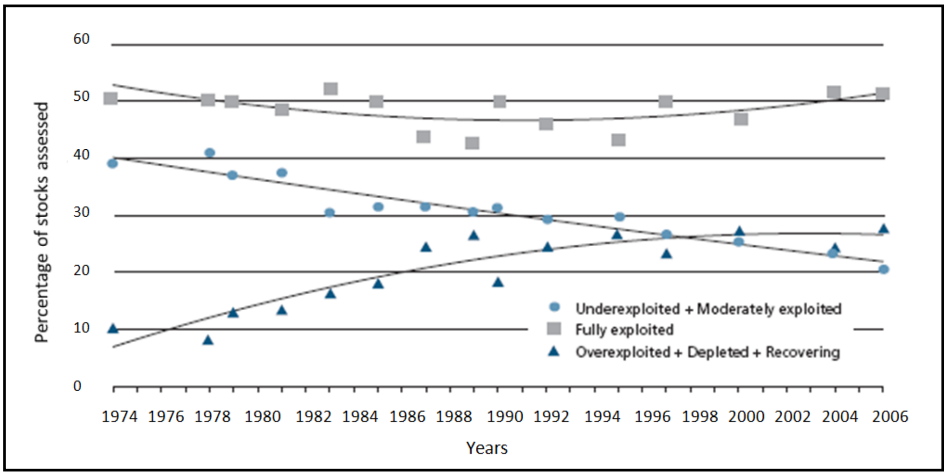

Figure 1 Global trends in the state of world marine stocks since 1974 (FAO 2008)

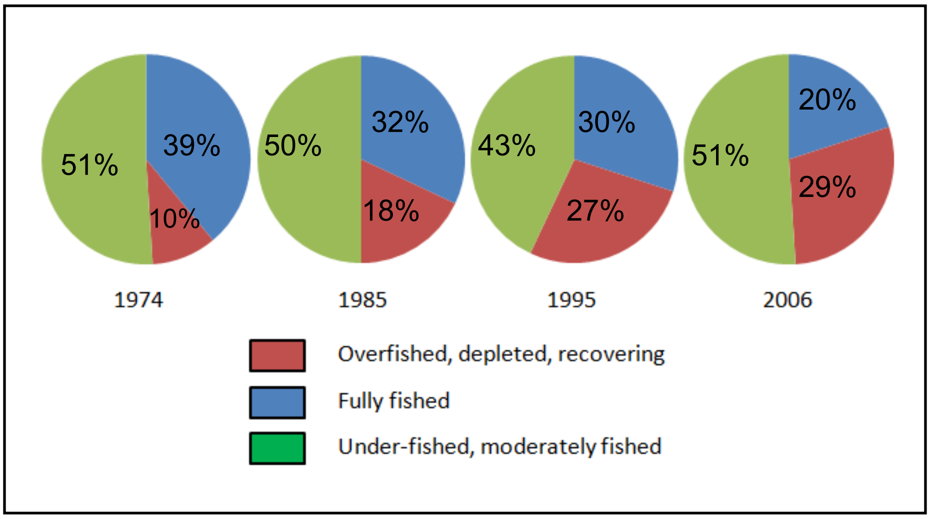

Figure 2 Global trends in the state of world marine stocks as a percentage of stocks assessed

Embarking on an aquaculture venture is a high-risk investment, where the possibility of an unfavourable situation occurring is significant. Start-up failures are very common in aquaculture, and globally only one out of every five aquaculture start-up ventures are in operation after two years (Timmons, Clark 2009). This statistic proves that adequate planning and research should be performed when entering this industry.

Aquaponics is the symbiotic farming of plants and aquatic animals in a recirculating environment (Rakocy, Masser & Losordo 2006) (figure 3). The plants are grown using hydroponics, which is a method where the plants' roots grow in an inert medium, and absorb nutrients from the water (Winterborne 2005). These nutrients come from the fish excretions, as well as the microbial breakdown of organic wastes (Rakocy, Masser & Losordo 2006). As water in the system is recirculated through the hydroponic component of the system, the fish waste metabolites, in the form of ammonia and nitrogen-containing compounds, are removed, thereby making the water suitable for re-use in the aquaculture component (Rakocy, Masser & Losordo 2006).

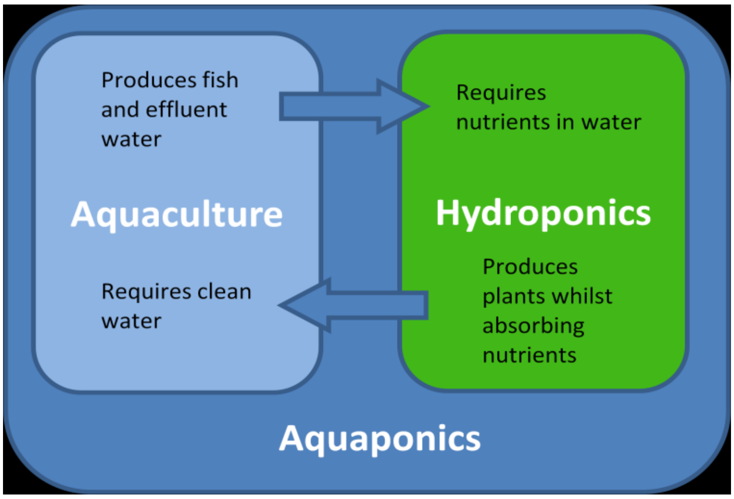

Figure 3 Simple Illustration of the relation between aquaculture, hydroponics, and aquaponics

The combination of operating a recirculating aquaculture system (RAS) and hydroponic system together presents a number of advantages. The hydroponic system acts as a biofilter for the aquaculture component, and in some cases eliminates the need for a separate filter as in conventional RAS's. In conventional hydroponic systems, fertilizers need to be added to the water in order to sustain plant growth. However, in aquaponics systems, the fish waste provides almost all the nutrients needed in order for the plants to grow (Rakocy *et al*. 2003). Water recirculation is increased, thereby prolonging water use and minimising discharge. Less water quality monitoring is required when compared to individual RAS's and hydroponic systems (Rakocy, Masser & Losordo 2006). The shared cost of operation and infrastructure further increases the profit potential. Section 2.6 covers an in-depth discussion on aquaponics and the various components of the system.

This project is undertaken in an attempt to identify avenues to develop the aquaculture industry in South Africa by investigating into aquaponics, which is a method of aquaculture. There are a number of constraints that impede the development of aquaculture in South Africa; this project addresses these constraints, and looks at the potential that exists in this unexploited sector. The constraints are detailed in section 2.4 of the literature study.

For this reason, a techno-economic feasibility study will address the reasons for these failures, and attempt to provide solutions and recommendations to help improve upon these odds.

1.3 Problem statement

There is a need for a techno-economic feasibility model to be developed for small to medium scale aquaponics farms in South Africa. From time to time, situations occur where the readiness of investors to invest in aquaculture outpaces the availability of information needed to make sound decisions concerning system design, construction, management and economics (Rakocy, Hargreaves 1993b). Since aquaponics is a method of aquaculture, this statement applies to aquaponics too. These situations will likely lead to suboptimal investment decisions for both current and prospective aquaponics farmers.

At present, the commercial farming of low-value fish species in South Africa is said to be economically unfeasible (Rana 2009). There are a number of reasons for this state of affairs, which are discussed in the thesis.

The market for farmed fish is not yet readily established in the country, causing a lack in the demand for the product. The South African population is not aware of the benefits of farmed fish (AASA 2009), and furthermore has a negative connotation towards freshwater fish and fish with a silver-black appearance (such as tilapia) (Britz, Lee & Botes 2009).

When deciding on whether or not to embark on an aquaculture venture, the first aspect that should be studied is the predicted future cash flows of the venture (Beckman, Bok 2009). From the information gathered on the case studies in section 4 of this thesis, it is apparent that the farmers who have built these aquaponics systems have not performed their market research thoroughly, and therefore are not certain of the demand for their produce. The information required for decision making when designing, building and operating an aquaponics system should originate from well established facts and / or scientific evidence. It is possible that the farmers are not receiving their information and advice from sources like these, which may well cause incorrect decisions to be made.

1.4 Hypothesis

An investigation and techno-economic model of aquaponics systems can be used to identify and analyse a number of aspects of the cases studies to determine the feasibility of these systems. The model can be used to determine near optimal configurations of aquaponics systems.

1.5 Scope

The study will examine the process of farming tilapia (*O. mossambicus*) and plants using aquaponics on a small to medium scale in South Africa, and look at the main factors that influence the success of such a venture. When known factors are omitted, these omissions are motivated or explained. This study is aimed at identifying and optimising aspects of current systems and using proven technology to do so.

1.6 Methods

An overview of the current state of aquaculture and aquaponics, both globally and in South Africa, will be presented. When studying the industry, a number of information resources are used. Library databases are used in order to gather information on the global and local industry. The attendance of the Aquaculture Association of Southern Africa's Biannual Conference helps to provide information on the latest developments in aquaculture in the region, as well as provide a networking opportunity with relevant people involved in the industry. In addition, structured interviews with people involved in the industry are carried out in order to gather information, as well as verify the relevance of the topic to the development of the industry. A three-day RAS course is attended in order to gather information and learn about this vital component of the system.

After the literature study is performed, the farms in the Garden Route area are visited, and information is gathered on these systems' complete designs, scale, production rates and management practices. This information is used as the "as-is" scenario of the industry in that area.

A model is then designed and implemented in Microsoft Excel using the information gathered from the literature study and case studies. This model and the design methods thereof are described in detail in section 3.

The model mathematically replicates the biological growth of the aquaculture and hydroponic components. Using this, as well as representations of a number of other aspects of the system, the model is then used to calculate the predicted cash flows of the system.

Using the predicted cash flows, a number of financial indicators are calculated to determine the feasibility of the systems at all times over a period of 10 years.

The model is then used to evaluate the current systems as documented in the case studies. The model is adapted to represent a particular case study system. The results of the model will show whether the case study is feasible. This process is repeated for all four case studies.

Since the aquaculture industry is a dynamic one (Britz, Lee & Botes 2009), all of the parameters that could possibly change in the techno-economic model are variable. A sensitivity analysis on these parameters is then performed; this is done to provide insight into the parameters and their effects on the feasibility of the operation. The sensitivity analysis also reveals the risks that the ventures are exposed to.

The results, insights and recommendations of the feasibility study, as well as information gathered from the literature study on aquaponics, are then utilized to design and specify a system that is theoretically more feasible than the current systems in operation.

Research into the seafood market in South Africa and the potential markets for tilapia is undertaken in order to establish the potential price for the aquacultural produce. Vegetables and herbs have a well-established market, and for this reason, little consideration is given to the marketing aspect of these products in this thesis.

2 Literature study

Aquaponics is the combination of aquaculture and hydroponics. Hydroponics is a fairly mature technology, and successful ventures operate worldwide (Carruthers 2002). Aquaculture, and particularly tilapia farming and aquaponics, is a high-risk venture, and the failure of such a venture is a regular occurrence (Timmons, Clark 2009). For this reason, the literature study should focus on the aquaculture component of the system in order to gain the information necessary to deal with this problem.

The history of aquaculture, the characteristics of the species, as well as industry trends in South Africa and elsewhere are some of the aspects that need to be studied in order to perform a comprehensive literature study.

The information on these subjects is obtained from sources that are relevant to the thesis. In cases where it is not possible to obtain the information required from published sources, compromises are made such as using information that is unpublished, or obtaining it from people who rely on personal experience for their information. This is particularly applicable to the assimilation of information for the case studies.

2.1 Aquaculture

Aquaculture, the farming of aquatic organisms, is the fastest growing type of food production in the world (Tidwell, Allan 2001). Nearly 50 % of the fish consumed by humans is farmed (Kourous 2006). Globally the wild fish stocks are declining whilst the demand for fish is constantly increasing, making the prospect of aquaculture increasingly attractive (Peters 2007).

2.1.1 Background of aquaculture

Aquaculture production has existed for thousands of years, and is said to have been practised by the Chinese as far back as 2500 BC (Rabanal 1988). The Japanese, Romans, Central Europeans and Hawaiians also practiced aquaculture at various stages through history (Rabanal 1988). In the past couple of decades, however, aquaculture has boomed significantly (Tidwell, Allan 2001).

2.1.2 Aquaculture in South Africa

Meaningful statistics on the aquaculture industry in South Africa are difficult to obtain. For this reason, the Aquaculture Institute of South Africa performed a nation-wide benchmarking survey on the aquaculture industry in order to gather data. The information in the following section is obtained from this survey (Britz, Lee & Botes 2009).

2.1.2.1 *Production*

The total South African aquaculture production in 2008 was 3654 tons, with a value of R327 million. Analysing these facts in terms of rand value of various aquaculture produce reveals some interesting information. Abalone represents 81 % of the rand value of aquaculture in 2008. Trout production represents a further 8.5 % of the total value of aquaculture in South Africa. The remaining products of significance produced are koi, ornamentals, oysters and mussels. Tilapia production accounts for an almost negligible fraction of the aquaculture industry in South Africa.

2.1.2.2 *Producers*

South African aquaculture enterprises are generally relatively young businesses. Approximately 50 % of organizations are less than 10 years old, and 31 % are less than five years old. Only 20 % of enterprises are older than 20 years.

A large proportion (76 %) of aquaculture enterprises are small businesses with a turnover of less than R5-million. Of the larger enterprises with turnovers of more than R5 million, the majority are marine ventures, producing abalone.

Most of the larger commercial enterprises (with a turnover of more than R5 million per annum) are located in the Western Cape; the small-scale commercial enterprises are distributed more evenly amongst the provinces of South Africa.

Vertical integration, the process by which a number of steps in the production and distribution are controlled by a single entity, is found to occur in the primary production phase in the industry. 68 % of producers operate their own hatcheries, and 75 % of producers raise fry or early juveniles.

Many of the producers are vertically integrated into secondary production activities. Almost half of the producers are involved with the packing and distribution of the product, and 31 % are involved in processing the produce.

The survey confirmed that the seafood market is in a period of transition, with declining supplies of local wild fish, and increasing market share by imported wild and farmed products. There is an opportunity for locally farmed products to gain a greater market share in the fresh high value product markets. It is unlikely that locally cultured products will be competitive in the frozen, commodity type product niches.

There is a growing trend towards pre-cooked, ready-to-eat products in supermarkets which aquaculture producers may be able to exploit.

South African seafood suppliers are buying into the concept of sustainable seafood, and sustainability is becoming important in purchase decisions. Aquaculture products are regarded as potentially sustainable products, although consumers and buyers were aware of some of the negative health and environmental associations with intensively farmed products. Therefore, if the aquaculture industry establishes itself as a credible source of sustainable seafood, this should help to secure market share in the future.

2.2 Tilapia

The species of tilapia considered in this project is *O. mossambicus*, a tropical fresh-water fish that occurs naturally in southern Africa (Grafman, Beckman & Blazek 2010). The *O. mossambicus* species is not one of the faster-growing species of tilapia, but due to a government ban on the farming of alien fish species, this is the species that the aquaponics farmers in South Africa farm with (L De Wet 2010, pers. comm., 27 Jan). More information on the ban is provided in section 2.4. There has been a dramatic increase in the production of *O. mossambicus* tilapia over the past 40 years (FAO 2008). Figure 4 shows the aquacultural production of tilapia *O. mossambicus* over time. There are other species of tilapia that have faster growth rates than *O. Mossambicus* (L De Wet 2010, pers. comm., 27

Jan), and allow the farmers to increase production throughput, thereby providing them with a greater return on their investment.

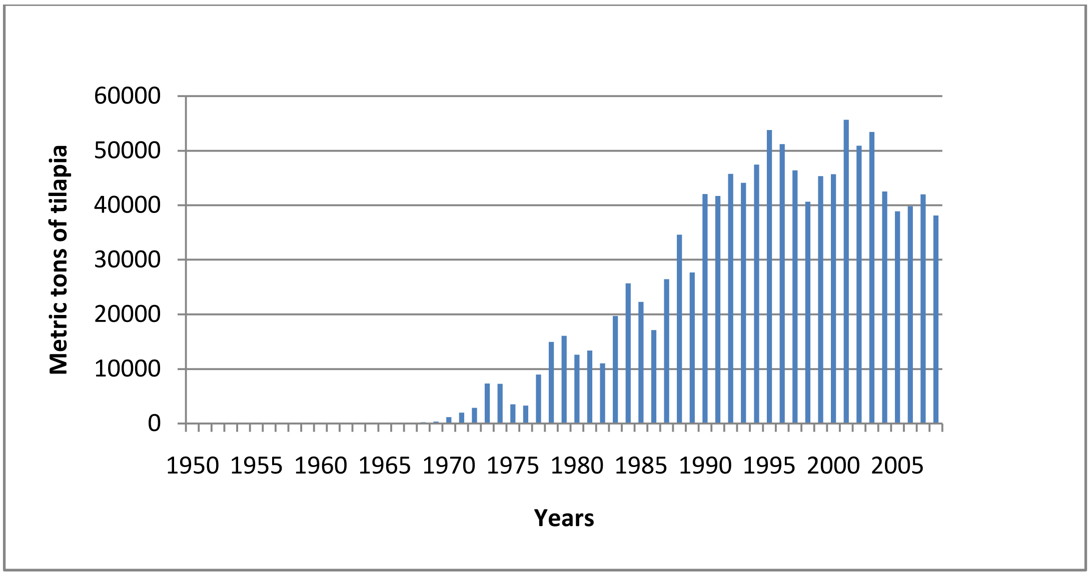

Figure 4 Global production of tilapia *O. mossambicus* (FAO 2008)

The global aquaculture production of tilapia increased steadily between 1998 and 2007 (figure 5).

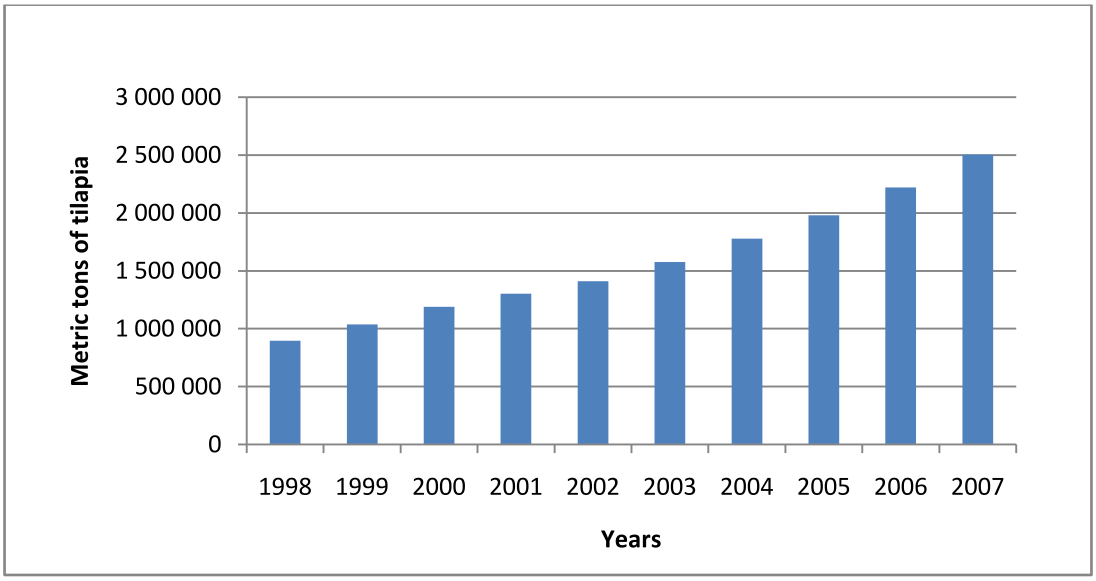

Figure 5 Global production of all tilapia (FAO 2008)

2.2.1 Tilapia characteristics

Tilapia is an omnivorous fresh-water fish. It is highly suited to aquaculture, and history suggests that is was one of the first species of fish cultured by man. Evidence of the culture of the fish species is found in Egyptian tombs that date back to 3000 years ago (Popma, Masser 1999). In recent times, tilapia was chosen for aquaculture as a means of producing cheap protein (Pillay 1990).

There are a number of characteristics that make tilapia attractive for tank culture. It is a hardy fish, breeds readily in almost any type of water body, and because it is omnivorous, it does not require a high percentage of protein in its diet (relative to carnivorous fish species). The species can tolerate the levels of crowding and handling that are required in a RAS. One of the reasons for this is because they have a heavy slime coat that protects them from abrasion and bacterial infection that would affect many other species adversely (DeLong, Losordo & Rakocy 2009). Tilapia grow well when stocked at high densities, and when good water quality is maintained; yet, they are also amazingly tolerant of bad or variable water quality (Popma, Masser 1999).

Tilapia need a smaller percentage protein in their diet, which allows them to be grown on diets that are high in vegetable matter such as soy protein (Shiau, Chuang & Sun 1987). This diet can be sourced in a more renewable and sustainable manner than those containing fish meal and fish oil derived from wild fish catches.

There are a number of biological constraints to the development of commercial tilapia farming. The inability of the species to withstand continued exposure to colder water temperatures is a drawback. Another drawback is that the species reaches sexual maturity at an early stage in the life cycle of the fish, resulting in spawning before the fish reach market size (Popma, Masser 1999). This stunts the growth of the fish, decreasing productivity of an aquaculture operation.

2.2.2 Water quality requirements for tilapia

Tilapia can withstand lower concentrations of dissolved oxygen, and higher concentrations of carbon dioxide, suspended solids and total ammonia nitrogen (TAN) compared to trout (table

1). These parameters are recommended to sustain acceptable growth and reduce stress levels for the fish.

Table 1 Guide to recommended water quality ranges for tilapia and trout (Timmons, Clark 2009)

parameter		tilapia	trout
temperature	°C	24 to 29	10 to 18
oxygen	mg / L	4 to 6	6 to 8
oxygen	mm Hg	90	90
carbon dioxide	mg / L	40 to 50	20 to 30
total suspended solids	mg / L	< 80	< 10
total ammonia nitrogen	mg / L	< 3	< 1
ammonia	mg / L	< 0.6	< 0.02
nitrite	mg / L	< 1	< 0.1
chloride	mg / L	> 200	> 200

For further reading on water quality requirements of tilapia, the following reading is recommended: (DeLong, Losordo & Rakocy 2009).

2.2.3 Breeding of tilapia

Breeding tilapia is a relatively simple procedure. However, to produce a large number of high quality fry regularly, requires greater attention, good quality feed, good broodstock and proper disease control (DeLong, Losordo & Rakocy 2009).

The *O. mossambicus* species of tilapia falls under the category of mouth-brooders, which means that the female tilapia incubates the eggs in her mouth until they hatch (DeLong, Losordo & Rakocy 2009). The breeding process of the fish takes place as follows (DeLong, Losordo & Rakocy 2009). The female lays the eggs on the bottom of the tank, after which the male fertilizers the eggs. The female then picks up the eggs into her mouth and incubates them. After around three to five days, the eggs hatch, and the hatchlings remain in the female's mouth while they absorb their egg-sac. The egg-sac is a membranous sac attached to the hatchling and provides the fish with nutrition in the early stages of its life cycle.

A method that is widely used to better manage the breeding process is to capture the eggs from the female's mouth before they hatch and place them into an artificial incubator (DeLong, Losordo & Rakocy 2009). This can be done by catching the female and removing the eggs from her mouth. Often the female expels the eggs when captured; if the female does not release the eggs, the fish can gently be thrust backwards and forwards in the water to expel the eggs. Figure 6 shows an incubator used by a hatchery in the Garden Route area. There is a gentle upward flow of water in the container so that the eggs are suspended. This prevents fungus from growing on the eggs, and increases the hatch rate. Once the eggs hatch, the hatchlings swim through the overflow at the top of the incubator and into another tank. Once the hatchlings have absorbed their egg sacs they become known as fry. Once a fish has grown to a slightly larger size and resembles a human finger in shape, they are referred to as fingerlings. The full life cycle of tilapia is shown in figure 7.

Figure 6 An incubator containing tilapia eggs

Another way to better control the breeding process is to stock the broodstock in net enclosures called hapas that are suspended in the tanks (DeLong, Losordo & Rakocy 2009). The hapas make it easier to manage and capture the broodstock and hatchlings.

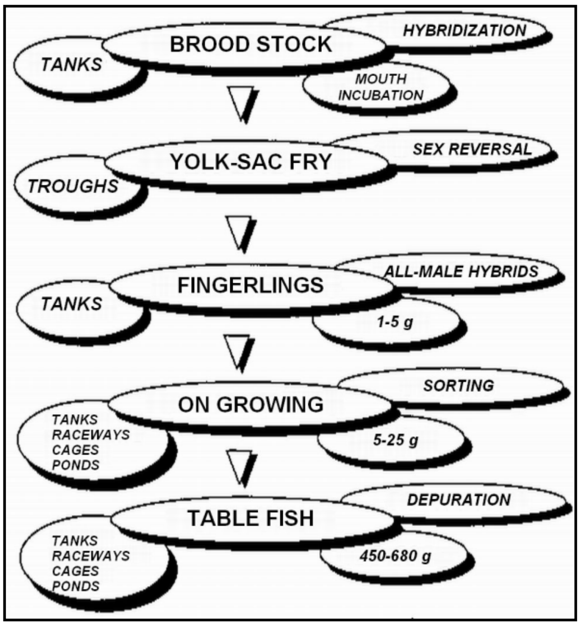

Figure 7 A description of the life cycle of cultured tilapia (Chapman 2000)

2.3 Tilapia farming in South Africa

In South Africa, the market for tilapia is almost non-existent (Britz, Lee & Botes 2009), and subsequently the production thereof is limited.

However, two cases have been found that suggest that the demand for tilapia may be increasing. There is a case in South Africa where a prospective tilapia producer signed a contract with a fishery to buy up their produce for R25 per kilogram whole fish. The fishery would then sell the fish for R39.95 under the names “red snapper” or “bream” (T Georgio 2010, pers. comm., 3 June). A pilot tilapia farm operated in 2008 and produced approximately 10 tons, which was valued at R300 000. This contributed 0.09 % of the total aquaculture value produced that year, and 0.27 % of the tonnage (Britz, Lee & Botes 2009).

The odds are stacked heavily against the entry of small organizations into aquaculture (Britz, Lee & Botes 2009). A number of organizations are not in production any longer, and furthermore a number stated that they were not producing any product at the time of the survey. The main reasons for the organizations not producing anything were because their operations are not financially viable, or there is a regulatory problem that they could not overcome.

Over the past three years, there has been a net exodus of small producers in the industry, juxtaposed with a period of consolidation and expansion of larger producers.

There have been very few small scale entrants into the aquaculture industry, apart from a number of government sponsored small scale farmers.

The majority of the constraints to developing an enterprise relate to the application of environmental legislation and permitting, the lack of coordination between government departments, and compliance with health and product quality standards.

The established medium size enterprises are the backbone of the South African aquaculture industry at present. These organizations have reached a size where they have the critical mass to run vertically integrated operations. These producers are generally optimistic about market prospects for aquaculture products, yet they are very conscious of the dynamic nature of markets which are increasingly influenced by global forces.

2.4 Constraints limiting the development of aquaculture

These constraints need to be taken into account throughout the thesis as they have an effect on the feasibility of the operations. Overlooking any of the constraints, or incorrectly assuming an aspect of a constraint without researching it duly, will likely cause an incorrect result.

2.4.1.1 *Energy constraint*

A reliable source of energy is needed to operate the aquaponics system (Timmons, Ebeling 2007). If the power source is not 100 % reliable, a backup source of power is needed in order to ensure the bio-security of the produce (Timmons, Ebeling 2007). In rural areas where electrical grid power is not available, renewable sources of energy are an option (MacColl 2009). The dilemma with this option is that renewable energies are expensive in terms of initial capital costs, which may prohibit the feasibility of this option (MacColl 2009).

In February 2010, the National Energy Regulator of South Africa (NERSA) approved an average price increase on all tariffs at 24.8 % per year (Eskom 2010). This inflation on the electricity price must be taken into account in the feasibility study.

The heat energy required may also be supplied by wood, oil or coal burners; this is verified by the case studies.

2.4.1.2 *Constraints on aquaculture of tilapia in South Africa*

The following are limitations that hamper the development of tilapia farming in South Africa:

- Species ban: superior species of tilapia, which have higher growth rates, such as the alien *Oreochromis. niloticus* and genetically improved / enhanced species, are banned from being farmed in South Africa because of their potential to adversely affect the natural ecosystem were they to escape into the wild (L De Wet 2010, pers. comm., 27 Jan). Therefore only *O. mossambicus*, a slower-growing species of tilapia, is allowed to be farmed in South Africa. After researching the literature and enquiring from people involved in the aquaculture industry, the author found no cases in South Africa where a permit has been issued for the *O. niloticus* or other alien tilapia species.
- Temperature constraint: Tilapia is a tropical species requiring relatively warm water in order to grow at a suitable rate (DeLong, Losordo & Rakocy 2009, Diver, Rinehart 2006). In South Africa, it is not possible to have water at these temperatures throughout the year without adding heat energy, which increases the cost of production (K Cuthbert 2009, pers. comm., 22 September). Tilapia grows best in the temperature range from 27 to 29 °C, but acceptable growth rates are reported between 25 and 32 °C (DeLong, Losordo & Rakocy 2009). Moreover, temperatures in the extreme upper range cause it to become more challenging to maintain acceptable dissolved oxygen concentration levels in the water (DeLong, Losordo & Rakocy 2009). Temperatures between 10 and 16 °C will stress the fish, reduce feeding behaviour, and make the fish more vulnerable to disease. Large variations in temperature also cause stress for the fish (Timmons, Clark 2009). For this reason, temperatures should remain constant, and should remain within the correct temperature range.
- Ensuring a reliable market for the produce of the operation is a critical aspect of any production industry (Gegner, Rinehart 2006). Therefore, the amount of attention given to marketing and other business aspects is one of the keys to success of commercial tilapia farming (Gupta, Acosta 2004). However, market evaluations are rarely undertaken by the farmers themselves because of the time, expense and difficulty of obtaining the cooperation of wholesalers and retailers (Watanabe *et al*. 1997).

- It has been found that a food-production facility in a greenhouse environment may not be successful unless it is in a speciality market such as culinary or medicinal herb (Gladon 2008). Niche marketing is the key to success for most private sector aquaponics operations (Nerrie *et al*. 2004).

2.4.2 Recommendations to promote aquaculture

The most significant constraints to enterprise development of freshwater aquaculture users in South Africa are (Britz, Lee & Botes 2009):

- environmental regulatory requirements;
- site selection;
- permitting; and
- access to finance.

The promotion of South African aquaculture products is another recommendation. Access to skilled labour as well as research and development are also viewed as constraints hampering development (Britz, Lee & Botes 2009).

Freshwater aquaculture producers currently operating in the industry have rated the following issues as extremely important government interventions to promote the aquaculture industry (Britz, Lee & Botes 2009):

- research, technology development and transfer;
- facilitation of access to finance;
- national policy, strategic plan and implementation plan for the sector;
- promotion of South African aquaculture;
- identify and zone areas for aquaculture development;
- promotion of best practice management;
- promotion of trade in aquaculture products;
- capacity to monitor and guarantee the safety of the aquaculture products; and
- promotion of aquaculture education, training and skills development.

The respondents of the benchmarking survey are predominantly not tilapia farmers, but the findings are noteworthy nonetheless.

2.4.3 Consumer and seafood industry

A brief study of the current state of the consumer and seafood industry in South Africa could uncover some aspects that are of interest to the study.

The aforementioned survey revealed some facts that have implications on the development of aquaculture (Britz, Lee & Botes 2009).

- Seafood consumers in South Africa lack awareness of aquaculture. A surprisingly high 85 % of consumers have not heard of aquaculture, and do not know the difference between wild and farmed aquaculture products. If given the choice between wild and farmed products, they would choose the wild produce, as it is perceived to be more “natural”.
- Consumer buying choices are not strongly influenced by religion and culture, but race and geographic location did.
- The consumers in the Western Cape Province displayed the greatest awareness of aquaculture.
- In general, South African consumers are conservative in their seafood choices. They tend to stick to what they know. This is a problem because the South African population is somewhat unfamiliar with tilapia.
- Consumers who are better educated were more aware of what aquaculture was. They also purchased a greater variety of seafood, including sushi.
- Consumers would like to get more information the products they purchase, such as whether they were farmed or imported. Consumers indicated a preference for local seafood products.

The following points relate to the seafood buyers in South Africa (Britz, Lee & Botes 2009).

- Seafood buyers for restaurants, wholesalers, and supermarkets, are familiar with aquaculture products and their positive product characteristics. The buyers expected a larger percentage of the market to be supplied by aquaculture products in the future.
- Buyers do not distinguish between aquaculture and wild products when deciding upon a purchase, but rather on the basis of required product characteristics, namely:

quality, freshness, availability, appearance and price. Generally, the buyers do not inform the customer whether a product is of wild or farmed origin.

- Restaurants and wholesale seafood outlets feature more aquaculture products than supermarkets. The latter sell mainly frozen, wild seafood products, primarily salmon, prawns and mussels.
- Seafood buyers indicated that the supply of certain wild seafood products such as fresh tuna and linefish was becoming increasingly limited.
- Restaurant and seafood wholesale buyers have indicated that they would purchase more aquaculture products, and particularly fresh products, if they were available.
- Seafood buyers are aware of the sustainability issues in the seafood and fishing industry, and generally supported awareness and labelling schemes such as the World Wildlife Fund's Sustainable Seafood Initiative, as well as the Marine Stewardship Council certification in their purchase choices. Aquaculture products are perceived as a potentially sustainable supply of seafood.

This section shows that the aquaculture industry is showing signs that it will grow in the future. It would appear that the image of aquaculture should be promoted in order to increase the awareness of the benefits thereof.

2.4.4 Commercial scale vs. small scale aquaponics

Aquaponics systems, or any relatively intensive aquaculture operation with a high productivity relative to the area used by the operation, are capital intensive ventures (Timmons, Clark 2009). Economies of scale occur in industries with high capital costs. This implies that any aquaponics venture should be done on a large-scale in order to maximise the efficiency of the operation.

However, according to Nerrie *et al*. (2004), small and medium scale aquaponics RAS are showing promise. The reasons for the increasing interest by farmers are food safety issues, farm diversification, labour efficiency and facility utilization.

The growth of aquaponics is mired by a lack of marketing and applied research, the availability of inputs, and the intensity of management (Nerrie *et al*. 2004). This thesis addresses one of the constraints that are placed on aquaponics, namely the lack of applied research.

2.4.5 Marketing of a niche product

The South African population is relatively unfamiliar with the tilapia species. They are conservative with their choice of seafood, furthermore decreasing their inclination to buy tilapia (Britz, Lee & Botes 2009). Therefore, the marketing of tilapia should be addressed.

In order for a niche marketing aquaculture enterprise to be successful, it will need to enter markets that are not in direct competition with larger-scale aquaculture (Gegner, Rinehart 2006). There are no large-scale tilapia aquaculture enterprises in operation in South Africa; however, the small scale tilapia farmers should not try to market their product in direct competition with other fish types such as hake. These fish sell for lower prices and the farmers would not be able to generate a profit from their operations. In order to demand a price premium for a product, a niche marketing approach should be used. A disadvantage of niche marketing is that considerable time must be spent analyzing and developing these markets (Gegner, Rinehart 2006).

It is important to identify a reliable market, and even a backup market (Gegner, Rinehart 2006). (T Georgio 2010, pers. comm., 3 June) recommends that signed contracts stipulating the terms of purchase for the farmed produce be arranged with buyers before an aquaculture venture is embarked upon.

2.5 Methods of aquaculture

The technology used and the design of an aquaculture system varies for different methods of producing fish. The following section discusses the various methods of growing fish, in order to illustrate how aquaponics relates to these methods. These methods are categorised as pond culture, cage culture, raceways and RAS.

Pond culture makes use of open earth ponds in which to grow the fish. This method is usually practiced on an extensive basis in terms of land utilization. Stocking densities are relatively low, and input costs are minimised. The fish may or may not be fed, as the ponds sometimes provide enough nutrients to sustain suitable fish growth.

Cage culture involves growing fish in a mesh or wire structure in an open water body. The fish are fed, and capital costs required are higher than in pond culture.

Raceways are another method of producing fish, where the fish are held in rectangular structures, with fresh water entering from one side, and leaving through the other. This allows the fish to be stocked at higher densities, increasing productivity. Raceways are normally open systems, with no filtration. These systems also require a higher capital cost, and operating costs are moderate as the fish are provided with feed.

RASs are more technologically advanced than pond, cage or raceway systems. These systems require a high capital cost, as the water is filtered and re-used, requiring the use of pumps and other accessories. These systems allow the fish to be stocked at high densities, which provides a higher income relative to the space used by the system.

Aquaponics falls into the category of RAS. The high capital cost of such systems requires that the systems be operated at near-maximum efficiency in order to generate sufficient income to repay the initial costs (Rakocy, Masser & Losordo 2006). Operating a system at near-maximum efficiency means that the system is operating at the level where the risk is the highest (Masser, Rakocy & Losordo 1999). The feasibility section of the study examines the risks that the systems are exposed by performing a sensitivity analysis.

2.6 Aquaponics

The section discusses the development of aquaponics, from its initial inception in ancient times, to the current cutting-edge of research and technology. The components of an aquaponics system are considered, and some aspects are discussed when considering the design, construction and management of an aquaponics system.

2.6.1 Development of aquaponics

Long before the term “aquaponics” was coined, ancient people made use of the symbiotic relationship between fish and plants. The Aztec Indians raised plants on rafts on the surface of a lake circa 1000 AD (Jones 2002). The Chinese also made use of integrated farming by constructing so-called flow-though systems, as explained below (Meux 2010). They would grow livestock and poultry in cages suspended above ponds. The animal droppings, as well as spilled food, would then fall through the cage and into the pond, where they would grow carp. The water would then flow to another pond where a hardier species like catfish would be grown. The fish consume the nutrients that are not utilized by the livestock. Finally the water, which is now rich in nutrients suitable for plant growth from the fish faeces and urine, would be used to irrigate rice paddies. The sludge that accumulates at the bottom of the ponds was also used for fertilizing rice paddies.

The concept behind aquaponics is that the efficiency of the utilization of input products is increased by using the so-called waste products of one trophic level to feed another trophic level of growing organisms.

In the past 40 years, much research has been done and progress made in RAS (Jones 2001). The benefit of RAS compared to traditional pond aquaculture is that large quantities of fish can be produced using a fraction of the water and space that traditional aquaculture uses.

The most notable research in aquaponics has been done at the Aqricultural Experimentation Station at the University of the Virgin Isles (UVI), St. Croix (Jones 2001). Dr. James Rakocy is the director of the station, and is credited as being the world leader in freshwater aquaponics science and technology (Wilson 2005). Dr. Rakocy's research, as well as that of the UVI, is referred to a number of times in this thesis.

2.6.2 Components of an aquaponics system

An aquaponics system is similar to a conventional RAS in a few aspects. Normal RASs have a rearing tank containing the fish, and a recirculating component where the water is treated. In aquaponics, this recirculating system incorporates the hydroponic component. This is illustrated by examining the components of an aquaponics system. These essential elements are (Rakocy, Masser & Losordo 2006):

- the fish-rearing tank;
- settleable solids and suspended solids removal component;
- biofilter;
- hydroponic component; and
- sump.

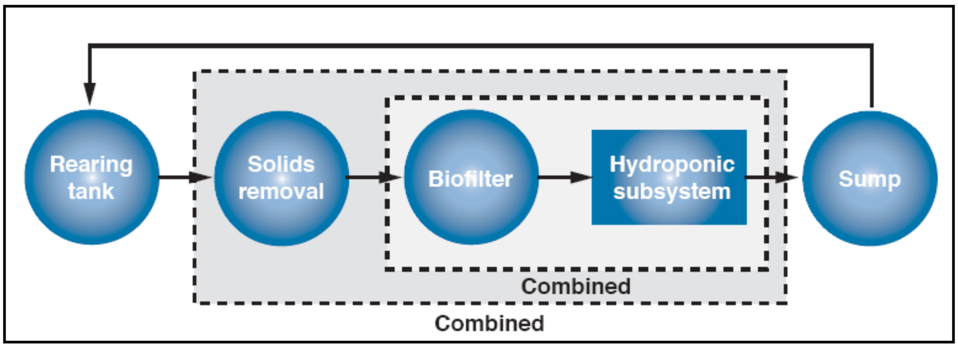

Figure 8 A typical arrangement of aquaponics system components (Rakocy, Masser & Losordo 2006)

Some designs combine the biofilter and hydroponic subsystem as one unit (figure 8). This can be accomplished in a variety of ways. Using gravel as the growing media for the hydroponic component provides a sufficiently large amount of surface area for beneficial bacteria to grow on. Another way to combine the two components when utilizing raft hydroponics is to design the hydroponic component sufficiently large that there is enough surface area for biofiltration to take place (Rakocy, Masser & Losordo 2006). Combining these two components is a desirable goal as it eliminates the need to construct a separate biofilter. This is one of the key advantages of aquaponics over separate RASs and hydroponics systems.

The combination of the solids removal, biofiltration and the hydroponic subsystem components is shown in figure 8. Care must be taken in designing systems in such a way, as solids capture is an important aspect of RASs. Solids capture and the significance thereof is discussed further in the next section.

The effluent water produced by the aquaculture component of the system has a higher concentration of organic matter (Rakocy, Masser & Losordo 2006). This water must be treated and the amount of organic matter reduced, to sustain an acceptable water quality. This is accomplished by the recirculating action of the water in the aquaponic system.

The water then flows to the hydroponic component of the system, where dissolved nutrients are absorbed by the plants. This reduces the concentration of nitrates and other nutrients, effectively cleaning the water for re-use in the aquaculture component of the system (Diver, Rinehart 2006). From there the water typically flows into a sump and is pumped back into the fish-rearing tank.

2.6.3 Solids capture

Solids capture is the component of a RAS that reduces the concentration of total solids in the system. Solids capture is a key component of RAS, as the accumulation of solids in a system decreases the water quality and can subsequently cause catastrophic failure of the system. In conventional RAS, solids removal is the key to a well-designed system, as it makes it easier to control other water quality parameters (Timmons, Clark 2009). This statement is applicable to aquaponics too, as the accumulated organic matter deteriorates the water quality because it decomposes, consuming oxygen.

The selection of the most appropriate solids capture device depends on the organic loading rate (the daily feed input and faeces production of the fish), as well as on the size of the plant growing area. If a larger aquaculture component relative to the plant growing area is designed, a highly efficient solids removal device is needed. Conversely, if a smaller aquaculture component area is used relative to the plant growing area, it may be unnecessary to use a solids capture device. It is, however, still important to ensure that solids do not build up in the fish-rearing tanks.

The mineralization process should be taken into account when selecting a solids capture device. Some accumulation of solids in the system may be beneficial, as when the solids are decomposed by micro-organisms, inorganic nutrients essential to the plants' growth are released (Rakocy, Masser & Losordo 2006). This decomposition process is known as mineralisation.

2.6.4 Biofiltration

The information in the following section is obtained from a textbook which is widely accepted as the leading resource for information on RAS (Timmons, Ebeling 2007).

2.6.4.1 *Background*

Biofiltration is a method of transforming harmful organic compounds into useful ones through the use of microbiological activity.

Fish expel various nitrogenous waste products through gill diffusion, gill cat-ion exchange, urine and faeces. In RAS, this ammonia must be broken down in order to prevent it from accumulating to toxic levels for fish.

Biological filtration is an effective way of controlling ammonia levels in RAS. There are two groups of bacteria that collectively perform nitrification. Nitrification is a two-step process where ammonia is first oxidised to nitrite and then nitrite is oxidised to nitrate. The steps are normally carried out sequentially.

Ammonia oxidising bacteria obtain their energy from catabolising un-ionised ammonia to nitrate, and are commonly known as *Nitrosomonas* spp. bacteria. The chemical reaction takes place as follows:

$$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2O \qquad (1)$$

Nitrite oxidising bacteria oxidise nitrite to nitrate, and are commonly known as *Nitrobacter* spp. bacteria. This reaction takes place as follows:

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \qquad (2)$$

The overall reaction is shown below.

$$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2\ H^+ + H_2O \qquad (3)$$

In biofilters, these beneficial bacteria co-exist with heterotrophic micro-organisms which metabolise biologically degradable organic compounds. These heterotrophic bacteria grow significantly faster than the nitrifying bacteria and will prevail over them in competition for space and oxygen given the opportunity. This will occur if the concentration of dissolved and particulate organic matter is high; in order to prevent this from happening, the source water for the biofilter should be as clean as possible, with a minimal concentration of total solids.

As part of the chemical reaction of nitrification, the following is applicable: for every gram (1g) of ammonia nitrified, 4.57g of oxygen is required, and 7.05g $CaCO_3$ is required. As shown, nitrification consumes oxygen, as well as alkalinity. In other words, nitrification is an acid-forming chemical process, so if the alkalinity is not maintained, the pH in the biofilter will decline, and affect biofilter performance. A rule of thumb is to add 0.25kg baking soda (alkaline) for every 1kg of feed added into the system.

2.6.4.2 *Ideal biofilter characteristics*

There are a number of different biofilter designs, each with their respective advantages and disadvantages. The ideal biofilter, however, according to RAS principles would have the following properties:

- maximise media specific surface area;
- remove 100 % of inlet ammonia concentration;
- generate minimal nitrite;
- maximise oxygen transfer;
- require a relatively small footprint;
- use inexpensive media;
- have minimal headloss;
- require minimal maintenance; and
- does not capture solids.

The advantages that are most beneficial to the system should be addressed when designing the system. In aquaponics, the footprint of the biofilter unit does not have to be minimised, because the hydroponic growbeds can be used as the biofilter. The media specific surface area also doesn't have to be maximised, as space is not a critical consideration. The performance properties of the biofilter remain applicable though, but the elimination of the two above-mentioned properties makes it easier to design the unit.

The performance of a biofilter can be quantified by the amount of total ammonia nitrogen (TAN) can be converted into nitrate. The unit grams TAN converted per square metre of biofilter per day (grams TAN/m^2.day) is used to rate the performance of biofilters. Although the TAN removal rate is actually proportional to the amount of surface area available for bacterial growth in the biofilter, the removal rates are expressed in a per unit volume basis, due to the difficulty in measuring the media's actual surface area.

2.6.4.3 *Biofiltration design*

The design of biofilters is a complicated process; this section will look at the important factors to be taken into account.

The biofilter should be designed such that a balance is struck between minimising the capital costs, operating costs, and risk management, whilst optimising productivity and profitability (Timmons, Ebeling 2007). There are a number of constraints that affect the design of a biofilter, and which must be taken into account when designing one. The pre-determined constraints that are used in the Excel model when calculating biofiltration include the following:

- system volume;
- maximum standing crop (culture density);
- maximum and average daily feed rate; and
- temperature;

There are various other constraints that have an influence on these constraints (e.g. final weight of the fish harvested affects the maximum feed rate), and these are calculated accordingly.

The aquaponics systems studied in this thesis do not compete on a large commercial scale. Therefore, the design of the biofilter is less critical than those of a commercial RAS farm (Timmons, Ebeling 2007). The reason for this is that for small farms, the biofilter component can be over-designed and the added cost should not be of critical importance to the overall economic success of the system. Smaller operations such as those considered in this thesis target niche markets, and therefore do not have to compete in the wholesale market where margins can be extremely small relative to niche markets.

In biofilters, the oxidation process from ammonia to nitrite and nitrate requires certain levels of oxygen in the influent water for the process to take place. The process consumes the oxygen according to equation 3 in (section 2.6.4.1).

In order to design the biofilter requirements, the following steps should be followed (Timmons, Ebeling 2007):

- calculate dissolved oxygen requirements;
- calculate water flow requirement for fish dissolved oxygen demand;
- calculate TAN production by fish;
- calculate surface area of media required to remove TAN;
- hence calculate volume of media, dependant on media type; and
- calculate biofilter cross-sectional area, depth and volume required.

The final calculation in the steps above is impractical to perform in the cases considered in this thesis. This is because the aquaponics systems do not use separate biofilters as in conventional RASs. The flow rates are, however, calculated to ensure that the biofiltration component is suitable for the production rates specified in the cases.

In aquaponics systems, a favourable situation would be for the hydroponic component of the system to serve as the biofiltration component as well (Timmons, Ebeling 2007). This can be done if the ratio of the aquaculture component and hydroponic component are designed appropriately. Once again solids capture is a critical component, as the clogging of media such as gravel has far-reaching implications and requires a large amount of labour to clean up. In severe cases where the gravel media is clogged, the hydroponic component actually produces ammonia as opposed to removing it, as a result of organic matter decaying.

The potential of a highly unfavourable situation occurring as a result of biofiltration failure necessitates that the biofiltration component of the system be designed accurately, and that a safety factor be used to provide additional robustness for unforeseen circumstances.

Biofilter design calculations for the case studies are performed in section 3.3.4.

2.6.5 Hydroponic component

The information in the following section is obtained from (Rakocy, Masser & Losordo 2006, Diver, Rinehart 2006). There are a number of different methods of hydroponic cultivation. The hydroponic component of an aquaponics system can be constructed in a number of ways. The two main types of hydroponics are medium culture and solution culture.

Medium culture uses an inert medium such as gravel or expanded clay in which the plants' roots grow. Typically, the system is operated on a reciprocating mode, where the growbed is flooded with nutrient-rich water, and the plants absorb the nutrients through its roots. The growbed is then slowly drained for a period, to ensure adequate aeration of the plants' roots.

Solution culture is a method where the plants' are suspended into a body of water where they absorb nutrients. It is categorised into static solution culture and continuous flow solution culture. The static solution flow method widely used in aquaponics is known as raft hydroponics. A number of rafts are floated on a water body known as a growbed. Seedlings are planted into net pots which are placed into holes in the raft. The plants' roots grow in the culture water, while the canopy grows above the raft surface. The water is aerated using airstones to increase the oxygen concentration in the water.

The continuous flow solution culture method of interest in aquaponics is called Nutrient film Technique. This method consists of a number of narrow troughs, in which the plants' roots are exposed to a thin film of water flowing through the troughs. The plants' roots are provided with water, nutrients and oxygen in this manner.

The design of the aquaponics system determines whether the plants will need additional nutrients to be added to the system in order to sustain satisfactory growth. For maximum growth, plants in aquaponics systems require 16 essential nutrients. The design of the system will dictate how much solids are retained and can be broken down in the mineralization process, thereby releasing essential inorganic nutrients. If the solids capture component is too efficient, the plants may require additional nutrients.

2.6.6 Stock management

There are a number of methods to manage fish stocks. The ponds can be stocked with fingerlings at low densities (kg/$m^{3)}$, and the fish grow to market size in the same tank. Alternatively, the fish can be transferred into larger tanks, and the number of fish reduced so that the average stocking density of the ponds is higher during a higher proportion of the grow-out period. The latter method makes the most efficient use of space and equipment. Additionally, in aquaponics, designing the system such that it produces a stable production of nutrients is beneficial to the hydroponic component of the system. The disadvantage of the latter method (transferring the fish to larger tanks at various stages) is that more tanks are needed in the system, requiring additional plumbing, as well as monitoring and pumping of the water. Another method of stock management is to periodically harvest a pond and remove the fish that have reached harvest size. A number of fingerlings can then be added to the existing stock. This method makes it very difficult to manage the fish stock, and does not remove slower-growing fish, thereby decreasing productivity.

2.6.7 Support components

Farms such as those considered in this thesis operate on such a small scale that it is often not affordable, nor is it necessary, to have the type of support components used in large-scale commercial units. Nonetheless, it is good practice to have dedicated spaces set aside for things like laboratory equipment, feed, chemicals, and equipment storage. Backup power is an important aspect of RAS, and without it, the system is solely dependent on the national grid power supply.

The following are recommendations for support components for a RAS (Timmons, Clark 2009):

- water quality testing equipment
- storage for feed, chemicals, products
- equipment storage
- staff support
- back-up generator
- quarantine area
- waste disposal

2.7 Observations from the literature study

From the literature study, a number of general trends are noted and discussed in this section. Aquaculture is an industry that is developing rapidly globally. It addresses a number of problems with the past and current methods of fish production, such as the depletion of fish stocks in the world's oceans, as well as the issue of food security.

In theory, aquaponics is an attractive prospect, due to the advantages it presents over conventional aquaculture. The environment can be controlled, effluent is minimised, subsidiary incomes are generated, infrastructure can be shared and labour reduced.

It is noted that South Africa is lagging behind the international trend to develop aquaculture. This might suggest that the prospect of aquaponics is very promising.

However, it was observed that tilapia farming in South Africa is almost non-existent. The constraints of aquaculture and tilapia in South Africa reveal that it is a difficult industry to enter successfully. A number of aspects need to be addressed, including the feasibility of the operations, determining a market for the produce, and overcoming the constraints that hinder a potential venture.

Owing to the type of aquaculture production type that aquaponics falls under, it features relatively high capital and operational costs, thereby requiring near-maximum productivity in order to regain the capital costs. This high productivity increases the risk of the operation, and necessitates that this aspect be addressed.

2.8 Feasibility models of interest in the literature

This section investigates the research that is available in the literature in order to do a feasibility study on an aquaculture or aquaponics system.

2.8.1 Current models

There are a few models available that can be used to help determine the feasibility of an aquaculture or aquaponics venture. Spreadsheets are often used to perform the calculations.

2.8.1.1 ***RAS course model*** (Timmons, Clark 2009)

This model is designed to assist in performing “matchbox” calculations on RASs. The model does not go into a great deal of detail on the daily growth of the fish, nor does it look at the financial aspect of the system. The model is designed to help with the design and feasibility calculations of large-scale intensive RAS. The same costs and economies of scale do not apply to smaller-scale aquaponics systems such as those studied in the case studies. The authors themselves warn that even though every effort has been made from their part to ensure that the calculations are correct, they recommend that all the calculations be re-done by hand before using their model to base decisions on.

This model is therefore not suitable for the purpose of determining the feasibility of aquaponics farms. Nevertheless, it is a useful model from which to reference a number of calculations. This model is used a number of times in the making of the feasibility model in this thesis.

2.8.1.2 ***Southern Region Aquaculture Center "Economics of Recirculating Systems" spreadsheet*** (Dunning, Losordo & Hobbs 1998)

This model is similar to the previous model since it makes a number of assumptions on behalf of the user, and it is not possible to modify the model enough to incorporate the scenarios of the case studies. The authors of this particular model concede that there is no single correct way to design an aquaculture system. For this reason, it is not possible to design a single model that can be applied to all aquaculture ventures.

As a result of the model making a number of assumptions, the model becomes too simple. The input data is simply entered in the sheet, then views the summary of the annual costs and returns to the system further down. This is not sufficient for the purpose of determining the feasibility of a number of fairly complex aquaponics systems.

2.8.1.3 ***Model from Lawrence*** (G Lawrence 2010, pers. comm., 12 April)

The model from Lawrence includes the required degree of complexity necessary to determine the feasibility of the aquaponics systems. The problem with the model is that it is not designed such that it can be used to determine the feasibility of an existing system. The model is designed such that it can be used it to specify a new aquaculture facility based on a predetermined amount of output that is to be produced. The model also lacks the ability to modify a number of the design parameters.

As a result of the model being designed for the purpose of specifying a new farming operation, and not to determine the feasibility of existing farms, the model is not suitable for the purposes of this thesis. It is, however, the most comprehensive model found by the author.

2.8.1.4 ***Aquaponics in conjunction with ethanol plants model*** (Hansen, Hardy 2008)

The model used in this case has the appropriate amount of detail on the growth rates, production and financials, and aspects of it are used in this thesis' model. The scale of the project is not the same as those in this project, and changes must be made in that respect. The structure of the model is also useful for the purpose of replicating it in this thesis' model.

2.8.2 Results from investigating other feasibility models

Research into the possibility of using other models for the purpose of determining the feasibility of the case study farms concludes that it is not possible to take an existing model and modify it to suit the needs of this thesis. Aquaculture and aquaponics systems are unique, and therefore a unique model must be designed for these case studies. The research uncovered a number of different methods for building models, and assisted the author in designing the model for this thesis.

3 The feasibility model

The purpose of the model is to determine the feasibility of the case study farms.

3.1 Methods used in designing model

After researching the various models available in the literature, the decision was made to design a unique model. This model can then be modified to mimic the individual case studies. Using selected aspects from a number of models, a model is designed that is most suitable to the environment and situation in which the cases are found.

The initial model was designed and implemented on a large number of Excel spreadsheets, and Visual Basic for Applications (VBA) programming was used to calculate a number of steps in the modelling process. The calculations became more and more complex, and the time taken to recalculate the model after changing any of the input parameters (on a fast computer with a quad core processor) was in excess of 25 minutes. This would have placed a time constraint on the sensitivity analysis, and would require that a number of computers be used in order to perform the sensitivity analysis.

The help of an expert mathematical- and financial model builder (M Lapere 2010, pers. comm., 8 Aug) was acquired in order to verify that the model was in fact working, and that the output values were correct. The author and the model builder began performing some small verification calculations on another excel sheet, and it was found that some of the calculations that were programmed using VBA could be replicated on the Excel sheets by manipulating some values to arrive at the same results. The consequence of doing this is that the new model can compute the calculations in a fraction of the time that it took with the initial model.

This advantage also makes the model suitable for use as a management tool by the farmers themselves. The input parameters of the revised version of the model are also completely variable, making the model highly flexible, allowing the author to perform a sensitivity analysis.

The original model is still valuable as it uses a complicated step-by-step process to derive the necessary values; therefore, more information is available at any point in time. The original model also helped to make the new model more efficient, as it only becomes evident after building a model which data is necessary and which is simply nice to have in order to perform verification checks. The outline for the old feasibility model is attached in Appendix B (figure 66).

3.2 Model overview

The flow diagram (Figure 9) below is a representation of the structure of the model designed in this thesis.

Each entity has some input data, as well as a number of logical calculations associated with it. The entities are discussed in separate sections, where the reasons for the individual input parameters and calculations are motivated and referenced. The arrows in the figure represent the flow of data from one entity to the next. This structure helps to represent each aspect of the model separately, to demystify the model.

The model is designed such that the inputs are stored in one location to prevent confusion and accidental errors.

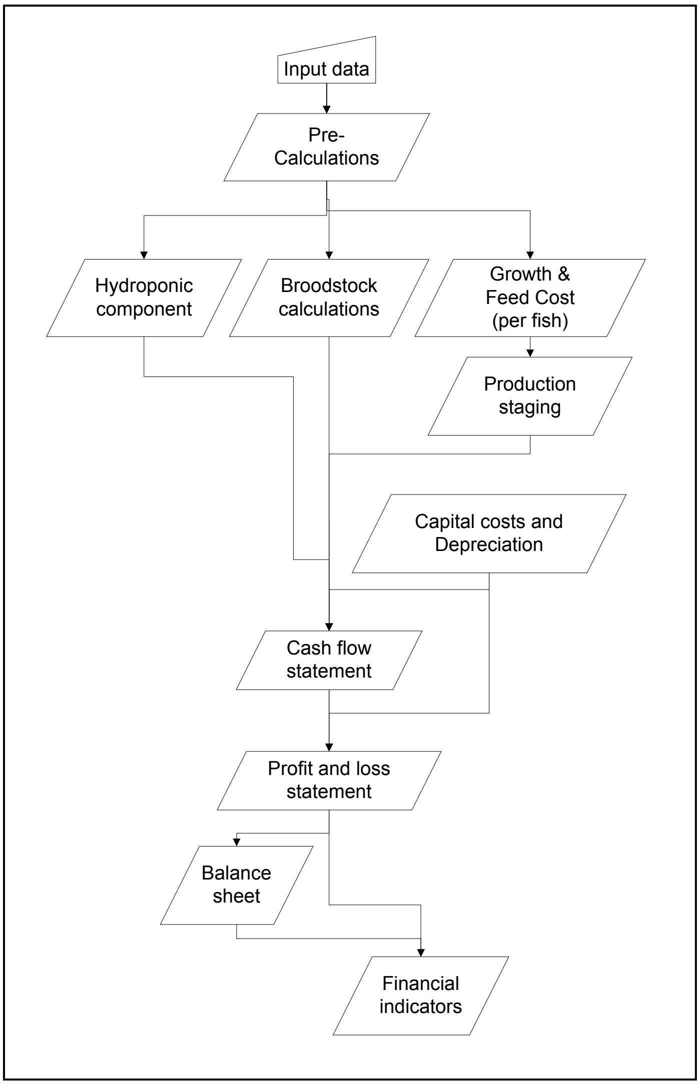

Figure 9 Outline of the model developed in this thesis to determine the feasibility of the case studies

There are a number of parameters that can be changed in the model. These parameters are grouped together and named *input data* (Figure 10 and 11).

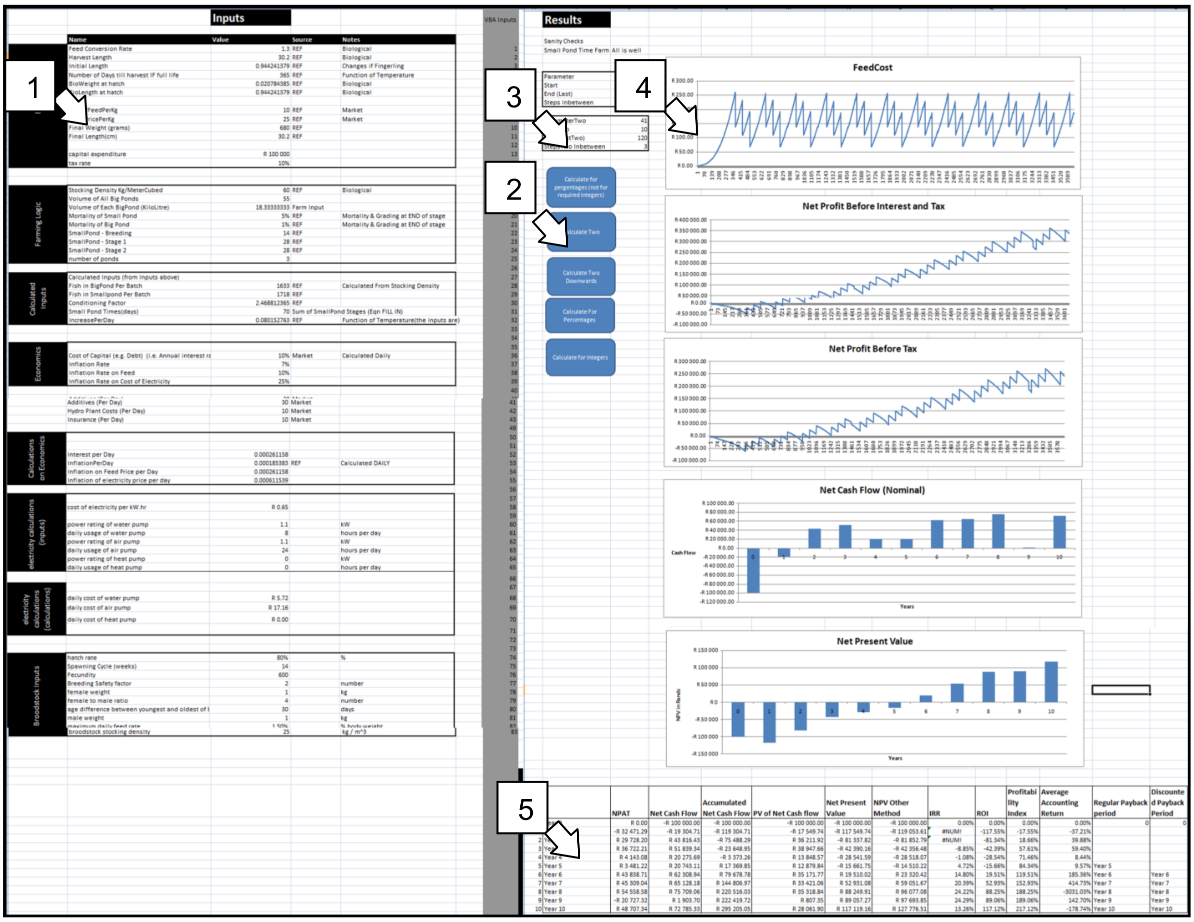

Figure 10 The input sheet of the model, showing input data (1), VBA buttons (2), input cells for the VBA calculations (3), graphs for assistance when testing input parameters (4), and a table showing the performance indicators for the system over a ten-year period (5)

Inputs

	Name	Value	Notes
Basic	Feed Conversion Rate	1.3	Biological
	Harvest Length	30.2	Biological
	Initial Length	0.944241379	Changes if Fingerling
	Number of Days till harvest IF full life	365	Function of Temperature
	BioWeight at hatch	0.020784385	Biological
	BioLength at hatch	0.944241379	Biological
	CostOfFeedPerKg	10	Market
	SalesPricePerKg	25	Market
	Final Weight (grams)	680	
	Final Length(cm)	30.2	
	capital expenditure	R 100 000	
	tax rate	10%	
Farming Logic	Stocking Density Kg/MeterCubed	60	Biological
	Volume of All Big Ponds	55	
	Volume of Each BigPond (KiloLitre)	18.33333333	
	Mortality of Small Pond	5%	Mortality & Grading at END of stage
	Mortality of Big Pond	1%	Mortality & Grading at END of stage
	SmallPond - Breeding	14	
	SmallPond - Stage 1	28	
	SmallPond - Stage 2	28	
	number of ponds	3	
Calculated Inputs	Calculated Inputs (from Inputs above)		
	Fish in BigPond Per Batch	1633	Calculated From Stocking Density
	Fish in Smallpond Per Batch	1718	
	Conditioning Factor	2.468812365	
	Small Pond Times(days)	70	
	IncreasePerDay	0.080152763	Function of Temperature(the inputs are)
Economics	Cost of Capital (e.g. Debt) (i.e. Annual interest rate)	10%	Calculated Daily
	Inflation Rate	7%	
	Inflation Rate on Feed	10%	
	Inflation Rate on Cost of Electricity	25%	
	Additives (Per Day)	30	
	Hydro Plant Costs (Per Day)	10	
	Insurance (Per Day)	10	
Calculations on Economics	Interest per Day	0.000261158	
	InflationPerDay	0.000185383	Calculated DAILY
	Inflation on Feed Price per Day	0.000261158	
	Inflation of electricity price per day	0.000611539	
electricity calculations (inputs)	cost of electricity per kW.hr	R 0.65	
	power rating of water pump	1.1	kW
	daily usage of water pump	8	hours per day
	power rating of air pump	1.1	kW
	daily usage of air pump	24	hours per day
	power rating of heat pump	0	kW
	daily usage of heat pump	0	hours per day
electricity calculations (calculations)	daily cost of water pump	R 5.72	
	daily cost of air pump	R 17.16	
	daily cost of heat pump	R 0.00	
Broodstock Inputs	hatch rate	80%	%
	Spawning Cycle (weeks)	14	
	Fecundity	600	
	Breeding Safety factor	2	number
	female weight	1	kg
	female to male ratio	4	number
	age difference between youngest and oldest of batch	30	days
	male weight	1	kg
	maximum daily feed rate	1.50%	% body weight
	broodstock stocking density	25	kg / m^3

Figure 11 The input parameters of the model

3.3 Calculations

The following section discusses a number of calculations that are performed in this entity of the model flow diagram. The calculations are divided into groups in accordance with their functions.

3.3.1 Pond re-stocking calculations

This section explains the calculations regarding the re-stocking of fish into the tanks.

The two ways of obtaining new fish with which to stock the ponds once the previous batch has been harvested are as follows. The first method is to have a separate broodstock pond where a number of fully-grown female and male tilapia breed new stock for the system.

Alternatively, the new stock could be bought from a hatchery in the form of fingerlings every time restocking is required.

Breeding the fish within the system eliminates the cost of having to purchase the fingerlings every time, but increases the labour and capital cost required for the system.

Buying new fry every time the ponds are restocked poses a threat that a disease could be introduced into the system which infects not only the new fish, but the other fish in the system too. The fry could be placed in quarantine in order to monitor them for diseases, but this requires that they be separated from the existing fish in the system. This is a large constraint for small-scale farmers such as those considered in this thesis.

3.3.1.1 *Calculating number of fry needed*

The number of fish in a particular growth stage is calculated backwards using the final stocking density, system volume and harvest mass, as well as the mortality rates during the various growth stages. It is calculated in this manner in order to arrive at the desired stocking density at the end of the final stage. The number of fish in each stage is calculated iteratively to determine the required number in the previous stage.

$$number\ of\ fish\ \left(stage(x)\right) = number\ of\ fish\ \left(stage(x+1)\right) \times \frac{1}{(1+\%mort(stage(x+1))}.....(4)$$

The loss of fish occurs as a result of mortality and culling.

The final survival rate for the fish's life cycle is calculated as follows.

$$final\ survival\ (surv)\ rate = \%surv(stage\ 1) \times \%surv(stage\ 2) \times \ldots \times \%surv(stage\ x) \ldots (5)$$

The number of fish required to re-stock the system is derived from the following: The

- maximum stocking density (kg/m^3);
- volume of water (m^3);
- final mass of the fish (kg); and
- final survival rate of the stock (% of initial number of fish).

$$number\ of\ fish\ required\ initially = \frac{stocking\ density \times volume\ of\ water}{harvest\ mass \times final\ survival\ rate} \ldots (6)$$

Using the following input data, the calculations below are computed:

- cost per fingerling; and
- number of ponds.

$$cost\ to\ stock\ system\ with\ fingerlings = cost\ per\ fingerling\ \times number\ of\ fish \ldots\ldots (7)$$

$$number\ of\ fingerlings\ required\ per\ pond = \frac{number\ of\ fingerlings}{number\ of\ ponds} \ldots\ldots\ldots . (8)$$

$$cost\ to\ restock\ per\ pond = \frac{cost\ to\ restock\ per\ cycle}{number\ of\ ponds} \ldots\ldots\ldots\ldots\ldots\ldots .. (9)$$

$$mass\ of\ fish\ harvested\ per\ cycle = stocking\ density\ \times volume\ of\ water \ldots\ldots\ldots\ldots (10)$$

$$number\ of\ fish\ harvested\ per\ cycle = \frac{mass\ of\ fish\ harvested\ per\ cycle}{mass\ of\ harvest\ size\ fish} \ldots\ldots\ldots\ldots (11)$$

$$number\ of\ fish\ harvested\ per\ batch = \frac{number\ of\ fish\ harvested\ per\ cycle}{number\ of\ ponds} \ldots\ldots\ldots (12)$$

$$mass\ of\ fish\ harvested\ per\ batch = \frac{number\ of\ fish\ harvested\ per\ batch}{mass\ of\ harvest\ size\ fish} \text{....................(13)}$$

The formula below can be used to determine the accuracy of the predicted mortality rate of the fish life cycle. The actual harvested mass can be compared to the calculated values.

$$mass\ of\ fish\ harvested\ per\ cycle = initial\ number\ of\ fish\ \times final\ survival\ rate \times final\ weight\ per\ fish \text{..(14)}$$

3.3.1.2 ***Broodstock calculations***

If the system breeds its own fish for re-stocking, the following calculations are used to determine the requirements of the system, as well as the broodstock. A step-by-step process calculates the requirements as follows.

The number of fry required per batch is determined in the section above. This value is used to determine the number of eggs required, using the hatch rate.

$$number\ of\ eggs\ required = \frac{number\ of\ fry\ required}{hatch\ rate\ (\%)} \text{......................(15)}$$

Using the female fecundity as well as spawning cycle time, the weekly production of eggs per female can be calculated.

$$weekly\ production\ per\ female = \frac{fecundity\ (number\ of\ egg\ produced\ per\ cycle)}{spawning\ cycle\ (number\ of\ weeks)} \text{...........(16)}$$

A method that can be used to calculate the number of eggs required per week to ensure that the batch of fry is approximately of the same age is shown. The user should specify how many weeks the oldest and youngest of a batch are allowed to differ by (G Lawrence 2010, pers. comm., 19 July). Using this information, the required production per week is calculated.

$$number\ of\ eggs\ required\ per\ week = \frac{number\ of\ eggs\ required\ per\ batch}{weeks\ allowed\ between\ oldest\ \&\ youngest\ of\ batch} \text{...........(17)}$$

The number of females required is calculated by dividing the required production by the production rate per female.

$$number\ of\ females\ required = \frac{number\ of\ eggs\ required\ per\ week}{number\ of\ eggs\ produced\ per\ female\ per\ week} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

A breeding safety factor is used to ensure that the required production rate of fry is attained.

$$number\ of\ females\ required = \frac{number\ of\ eggs\ required\ per\ week}{number\ of\ eggs\ produced\ per\ female\ per\ week} \times safety\ factor \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

A female to male ratio is used to specify the number of males required to fertilize the females.

$$number\ of\ males\ required = \frac{number\ of\ females}{female{:}male\ ratio} \ldots\ldots\ldots\ldots\ldots (20)$$

Once the number of male and female broodstock fish has been determined, the feed costs can be calculated in the same manner as in the growth section, explained in the next section. The maximum feed rate is ordinarily in the region of 1.5 % body weight fed per day.

The water volume required can be determined once the maximum stocking density for the broodstock has been decided upon.

3.3.2 Growth

The model calculates the fish growth based on information gathered on the species.

The following aspects are calculated on a daily basis:

- length
- weight
- feed cost

The growth is calculated in the following manner. All fish increase in length at linear rate (Timmons, Clark 2009). Their weight, however, increases by a cubic function relative to length. Figure 12 shows the length and weight of a fish relative to time (length and weight are normalised to show the relation).

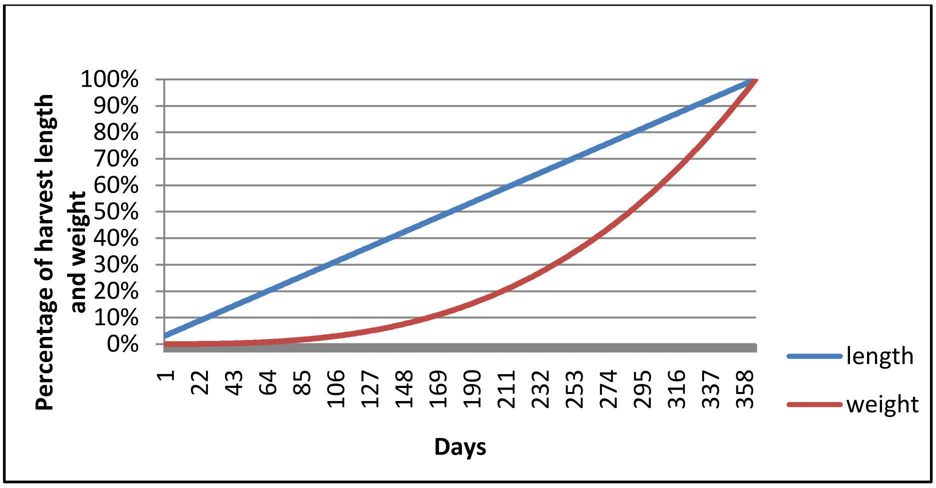

Figure 12 Normalised graph showing the relation between the length and weight of fish

The length and weight are mathematically related, as shown in the following formula:

$$WT(g) = \frac{K \times (L_{cm})^3}{100} \text{ (Timmons, Clark 2009) } \ldots\ldots(21)$$

where: WT(g) = weight of fish in grams

K = condition factor

L_{cm} = length of fish in centimetres

The weight and length of the fish on day one of its life, as well as on the harvest day, are input values. Using these values, the value of K can be calculated. The value of K is influenced by the age of the fish, sex, stage of maturation, season, fullness of gut, type of food consumed, amount of fat reserve and degree of muscular development (Barnham, Baxter 2003). The model developed in this thesis assumes that K is a constant, as cited by (Timmons, Clark 2009). This assumption is a limitation of the model, and is made so that the model can calculate the fish's weight at certain stages of its lifespan.

The formula for this calculation is as follows:

$$K = \frac{WT(g) \times 100}{(L_{cm})^3} \ldots\ldots(22)$$

For tilapia, this factor K usually ranges between 2.08 and 2.50. Once the condition factor is calculated, the weight at any given length can be calculated using the above equation.

The daily increase in length is calculated by taking the difference in length between the hatchling and harvest size fish, and dividing it by the number of days it takes to reach harvest size, as shown in the formula below.

$$length\ increase\ (per\ day) = \frac{(harvest\ length - hatchling\ length)}{days\ taken\ to\ reach\ harvest\ length} \text{.................................(23)}$$

The model calculates a number of elements relating to the growth of the fish on a day-to-day basis. The initial length of the fish (as specified in the input data) is used as a starting point, and each subsequent day the length is incremented in accordance with the calculated growth per day.

$$length\ (day\ t) = inital\ length + (day\ t) \times length\ increase\ (per\ day) \text{ ....(24)}$$

Using the equation above, the weight of the fish on the corresponding day can be calculated.

The amount of feed fed on day(t) is determined by taking the product of the feed conversion ratio (FCR) and the difference in weight between day(t+1) and day(t).

$$mass\ feed\ fed = (weight\ (day(t+1)) - weight(day(t))) \times FCR(\frac{kg\ dry\ feedfed}{kg\ wet\ weight\ gained}) \text{..(25)}$$

3.3.3 Staggering production

Staggering production is a method of staging the production of the aquaculture component in such a way that the tanks contain batches of fish that are of different ages. A delay of a number of weeks between the ages of the various batches is planned. Staggering production is considered to be advantageous for a number of reasons (Rakocy, Masser & Losordo 2006). This method helps to optimise the utilisation of the fish-rearing tanks. The staggering of production also assists in optimising the production in another manner. This method of production decreases the variation of daily feed input by staging various batches of fish at various stages in time. This is advantageous to the hydroponic component of the system, where a stable level of nutrient loading is desired. Unstable nutrient loading levels could cause the plants to suffer from nutrient deficiencies. Managing the stock in this manner also results in more regular harvests compared to a situation where all the tanks are stocked with fish at the same time.

If a system breeds its fingerlings in-house, then moving the fish from one tank to the next at the most favourable times will be advantageous. The model has a separate functionality where it is possible to optimise the production staging of the fish batches. The optimal times to transfer the fish to a larger tank can be determined. The model shows the stocking densities at the start and finish of each production stage. This is used to determine the optimal time to transfer the batch of fish. It should be noted that most of the farms in the case studies have three or four large tanks, and no smaller tanks where fish could be bred or grown. In these cases it is evidently not possible to optimise the movement of fish from one tank to another.

The staggering offsets each batch of fish by a pre-determined number of days. This results in the batches reaching harvest size at time intervals equal to the aforementioned offsets.

3.3.4 Biofilter design calculations

The purpose of the following calculations is to verify that the system's biofiltration component has sufficient capacity to filter the water under the operating conditions specified by the input parameters. Insufficient biofiltration capacity would result in the buildup of the TAN in the system, and the subsequent deterioration of the water quality.

A number of the input parameters are variable, and for this reason, three scenarios are calculated in each step. A minimum, maximum and expected scenario is calculated. The variation in the input parameters is a result of the variation in daily feed, as well as the design parameters that are proportional to the feed. These design parameters are shown in figure 13.

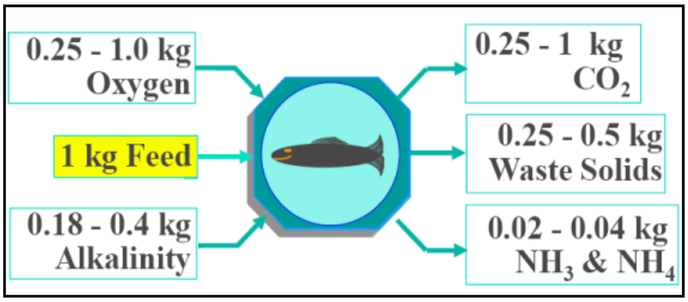

Figure 13 The relation between feed rate and design parameters (Timmons, Clark 2009)

The steps required to design a biofilter are explained in section 2.6.4.3 earlier.

The first step is to calculate the dissolved oxygen requirements of the system. The required oxygen is calculated based on the amount (in kg) of oxygen consumed by the system per kg feed used in the system.

A good starting point for the amount of oxygen required for a system is 1kg oxygen per kg feed used in the entire system (Timmons, Ebeling 2007). This includes oxygen used by all chemical reactions that consume oxygen in the system, including bacterial activity.

The contribution of oxygen consumption by the fish's metabolism is often estimated at 250 g oxygen per kg feed (Timmons, Ebeling 2007). In certain biofilter designs, the ambient atmosphere will supply sufficient oxygen for the nitrification process, as well as for any heterotrophic bacteria. If not, additional oxygen must be added to the system in order to ensure that the nitrification process is not constrained by dissolved oxygen levels.

The dissolved oxygen requirement is calculated as follows:

$$Dissolved\ O_2\ requirement\ \left(\frac{kg_{DO}}{day}\right) =$$
$$kg\ O_2\ required\ per\ kg\ feed \times average\ daily\ feed\ rate(kg) \quad \text{.........................(26)}$$

The average daily feed rate is calculated using the daily feed calculations performed in the biological growth model.

Water flow requirement: assume that dissolved oxygen (DO) level in the culture tank is 5mg/L(Timmons, Ebeling 2007). This measurement is taken from the effluent water, as this is the water that has the lowest DO level.

Most of the farms examined in the case studies have aerators in the culture tanks. This provides an additional source of oxygen to the oxygen provided by the influent water.

Table 2 Oxygen saturation levels in fresh water at sea level atmospheric pressure (Masser, Rakocy & Losordo 1999)

temperature (°C)	dissolved oxygen (mg / L)
10	10.92
12	10.43
14	9.98
16	9.56
18	9.18
20	8.84
22	8.53
24	8.25
26	7.99
28	7.75
30	7.53
32	7.32
34	7.13
36	6.95

The DO level of the influent water to the culture tank should be 7.75 mg/L (Timmons, Ebeling 2007) (table 2). Using the mass balance equation from the aforementioned reference, the flow rate can be calculated.

$$flow\ rate = \frac{Dissolved\ O_2\ requirement(\frac{kg_{DO}}{day})}{Dissolved\ O_2(\frac{mg}{l})\ (inlet) - Dissolved\ O_2(\frac{mg}{l})\ (outlet)} \times \frac{1\ day}{1440\ min} \times \frac{10^6 mg}{1\ kg} \quad \text{................(27)}$$

The mass of TAN produced by the fish in the process of metabolising is calculated by multiplying the amount of TAN produced per kg by the feed rate.

$$mass\ of\ TAN\ produced = \frac{kg\ TAN\ produced}{kg\ feed} \times (\frac{kg\ feed\ fed}{day}) \quad \text{............................(28)}$$

Using the areal TAN removal rate specified by Timmons (Timmons, Ebeling 2007), the surface area can be calculated using the following formula:

$$surface\ area\ required\ (m^2) = \frac{TAN\ production\ (\frac{kg\ TAN}{day})}{TAN\ removal\ rate\ (\frac{g_{TAN}}{m^2.day})} \times \frac{1000g}{1kg} \quad \text{...................(29)}$$

The volume of biofilter media required is calculated by dividing the surface area required by the specific surface area of the biofilter media.

$$volume\ of\ biomedia\ required(m^3) = \frac{surface\ area\ required(m^2)}{specific\ surace\ area\ of\ media(\frac{m^2}{m^3})} \text{.................(30)}$$

3.3.5 Hydroponic component

The model calculates the production capacity of the hydroponic component. The surface area of the farm's hydroponic component is determined at the site visits.

$$surface\ area\ of\ hydroponic\ component(m^2) = \sum_{x=1}^{\text{number of growbeds}} (growbed(x)length(m) \times growbed(x)width(m)) \text{...(31)}$$

The productivity and value of the produce from the hydroponic component is calculated as follows. The production per square metre of the various plants is obtained from the reference below.

$$mass\ of\ production(kg) = production\ of\ plant\ \left(\frac{kg}{m^2}\right) \times surface\ area\ of\ hydroponic\ component(m^2) \text{.............(32)}$$

$$value\ of\ production(R) = mass\ of\ production(kg) \times selling\ price\ \left(\frac{R}{kg}\right) \text{.............(33)}$$

The production rates for the hydroponic component of an aquaponics system at the UVI are shown in table 3.

Table 3 Production and economic data from the UVI aquaponics system (Rakocy *et al.* 2003)

	annual production kg / m²	value R / m²
tomatoes	29.295	10.61
cucumbers	60.544	13.69
eggplant	11.230	8.20
genovese basil	30.272	287.00
lemon basil	13.183	139.61
osmin basil	6.836	81.85
cilantro	18.554	243.50
parsley	22.948	328.78
portulaca	17.089	267.87

3.3.6 Calculations to determine cash flows

3.3.6.1 *Depreciation*

Depreciation is non-cash deduction which occurs in the profit and loss statement. As a result, depreciation has cash flow consequences because it influences the tax bill. The manner in which depreciation is computed for tax purposes is thus the relevant manner to calculate depreciation for feasibility study decisions.

The various components that comprise the aquaponics system depreciate at different rates, and should be calculated as such. By researching the depreciation rates used in other aquaponics business plans in the literature (Hansen, Hardy 2008), the depreciation for the components in the case studies are determined.

The annual depreciation is calculated by dividing the value of the asset by the lifespan of the asset.

$$annual\ depreciation = \frac{value\ of\ asset}{lifespan\ \ (years)} \quad \text{.......................................(34)}$$

3.3.6.2 *Capital expenditure*

Using the depreciation rates from the section above, the point in time when an asset needs to be replaced can be determined. The cost of replacing the asset is incurred to the system at such time.

3.3.6.3 ***Operating expenses***

The operating expenses are divided into direct production costs, and overheads costs. The direct (or variable) costs are feed cost for the growout stock, costs for additives, chemical testing equipment, organic pesticides, seedlings, and either feed cost for the broodstock, or fingerling restocking cost (depending on the design of the system).

Overhead costs (otherwise known as fixed costs) are insurance, electricity, capital purchases, labour and maintenance.

Normally labour is a cost for these systems, but in the case studies the owners perform the labour tasks themselves. The model has an input for labour cost but this value is set to zero for the case studies.

3.3.6.4 ***Sales***

The sales are calculated by determining the times when the products are ready for sale. The mass of fish harvested, as well as the selling price, are used to calculate the revenue of the aquaculture component. The revenue generated from the hydroponic component of the system is calculated using the production rates from table 3, as well as the selling price.

3.3.7 Cash flow

The cash flow statement incorporates the operating expenses as well as the sales sheet. Loan repayments, as well as loan interest, is also deducted from the cash flow. Inflation of all the elements is factored in at this stage. Some of the elements which are expected to have inflation rates that are expected to vary from the average inflation (such as feed cost and electricity cost) have separate inflation rates that can be adjusted at the input data.

3.3.8 Profit and loss statement

The profit and loss statement follows a specific format. The gross profit is calculated by deducting the direct cost of sales from the income value. Net profit before income and tax is calculated by deducting overhead costs, as well as depreciation. Deducting interest provides the net profit before tax. Deducting tax provides the net profit.

$$gross\ profit = sales - cost\ of\ sales \quad (35)$$

$$net\ profit\ before\ interest\ and\ tax = gross\ profit - overhead\ costs - depreciation \quad (36)$$

$$net\ profit\ before\ tax = net\ profit\ before\ interest\ and\ tax - interest \quad (37)$$

$$net\ profit = net\ profit\ before\ tax - tax \quad (38)$$

3.3.9 Financial indicators

A number of financial indicators are used in the feasibility model. The Net Present Value (NPV) and Internal Rate of Return (IRR) are two of the most popular financial indicators used in financial management. The IRR, however, is a not suitable indicator for ventures such as these as a result of the nature of the cash flows that the systems experience. The financial indicator that is used the most in this thesis is therefore the NPV. Appendix C contains a detailed description of the financial indicators used in this thesis, describing the method of calculation, advantages and disadvantages of each.

3.4 Testing the model

The final model to be used for the feasibility studies has been rigorously tested in order to ensure that there are no calculation errors in the model logic. The model outputs have been compared to previous models designed by the author to ensure the validity of the results. Numerous calculations were also done by hand and compared to the model outputs. Due to the complexity of the model, errors were found and corrected. Finally, the model was verified by an industry professional from the aquaculture sector who has vast experience in feasibility study modelling (G Lawrence 2010, pers. comm., 19 July), as well as an industry professional who specialises in mathematical and financial model building (M Lapere 2010, pers. comm., 8 August).

4 Case study on existing aquaponics farms

This section details the farms in the Garden Route area that will be used as case studies in order to study and model the current practices of the aquaponics farmers in the region. Information on the climate and demographics is supplied, as these attributes form part of the external environment in which the farms find themselves.

4.1 Introduction and methods to case study

4.1.1 Location

Figure 14 The location of the case study farms, with an exploded view showing the location of the individual farms

The case study farms are situated in a coastal strip of 150km long between Sedgefield and Plettenberg Bay, all within approximately 10km from the coast (figure 14).

This area is near the border between the Western- and Eastern Capes. Both provinces show promise for the development of aquaculture (Hinrichson 2007, Britz 2008).

4.1.2 Climate

The Garden Route has a temperate climate, with an average rainfall of 73mm per year. Monthly rainfall during the summer averages 75mm, with winter at 71mm. The region receives rain throughout the year, yet sunny days are also common throughout the year. Summer features warm to hot days with cool evenings. Winter is cool to warm during the day, with cold evenings. In summer the daytime and night time averages are 22 and 14 °C respectively, whilst the winter averages are 19 and 10 °C (Coastal & Environmental Services 2009).

Since December 2008, the region has been experiencing a drought and in 2009 the region experienced its worst drought conditions in recorded history (Life Beyond Our Rivers 2010). Water restrictions are still in place in October 2010, and are expected to remain in place for the foreseeable future until the drought subsides (Oelofse 2010).

4.1.3 General

About 60,000 people live in the 1,059 km² of Knysna's municipal area. The majority of the population speaks Afrikaans; English and African languages are also widely spoken in the area. Unemployment in the area is 19 %, indicating that there is no shortage of labour in order to potentially operate the systems.

Another factor that should be taken into account when performing a feasibility study in the area is the abundant availability of scrap wood. The area has a large forest plantation industry, and the subsequent harvesting and refining of the wood produces a large amount of scrap wood as a by-product. This wood is suitable for burning in wood-powered boilers, and can be used to heat water in an aquaponics system.

4.1.4 Data collection methods

The case studies of the farms are conducted in order to gather information on the current practices of aquaponics farmers in South Africa. The cases are approached in the following manner. The farms in the area are identified as being of interest to the investigation, and contact is made with the farmer. A meeting is then arranged with the farm owner. This meeting takes place at the site of the aquaponics system, in order to gather the maximum amount of information. A structured interview is then undertaken with the system operator, which in these cases is the investor themselves. The farms are revisited a number of times as the thesis progresses to gather information as needed. All information is documented to be used in the feasibility model.

The farms that will be used as case studies for the thesis are described below. They have a number of aspects in common, namely:

- the systems are housed in one or more greenhouses containing the fish tanks, hydroponic growbeds, pumps and plumbing used in the system; the tunnels have approximate dimensions of 30m X 16m X 4m;
- the species farmed is tilapia (*O. mossambicus*); a mixed-gender population is farmed;
- the farmers use fish feed supplied by Aqua-nutro (Pty) Ltd (Malmesbury, South Africa);
- the water in the system is heated by either an electrical heat exchanger, boiler, geyser element, or solar water heating device or a combination thereof; and
- the fish are grown in circular wire-mesh ponds with a plastic liner.

4.2 Case study farms

A brief comparison of the case studies is shown in table 4, in order to give the reader a summary of the farms.

Table 4 A comparison of some key aspects of the case study farms

Comparison between the case study farms							
		farm 1	**farm 2**	**farm 3**	**farm 4**	**farm 5**	**farm 6**
capital cost		R 100 000	R 250 000	R 250 000	R 200 000	R 150 000	R 60 000
ponds	Volume	55kL	112kL	88kL	28kL	15kL	12kL
hydroponics	Construction	brick and concrete	wood & plastic	wood & plastic	PVC half-pipe	wood & guttering	PVC half-pipe
	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	biofilter tanks	gravel & airpump-powered biofilters	gravel medium	biofilter tanks	gravel medium
performance	Aquaculture component	good	good	good	bad	good	bad
	Hydroponic 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 & fire-powered boiler	fire-powered boiler	heat pump	heat pump	heat pump	none

4.2.1 Farm 1

Farm 1 was constructed around 13 months ago. The capital cost of the system is estimated by the owner at R100 000. This cost is rather low when considering the size of the system; the reason for this is that the farmer oversaw the construction of the system himself, and managed the costs well. If the construction were to be outsourced, the cost would likely have increased by over 100 %. The hydroponic growbeds double as the system's biofilter component (figure 15).

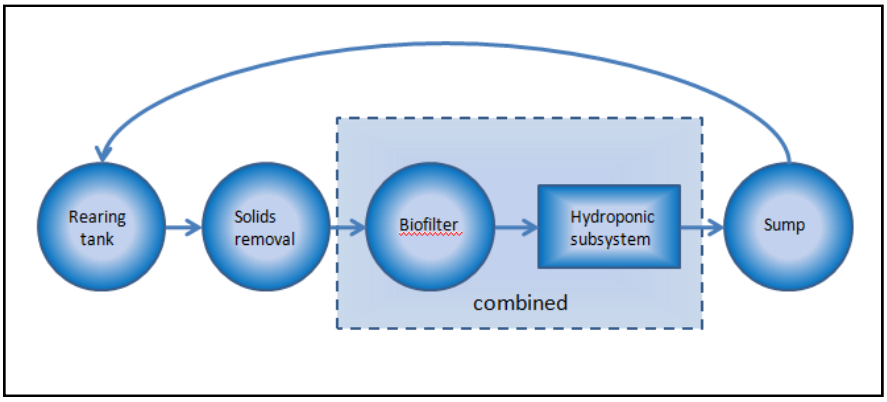

Figure 15 A representation of the components of farm 1

The system consists of two tunnels (figure 16), one containing the hydroponic component (figure 17), and the other the aquaculture component (figure 18).

Figure 16 Exterior of farm 1 greenhouses

Figure 17 Interior of the hydroponic greenhouse on farm 1

Figure 18 Interior of the aquaculture greenhouse on farm 1

The water in the system is heated using solar water heaters. The heater is composed of two panels containing hundreds of thin black pipes (figures 19 and 20) through which the water flows and is heated.

Figure 19 Solar water heater panels

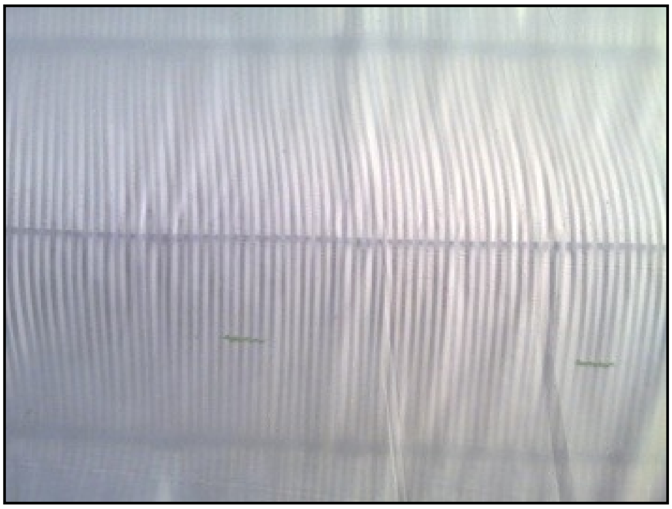

Figure 20 Close-up of the capillary pipes that comprise the solar water heaters

Additional heating is provided by a boiler powered by wood fire; the boiler is used during periods of extreme cold (figure 21).

Figure 21 Wood-fire powered boiler used for heating system water on farm 1

The hydroponic component of the system is constructed in a cost-effective manner; the growbed is situated on ground level, and is made of concrete and bricks as illustrated in figure 17.

The water recirculating system consists of a regular pool pump with sand filter, controlled by a programmable logic control unit. The sand filter is backwashed daily, and the sand is loosened up by hand in order to prevent clogging and to prevent the water short-circuiting the filtration process. The backwashed water is stored in an outside pond. The nutrient-rich water is then used to irrigate crops grown in soil nearby.

The tank arrangement in the aquaculture tunnel is not efficient in terms of space utilization. The initial design incorporated a few hydroponic growbeds in the fish tunnel as well, but that was abandoned in favour of a number of smaller fish tanks.

4.2.1.1 *Preliminary result on farm 1 investigation*

At present the farmer is not operating the boiler in order to heat the water. This has caused the water temperature to decrease considerably during the colder winter months, thereby causing the growth rate of the tilapia to decrease.

4.2.2 Farm 2

Farm 3 consists of three greenhouse tunnels, at cost of around R250 000 for the investors. The first tunnel contains four 28kl grow-out ponds (figure 22).

Figure 22 Interior of the hydroponic greenhouse on farm 2

Figure 23 Interior of the aquaculture greenhouse on farm 2

The second contains four gravel growbeds (figure 23), manufactured from pine wood and welded plastic, in the same way that the raft hydroponics on farm 2 are constructed. The third tunnel houses D-ended raceways in which algae are to be grown (figure 24). The construction of the third tunnel is not yet completed, but the plan is to grow algae in the effluent fish water, then concentrate the algae in a settling pond, and finally strain the algae out. The algae type spirulina (*Arthrospira* spp.) will be grown in the raceways, and sold to companies that process it into a tablet form for consumption.

Figure 24 Interior of the algae production greenhouse on farm 2 (in the construction stage)

As shown, the solids removal, biofiltration and hydroponic subsystem components on farm 2 are combined (figure 25).

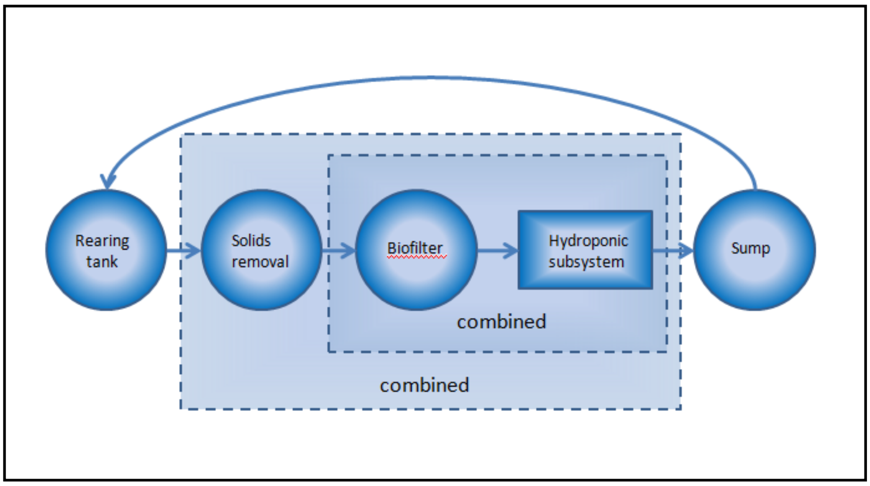

Figure 25 A representation of the components of farm 2

Farm 2 is the largest-scale farm of the case studies, and has the potential to be a successful venture, as the system produces a number of products. The investors are considering expanding the farm with an additional two and a half standard size greenhouses if the initial system is successful.

4.2.2.1 *Preliminary result on farm 2 investigation*

The fire-powered boiler is the only source of heat for the system. This makes it difficult to maintain the water temperature at a consistently high range during the colder months. A compromise will have to be made between allowing the water temperature to fluctuate, buying expensive automation equipment, and increasing labour requirements.

4.2.3 Farm 3

Farm 3 was constructed 18 months ago, and cost the investor R250 000. The system is housed in a single greenhouse tunnel, with four large grow-out tanks (figure 26), and four raft hydroponics growbeds (figure 27).

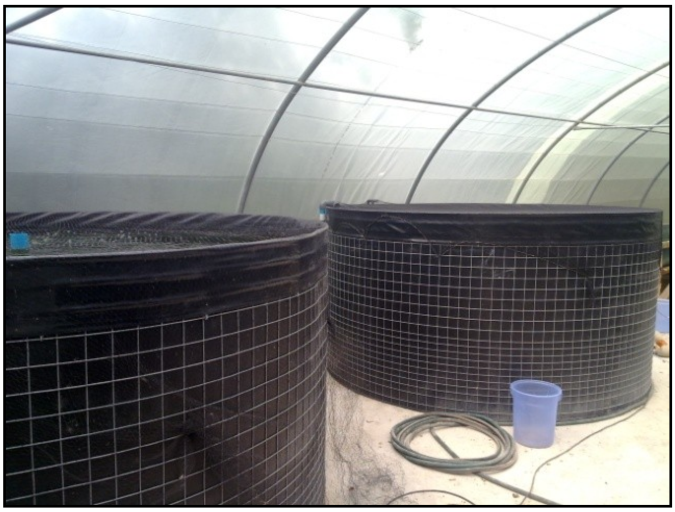

Figure 26 Two of the four growout tanks on farm 3

Figure 27 Raft hydroponics growbeds on farm 3

The hydroponic growbeds are constructed of pine wood and welded plastic, and the solids capture device and biofilter are constructed from concrete; the material type and construction of these components contributes to the high capital cost.

Figure 28 shows the components of farm 3. None of the components are combined in this system.

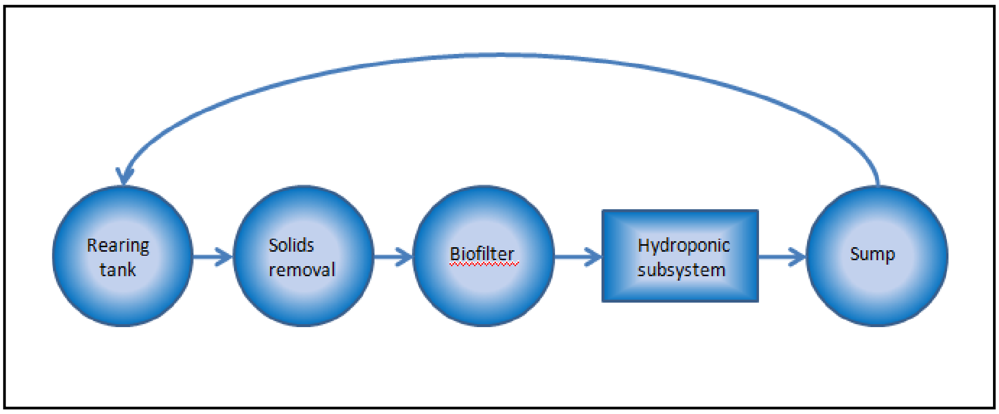

Figure 28 A representation of the components of farm 3

4.2.3.1 *Preliminary result on farm 3 investigation*

The farmer experienced little success with the operation of the system. The fish growth rates were not as predicted, possibly as a result of problems with the water quality and temperature. The raft hydroponics component experienced problems with plant growth, as well as pests. The organic pesticides recommended to the farmer apparently did not remedy the problem. The monthly electricity bill is allegedly in the region of R1500 to R1700, which is an exceptionally high operating expense for a system of this size.

Upon the most recent visit, it was noted that the farm had shut down and was selling its assets in order to salvage some of the investment costs.

4.2.4 Farm 4

Farm 4 is the oldest of the case studies, and has been in operation for three years. It was built at a cost of R200 000, and consists of one greenhouse tunnel with four 7kl ponds, and 24 six-metre gravel growbeds (figure 29 and 30). The system combines the solids removal, biofilter, and hydroponic components (figure 31).

Figure 29 Interior of farm 4 greenhouse in June 2007

Figure 30 Interior of farm 4 greenhouse in June 2010

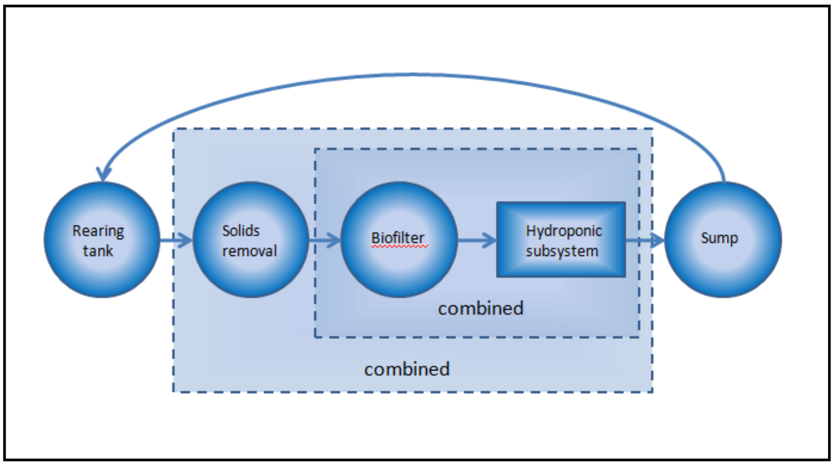

Figure 31 A representation of the components of farm 4

The relatively high capital cost is attributed to the outsourcing of the construction, and the use of expensive materials and construction methods.

This aquaponics system is unique from the other case studies, in that it incorporates an additional trophic level of integrated farming using poultry. The system incorporates 300 chickens (*Gallus domesticus*), housed in mesh cages suspended over plastic sheeting. The chickens' droppings accumulate on the sheeting; thereafter, the sheeting is replaced, and the old sheet with droppings is put in the sun to dry. Once the droppings are dry, they are filtered through a fine mesh screen to break the droppings into smaller pieces. The droppings are then placed into the growout tanks where it acts as a fertilizer for algal production and generates algal biomass, which the fish feed on. This process integrates the chicken component into the aquaponics system. The use of chicken droppings as fish feed eliminates the cost of fish feed from the operating costs. The disadvantage is that fish growth rates, as well as water quality, are adversely affected by the change from commercial fish feed to chicken droppings.

Figure 32 One of the four tanks on farm 4, showing pump, heat pump and suspended chicken cages

Vegetables produced in the hydroponic component that are not suitable for sale are fed to the chickens, saving further on feed costs. Another process that takes place is the growing of algae using the system's water. Algae are grown in trays outside of the tunnel in the sun. The algae are then strained out of the water, dried, and fed to the chickens.

4.2.4.1 *Preliminary result on farm 4 investigation*

The plants in the hydroponic component grow exceptionally well, as a result of the high concentration of nutrients in the water. In terms of suitability for the aquaculture component, however, the water quality is not ideal. The decomposing solids in the water consume oxygen and produce compounds (e.g. hydrogen sulphide) that are harmful to the fish. It is not possible to stock fish in moderate densities in water of this quality.

Organic pesticides are used in the system to prevent the hydroponic crops from being damaged.

4.2.4.2 *Note:*

The farm owner has made a projected income statement of his own which does not correspond with those made in this thesis. It is possible that the farm owner has inflated his income figures in order to make it seem as though the system is more profitable than it is. The farm owner is building very similar systems for other investors, which is where the suspicion of incorrect projections stems from.

4.3 Additional case study

Another aquaponics system is also investigated in the same manner in order to gather some more information. However, this system is not designed in the appropriate manner or to the correct scale to be suitable for commercial use. The feasibility of this system, referred to as system 5, is not determined.

System 5 is constructed in a similar way to farm 3, but on a much smaller scale. The produce of the system is used by the owners for personal consumption, and for use in their guest house. The system is also used as a training facility where people can do a course in aquaponics, and gain hands-on experience.

4.3.1 System 5

System 5 was constructed around eight months ago, at a cost of R60 000. The system consists of a small greenhouse tunnel which houses one of the ponds, and three short growbeds. Shade cloth covers the other pond and three growbeds (figure 33 and 34).

Figure 33 Section of system 6 enclosed in greenhouse showing a tank and growbeds

Figure 34 Section of system 6 covered with shade cloth showing a tank and growbeds

4.3.1.1 ***Preliminary result on system 6 investigation***

This case study shows that the cost of the system per unit produce decreases considerably when the scale of the project is increased. At the initial visit it was noted that the plant growth in the growbeds was struggling.

The most recent communication with the system owner has shown that the system is operating at extremely low productivity levels during the winter months. This is attributed to the lack of heating in the system, as well as the poor insulation of the section of the system covered in shade cloth. The fish feeding rate has dropped drastically as a result of the low water temperatures. The plant growth has also deteriorated, with a number of the plants dying.

5 Feasibility study

In order to investigate the feasibility by modelling the case study farms, the necessary information is gathered and stored in Microsoft Excel. A separate feasibility study is done on each of the case study farms. The model contains all of the input parameters of the farms, as well as step-by-step calculations. These calculations are based on the literature study, available scientific research, and personal communication with farmers, aquaculture and aquaponics consultants and experts. Appendix D lists and describes the people from whom information was obtained.

According to research (Rakocy, Hargreaves 1993a), the recommended sequence to determine the feasibility of an aquaculture operation is a follows:

- calculate the growth projections of the fish species, hence calculating the system requirements;
- calculate the capital cost of the system;
- calculate the operational cost of the system;
- project the sales; and
- combine the above calculations into financials in order to determine whether the venture will be financially viable.

This sequence is also recommended by an industry professional (G Lawrence 2010, pers. comm., 12 April). The purpose of this study is to model the current situation that the farmers find themselves in. For this reason, it is not necessary to calculate the system requirements and capital cost of the system. However, for the sake of completeness, the system requirements are calculated in the model in order to verify that the systems are suitable to the production rates specified.

The capital cost of the system is supplied by the farmer and is not investigated further.

5.1.1 Reservations on the case study predictions

A number of assumptions are made in order to perform the calculations on the feasibility of the farms. It is necessary to make assumptions to focus the study on the actual feasibility. If no assumptions are made, the model would have to take into account every scenario that could possibly occur.

Assumptions:

- The farmers are farming an all-male stock of fish in their ponds. This assumption is made so that the fish's growth rates can be predicted more accurately (Abernathy, Lutz 1998). As explained later in section 5, mixed-sex tilapia do not grow uniformly, which significantly retards and complicates the process of producing a uniform batch of market-size fish. It is a reasonable assumption that the farmers farm sex-reversed all-male tilapia that are either bought or bred themselves.
- The expected production rates are used for this system. In some cases this may be the best-case production rate, such as in the case of the bio-security issue described below. Rational calculations have been performed to ensure that the system is capable of handling the production rates specified. The reader may be inclined to think that the predictions are a bit optimistic, and in some cases rightfully so. It was established fairly early on in the investigation and modelling process that the farms are not foreseen to be profitable.

  Therefore, in order to convincingly demonstrate that they are not economically feasible, the best case scenario should be studied. When considering the near-ideal model later in the thesis, risk factors and other considerations are taken into account.
- Major bio-security risks are not accounted for in this model. A bio-security risk could adversely affect the fish's growth rate and mortality. However, a realistic mortality rate is accounted for in the model.
- Labour obligations are assumed to be undertaken by the farm owner. This model is theoretically a realistic model of the current state of the case studies. Therefore, as in reality, the system does not incur any costs related to labour in the system. The owner must take into account the opportunity cost of spending their time on the system. In reality, a cost should be incurred for labour in the system, but for the purpose of the case studies the labour cost will be set to zero in the model.
- No cost is incurred to the system for the land which it occupies. In the case studies, the systems are located on land owned by the farmer. The opportunity cost of using the land for this purpose should be taken into account by the farmer.

The feasibility model used in the case studies also does not take into account any risks that the systems might be exposed to. Not taking into account any risks can have repercussions on the actual performance of the system. A number of risk factors can have detrimental effects on the performance of the system.

The inherent risk of the aquaponics ventures also affects the cost of capital. The higher the risk of the venture is perceived, the higher the cost of capital will be. Regardless of where the investment funds are raised, the investor will demand a higher rate of return on their investment if the risk rate is higher (Firer *et al*. 2008).

5.2 Methods of determining feasibility

One of the first results that should be studied is whether the operation is generating positive or negative cash flows. Financial indicators can also be used to help determine the feasibility.

5.2.1 Cash flows and NPV

Although a number of calculations are performed in the model, and a number of performance indicators are available for analysis, only two figures per farm are shown, so that the comparison process does not become tedious. A more complete set of figures and financial indicators for the case study farms are provided in Appendix E.

The predicted net cash flows for the systems for a 10 year period are an important set of indicators of the performance of the farms (figures 36 to 39). A number of performance indicators are calculated in the model, but the NPV is the performance indicator that is used in this section. The NPV is included as it is the performance indicator that is the easiest to evaluate and to compare the farms.

5.2.2 Results of the feasibility study

The cash flows of farms 1 to 4 are shown (figures 35 to 38). The variations to the upward trend on various years are attributed to the high capital purchases costs incurred on those years. As stated in the feasibility model section, the various components of the system depreciate at different rates, and must be replaced accordingly.

Farm 1 produces positive cash flows on the majority of the years studied (figure 35).

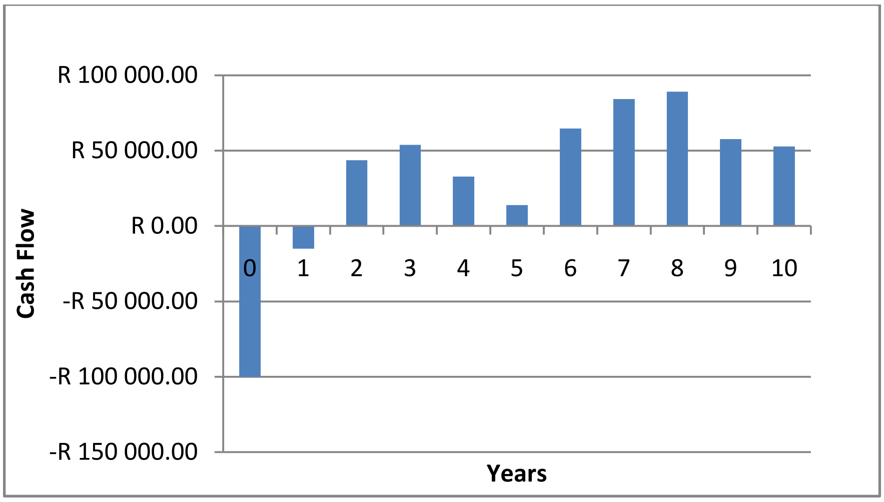

Figure 35 Net cash flow of farm 1

Farm 2 also produces positive cash flows on the majority of the years studied (figure 36). However, these positive cash flows are smaller than those of farm 1 relative to the respective initial capital costs.

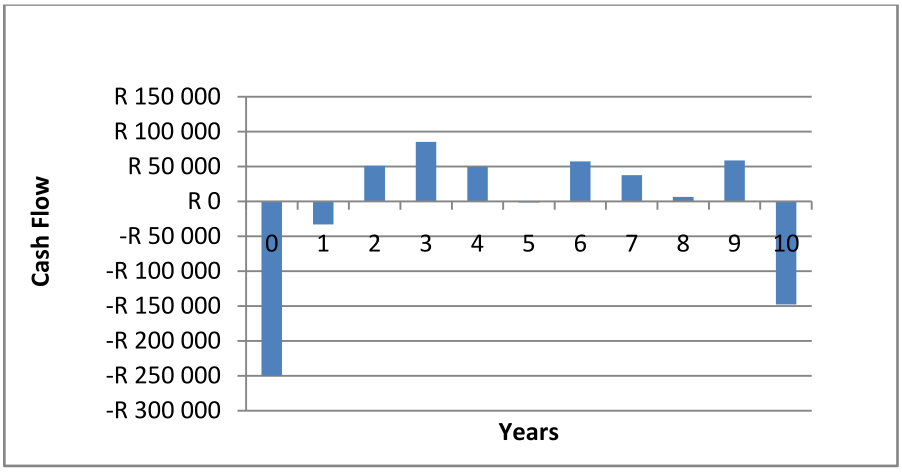

Figure 36 Net cash flow of farm 2

Farms 3 and 4 produce negative cash flows on the majority of the years studied (figures 37 and 38).

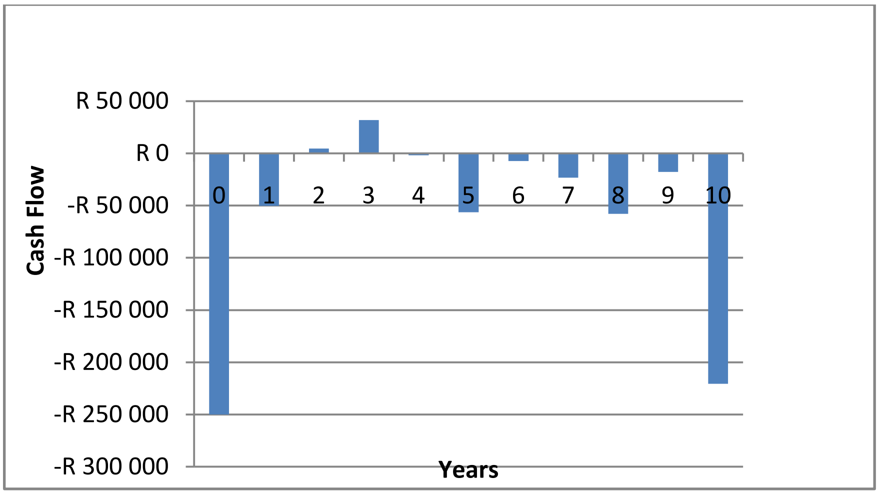

Figure 37 Net cash flow of farm 3

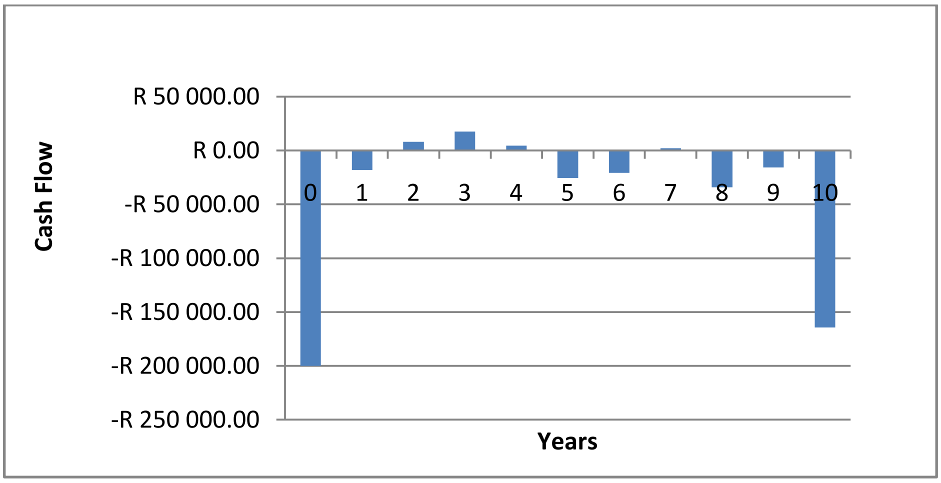

Figure 38 Net cash flow of farm 4

The NPVs of the case study farms are shown for a 10 year period (figures 39 to 42). Farm 1 generates a positive NPV during the study period (figure 39).

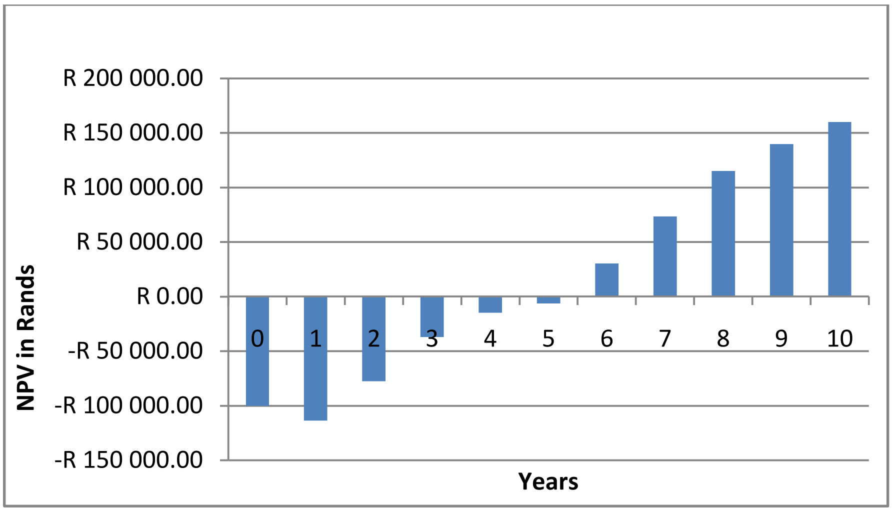

Figure 39 Net present value (NPV) of farm 1

Farms 2, 3 and 4 produce negative NPVs over the 10 year study period (figures 40 to 42).

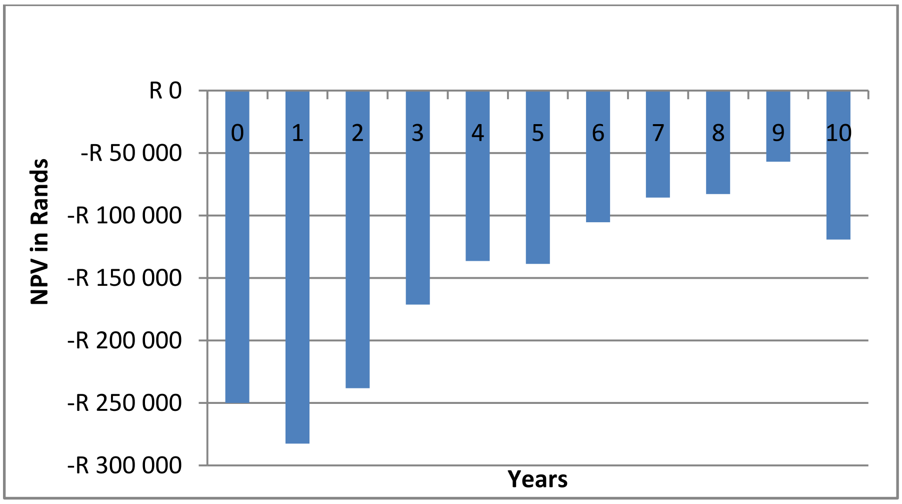

Figure 40 Net present value (NPV) of farm 2

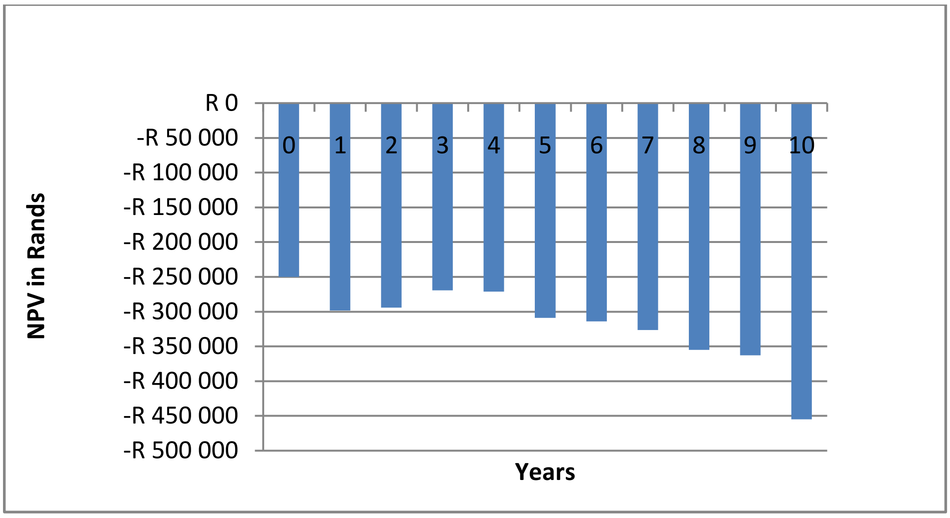

Figure 41 Net present value (NPV) of farm 3

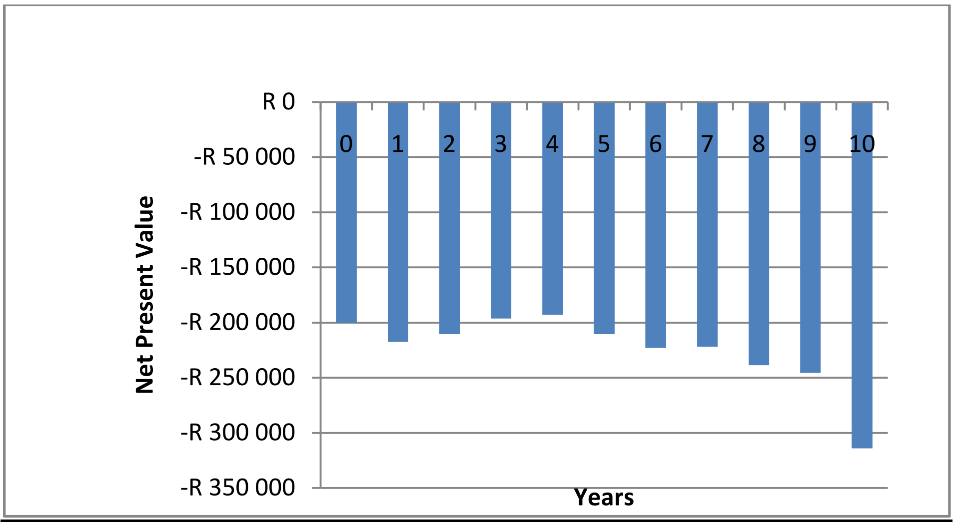

Figure 42 Net present value (NPV) of farm 4

5.2.3 Discussion on the feasibility study

The results show that farm 1 is the only farm generating an accumulated positive cash flow at any stage during the 10 year study period. The best case scenario is used (section 4.1.4); along with other aspects, labour and land rental is not accounted for. Thus, even though all these factors are in favour of the farms being successful, the figures show that farms 2 to 4 would make for highly undesirable investments.

However, the NPV for farm 1 becomes positive at some stage in year 5. This also signifies the discounted pay-back period.

The revenue received from the algae production tunnel on farm 2 is not taken into account in the model as it is difficult to estimate the value thereof. The component is expected to produce an income when built; however, it is extremely unlikely that the additional revenue of this component will cause the system to become economically viable.

The contribution of the poultry component in farm 4 produces an additional revenue stream, but the entire system still produces negative cash flows (figure 39).

5.3 Analysing the case studies

The following section analyses the farms by varying the parameters in order to determine what changes are needed in order to make the last 3 farms successful, and also which parameters would cause farm 1 to generate negative cash flows. A number of different situations are considered in this analysis. These situations are selected as a consequence of their relevance to the feasibility of the farm. The decision to perform the sensitivity analysis is motivated whenever an analysis is performed to state the relevance of the analysis to the study.

5.3.1 Sensitivity analysis

Sensitivity analysis is defined as an investigation of the effect of changing a variable (e.g. selling price) on a performance measurement (e.g. NPV).

The sensitivity analysis performed in this section addresses the “Technical” and “-Economic” aspects of the feasibility study. The parameters that are changed in this analysis include both technical aspects such as growth rates and FCRs, and economical aspects such as market prices. All of the parameters have an effect on the economical aspect of the case studies, as reflected in the financial indicators.

5.3.1.1 ***Profitability index***

The profitability indexes for the four case studies are shown below. Profitability index is closely related to the NPV indicator (Appendix C), and is used in this case to compare the farms. A comparison of the profitability of the farms shows the variation in performance according to the profitability index performance indicator (figure 43).

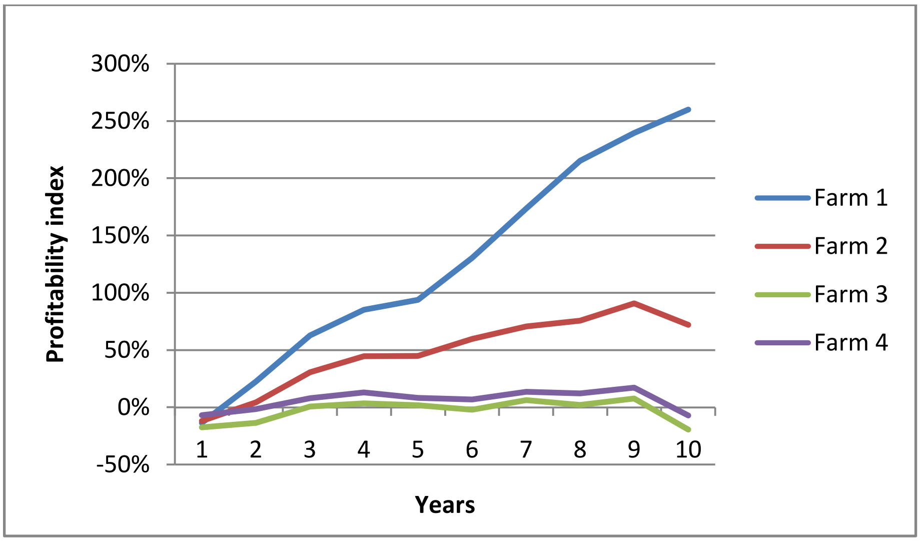

Figure 43 Profitability Index of the farms

5.3.1.2 ***Varying the capital cost parameter***

A calculation that could provide an explanation for the poor performance of some of the farms is to determine the effect on a financial indicator after setting each farm's capital cost to a lower value. As such, the farms' productivity in relation to capital cost can be determined and compared.

The reason for performing this analysis is motivated by comments made by some of the farmers. They claim that they are going to apply for a government rebate on the capital cost of their systems, and that if approved, the government would pay back 70 % of the capital cost of the system.

The capital cost of farm 1 is left unchanged to be used as a reference point. The effect of reducing the capital costs of the remaining three farms by 70 % on the profitability index is shown (figure 44).

Figure 44 shows that the performance of farm 2 increases substantially as a result of the decrease in capital cost. The performances of the remaining three farms are comparable to that of farm 1 without having reduced the capital cost of that farm.

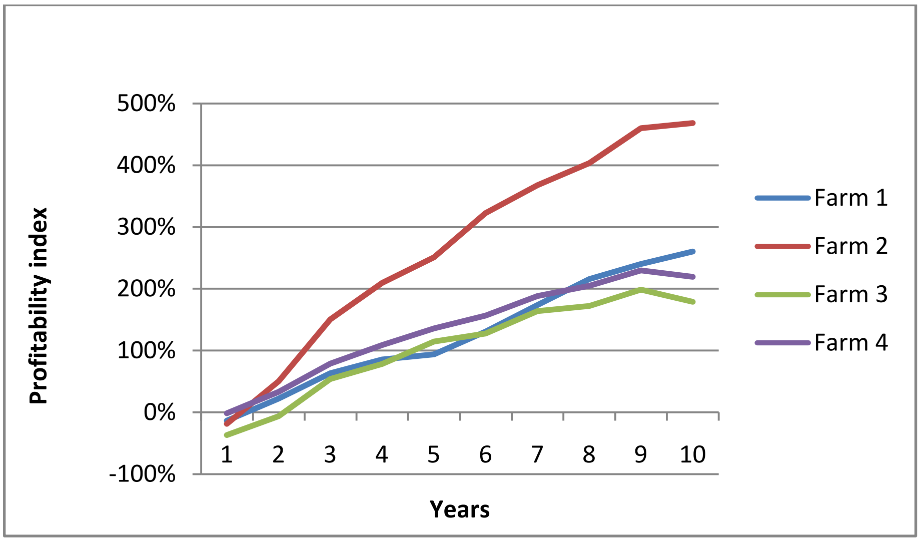

Figure 44 Profitability of the farms with the capital cost of farms 2,3 and 4 reduced by 70 %

5.3.1.3 *Note on this test*

The investigation above is based on a hypothetical situation where the farmers receive assistance from the government in the form of a rebate on their capital costs. The author could find no evidence in the literature or from any government source that there are policies of such a nature in place. The author is therefore neither denying nor agreeing that this scenario may become a reality. The test shows, however, that were the farmers to receive a rebate, their chances of success would increase notably (Appendix F).

For the following number of tests, farm 1 is used in the analyses as it is the farm that shows the most potential to be successful. Farms 2, 3 and 4 produce negative cash flows under best-case scenarios, and will therefore not be investigated further.

5.3.1.4 *The effect of changing the selling price of the fish*

The effect on the NPV at year 10 of varying the selling price of the fish from R15 to R30 per kg is shown below. This shows the system's sensitivity to the selling price, and also shows the break-even selling price.

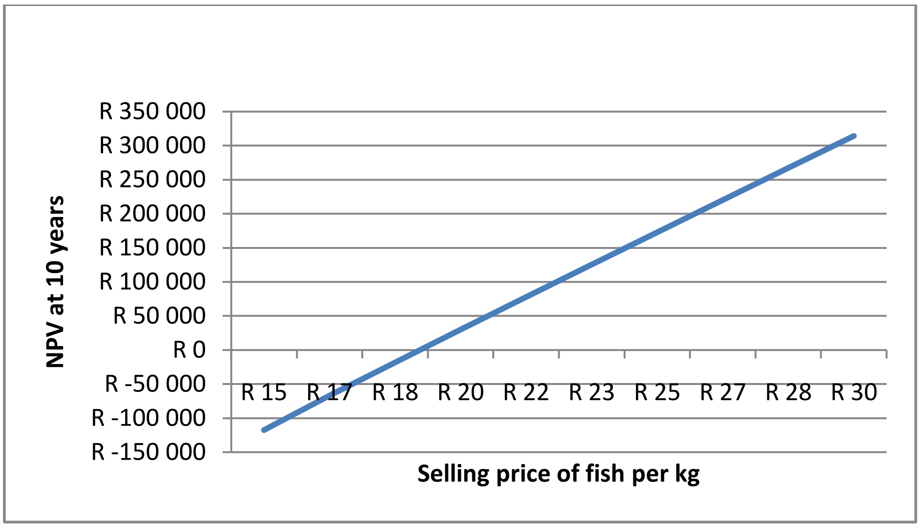

Figure 45 Net present value (NPV) of farm 1 at 10 years with varying selling price

The relationship between NPV and selling price is linear in the model (figure 45). The break-even selling price is calculated as R19.

5.3.1.5 *Effect of varying the growth rate of the fish on the NPV*

The study does not focus on determining highly accurate values for many of the parameters such as growth, operating cost and such. If these values become available through future research, the model can accommodate them.

The growth rate of the fish depends on a number of factors, such as water temperature, feed quality, water quality, species and management practices. Therefore, it is essential that the effect of varying the growth rate on the performance of the system is identified.

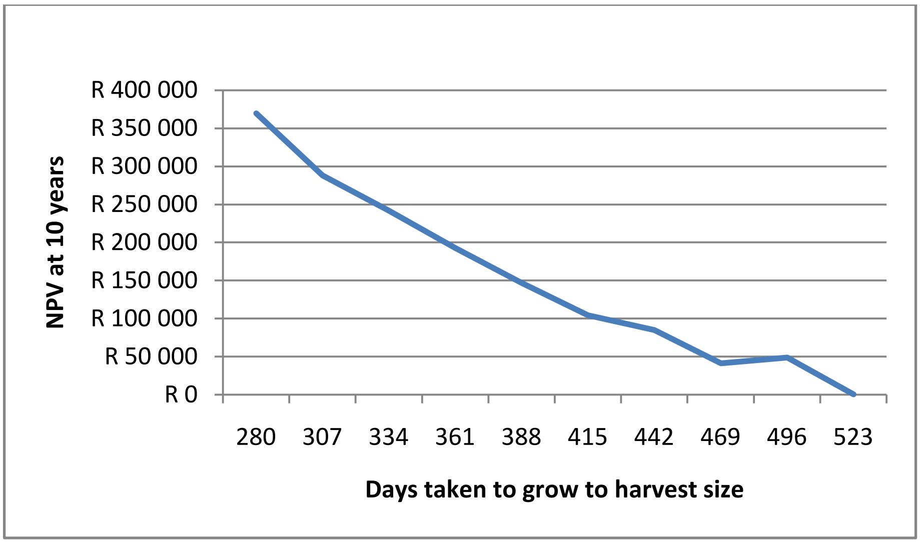

Figure 46 Net present value (NPV) of farm 1 at 10 years with varying growth rate

Figure 46 shows that the NPV will decline to zero if the days taken for the fish to reach harvest size reaches around 500 days. There is a relatively steep gradient on the NPV vs. growth rate graph where the days taken are in the 300's, indicating that the system performance is particularly sensitive to the growth rate in this region (figure 46).

The use of faster-growing species could make farms that are currently not economically viable, to become viable. This is demonstrated in section 6, where the NPV over 10 years is shown for a near-ideal system with a genetically superior species.

5.3.1.6 *Effect of varying the daily operating costs on the NPV*

A common cause of business failure is when a business runs out of cash (Richardson, Nwankwo & Richardson 1994). An unexpected increase in the operating costs of a system could cause the business to go under. This analysis looks at the sensitivity of the system to an increase in daily operating expenses.

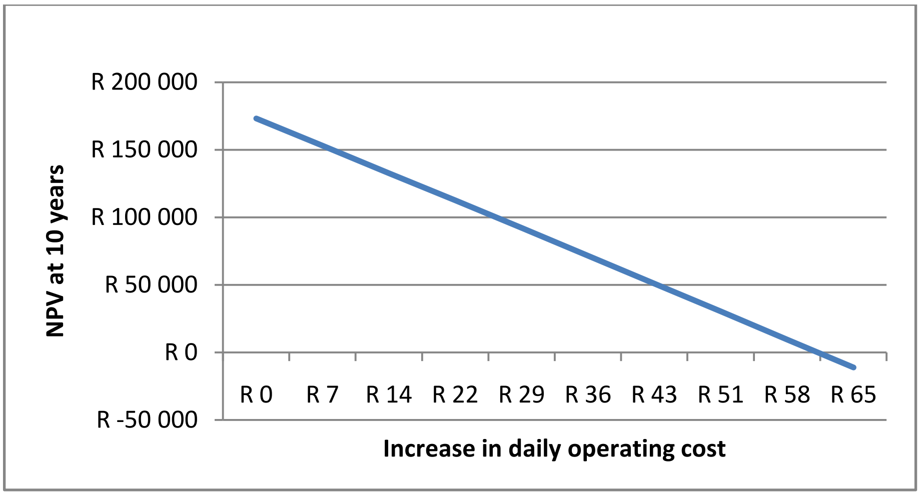

Figure 47 Net present value (NPV) of farm 1 at 10 years with varying operating costs

The system performance is very sensitive to the daily operating costs. If the operating costs were to be increased by a mere R65 per day, the NPV would be reduced to zero (figure 47).

The current model of farm 1 used above does not account for any labour or land rental costs, which makes the resulting sensitivity to the daily operating cost a point of concern. A recommendation to designing a near-optimal system would be to make the system less sensitive to an increase in daily operating costs. This is discussed later in the thesis.

5.3.1.7 *Effect of varying the capital cost on the NPV*

This calculation will determine how the financial performance of farm 1 compares to the other farms when its capital costs are increased to levels near to those of the other farms.

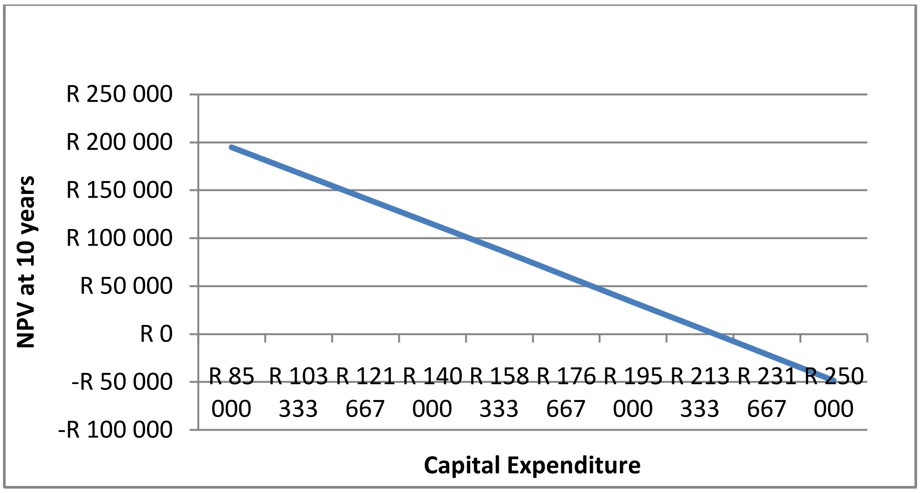

Figure 48 Net present value (NPV) of farm 1 at 10 years with varying capital cost

Figure 48 shows that the break-even capital cost is R220 000. Farm 1 is in a good position in this respect, as the capital cost is far lower than the break-even value.

5.3.2 Sensitivity analysis changing two parameters simultaneously

The study now looks at the effect of changing two parameters at the same time to establish an optimal point for the parameters. The reasoning behind this analysis is that varying one input parameter has an effect on another parameter.

The feasibility model has a VBA program built in that is capable of comparing the effect of changing two parameters at the same time. The VBA code is attached in Appendix G. The program can generate three-dimensional graphs of a performance indicator under different input parameters. Using the graphical representation, locations can be identified where the performance indicator is at an optimal point; the input parameters at that point can subsequently be identified.

The model requires a range for each of the input parameters. The number of data points to be calculated in the range should be specified for both parameters. The resolution of the graph can be increased to display more information by increasing the number of data points to be calculated in the range. This can be accomplished by setting the number of steps in-between the two endpoints of the VBA inputs to a higher value. This will, however, increase the time taken to calculate the results.

5.3.2.1 *Sensitivity of NPV to growth rate vs. FCR/feed price*

In RASs in Louisiana, it was seen that moderate improvements in growth rate increased the profitability of the system to a greater degree than large improvements in FCR (Abernathy, Lutz 1998). This statement is tested in this section in order to determine the relation between improvements in growth rate and FCR. The motivation behind this test is as follows.

In the case studies and in the literature on aquaponics in South Africa (Konschel 2009), some individuals claim that they grow tilapia using chicken droppings to fertilize the water and stimulate algae growth, or aquatic plants such as duckweed, as feed for the fish. Using these feed sources as opposed to commercial pellet type feed would have an adverse effect on the FCR of the system. The feed source with a lower conversion rate is cheaper than the commercial feed, and this must also be taken into account. In order to accomplish this, the feed price per kilogram is used as the variable parameter. The feed price can be manipulated to take into account the decrease in FCR when using alternative feed sources. The adjusted feed price can be calculated as follows.

$$Adjusted\ feed\ price\ for\ alternative\ feed = \ feed\ price\ for\ alternative\ feed \times \frac{FCR(alternative\ feed)}{FCR(commercial\ feed)} \quad (39)$$

An analysis of the effect of placing these two parameters against each other would reveal the financial outcome of this test.

The VBA program in the model calculates the value of the performance indicator (in this case the NPV) at each point in the array of parameters. Table 5 shows the output of the calculation.

Table 5 The NPV of farm 1 at an array of input parameters

		days taken to reach harvest size				
		440	**421**	**403**	**384**	**365**
feed price	**R 6**	R 190 980	R 221 053	R 251 125	R 281 198	R 311 271
	R 7	R 161 742	R 189 862	R 217 982	R 246 102	R 274 222
	R 8	R 122 149	R 148 542	R 174 924	R 201 306	R 227 688
	R 9	R 103 115	R 128 208	R 153 283	R 178 358	R 203 433
	R 10	R 82 979	R 106 356	R 129 732	R 153 109	R 176 486

The ranges for the two input parameters are as follows. The time taken to reach harvest size is set to 440 days at point 1, and decreases at equal intervals to 365 days at point 5 (figure 49). The adjusted feed price is set to R10 at point A, and decreases at equal intervals to R6 at point E (figure 49).

The three-dimensional graph (figure 49) shows the plane which represents the NPV of the system over an array of varying parameters.

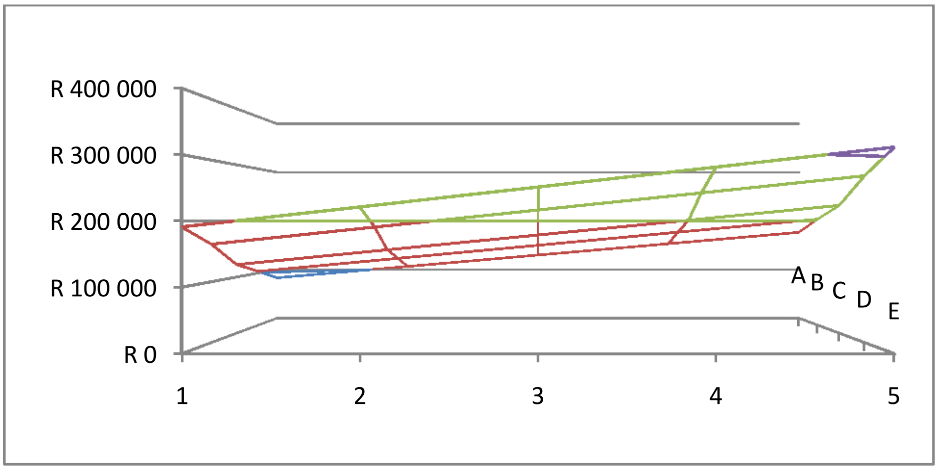

Figure 49 Area displaying the net present value (NPV) of farm 1 over a range of different growth rates (points 1 to 5 represents growth rate varying between 440 and 365 days) and feed costs (R10 to R6 between points A to E)

In order to make use of the data in this result, the data is simplified so that it shows the information that is of interest to the study. Two of the corners of the plane represent the starting and ending points of the test, where the one variable is at its value which maximises the NPV, and the other is at its value where it minimises it. At the opposite end of the plane, the converse applies. Assuming the relation between the two parameters is linear, the line connecting the end-points can be plotted. At point 1, the feed price is set at R6, and time to reach harvest size is set at 440 days. Point 5 shows the NPV when the feed price is increased to R10 and the days to reach harvest size is set at 365 days. Steps 2-4 show variations of these input parameters. Figure 50 shows the line representing this diagonal. Using this, the optimal parameters can be chosen.

The relationship between varying both parameters by an equal amount respectively is shown (figure 50). The worst combination of parameters is observed when the growth rate and feed price are set at half way between the parameters' ranges (figure 50).

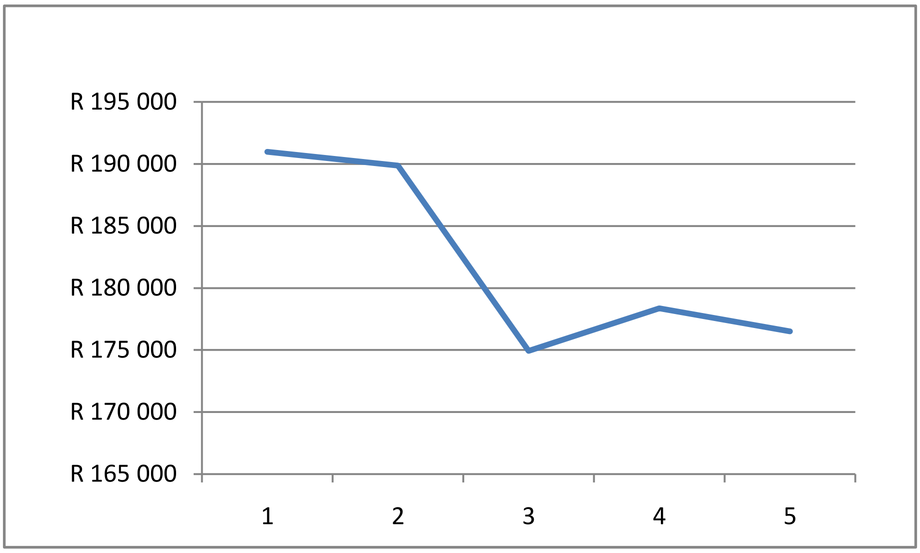

Figure 50 A line displaying the net present value (NPV) of farm 1 over a range of feed costs and growth rates (point 1: feed price R6, growth rate 440 days; point 5: feed price R10, growth rate 365 days)

The conclusion of this analysis is that it is more profitable to feed the fish a cheaper, substituted diet which decreases the growth rate. This conclusion contradicts the findings of (Abernathy, Lutz 1998); however, the reader should note that it is difficult to accurately estimate the input data without scientific results that state exactly what the FCR and feed cost is at the start and end points of the test range. Therefore, this figure may be slanted in the opposite direction if it were found that, for example, the cheaper feed decreases the growth rate to a larger extent than estimated in this test. This should be taken into account when considering the conclusion of this analysis. This topic by itself could be a prospect for future studies.

5.3.2.2 *Sensitivity of NPV to growth rate vs. operating costs*

The purpose of this analysis is to determine the optimal parameters when weighing up growth rates and operating costs. The two parameters are related in a number of ways. A number of operating practices have an effect on the growth rate of the system. These operating practices affect the operating costs of the system. Some examples of operating practices that affect the operating costs as well as the growth rates are:

- maintaining the system water temperature, which incorporates:
    - ensuring that the water is in the optimal temperature range; and
    - ensuring that the fluctuations in water temperature are not excessive.
- feeding the fish at regular intervals; and
- backwashing the filtration component at appropriate times.

Determining the end values for these three-dimensional calculations can be challenging, as it is difficult to exactly estimate all the hypothetical scenarios that could play out. The end values of this particular example tests the days to reach harvest size at 300 days and daily cost at R120 on the one end (step 1), and increments through to the other end point where the input values are 440 day to harvest and R0 additional operating cost (step 5).

The cost of R120 at step 1 could be incurred in a number of ways. An example would be heating the water entering into the aquaculture component at a certain flow rate of litres per minute by a certain number of °C. The electrical heating cost can be calculated using these values.

$$Electrical\ heating\ cost\ per\ day\ (R) = 0.65\left(\frac{R}{kW.hr}\right) \times \frac{1}{3.6\times10^{6}}\left(\frac{kW.hr}{Joules}\right) \times 4186\left(\frac{Joules}{kg.°C}\right) \times litres(kg)of\ water\ pumped\ per\ day \times \Delta temperature \quad (40)$$

The plane of the NPV under varying growth rates vs. operating costs is shown (figure 52).

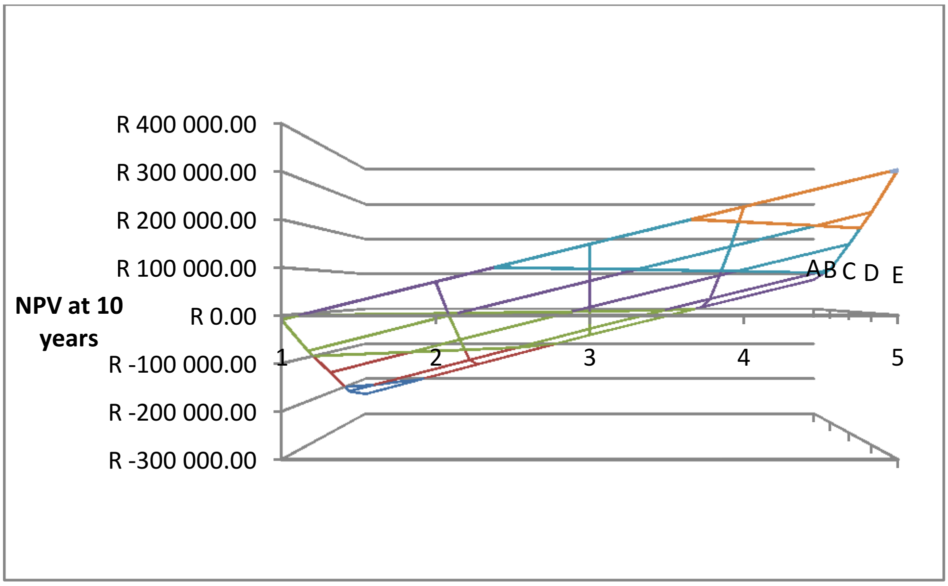

Figure 51 A plane representing the net present value (NPV) of farm 1 over a range of different growth rates and operating costs (points 1 to 5 represent the additional operating cost from R120 to R0; points A to E represent growth rate from 300 to 440 days)

From results, the straight line between the end points of the parameters' ranges is plotted (figure 52).

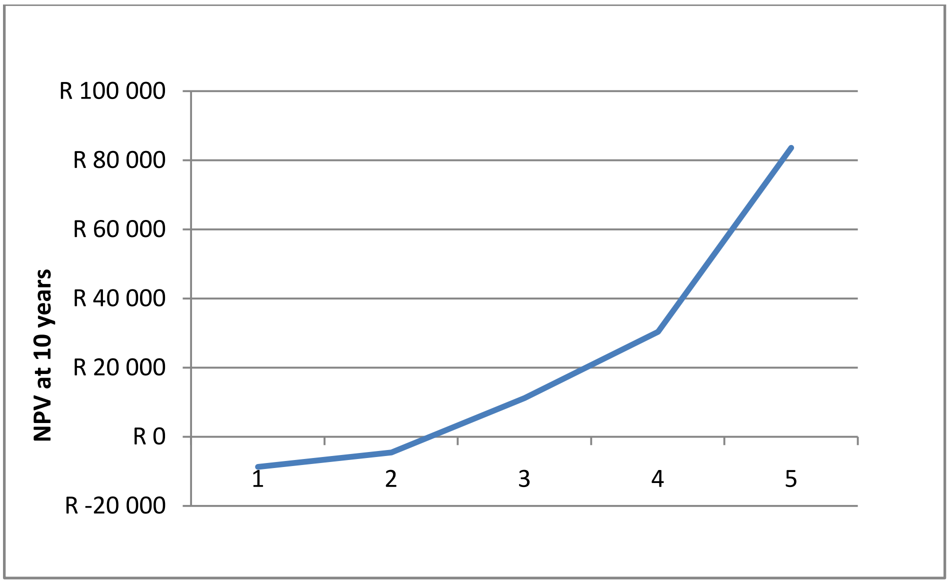

Figure 52 A line displaying the net present value (NPV) of farm 1 over a range of growth rates and operating costs (point 1: additional operating costs R120, growth rate 300 days; point 5: additional operating costs R0, growth rate 440 days)

The test confirms that step 5 is the most profitable scenario. This implies that the operating cost of the system should be minimised, at the expense of the growth rate. Again, changing the input parameters could result in a different conclusion from this test. For example, if there were a method where the growth rate could be increased without increasing the operating expenses as much, this scenario might be favourable.

5.3.2.3 *Sensitivity of NPV to capex vs. growth rate*

Another test that can be performed using this functionality is analysing the effect of simultaneously varying the capital cost, as well as the growth rate in the model, and analysing the effect of these parameters on the NPV (figure 53). The motivation for this test is as follows. In the same way that the growth rate can be affected by operating costs, it can also be affected by the capital expenditure. Hypothetically, purchasing more effective filtration equipment, automation equipment, or a solar heating apparatus would have a positive impact on the growth rate, but it would also increase the capital costs.

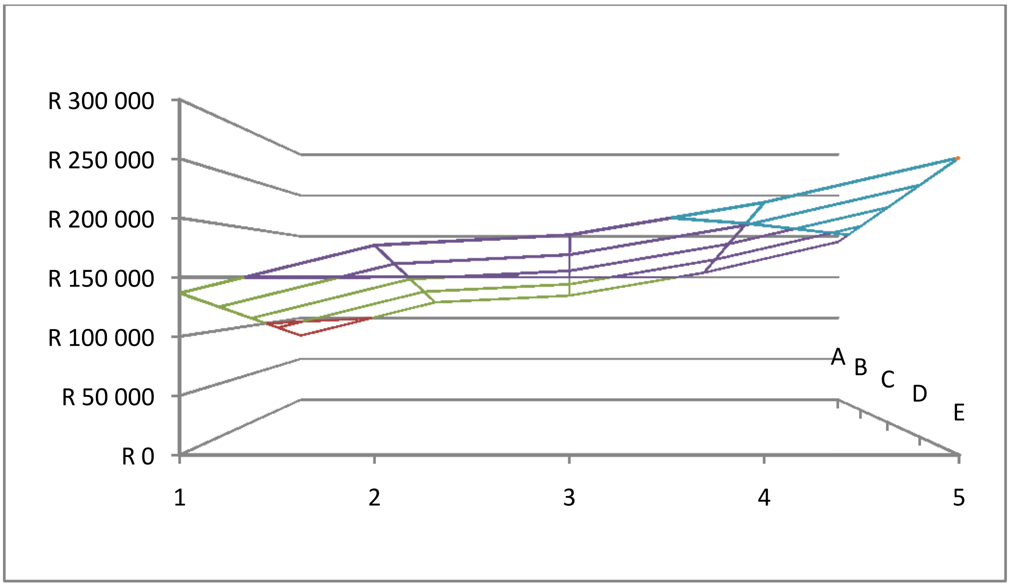

Figure 53 A plane representing the net present value (NPV) over a range of growth rates and capital costs (points 1 to 5 represent the capital cost from R 90 000 to R 130 000; points A to E represent growth rate from 300 to 440 days)

The line taken from the one corner of the plane to the opposite side (as in 5.3.2.1 and 5.3.2.2) is calculated (figure 54).

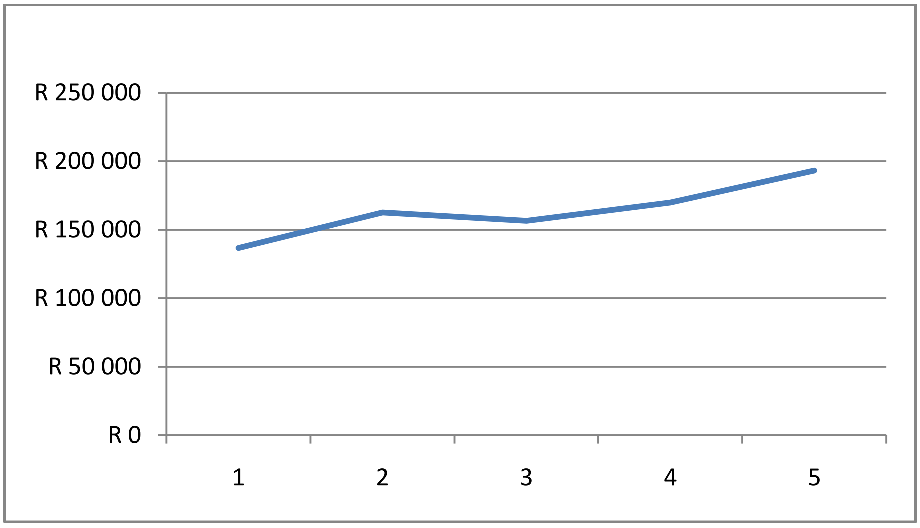

Figure 54 A line representing the net present value (NPV) over a range of growth rates and capital costs costs (point 1: capital cost R 90 000, growth rate 440 days; point 5: capital costs R 130 000, growth rate 300 days)

Once again the result of this test would be different if other input parameters were used. It is difficult to estimate the effect of purchasing more expensive equipment on the growth rate; an in-depth investigation would establish more accurate input parameters for this test.

5.3.3 Effect of capital cost on profitability

The proportion of the capital cost to total costs for each of the case study systems is calculated. The sections of the chart show the proportions of the various elements that comprise the sales income of a system (figure 55).

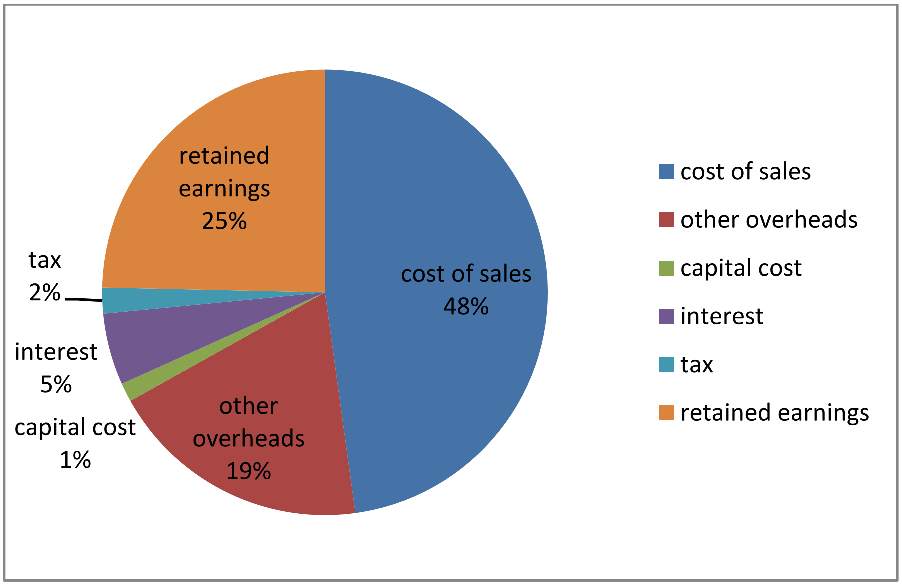

Figure 55 A breakdown of the sales generated when operating an aquaponics farm

It was noted that the farms that spend a high proportion of their costs on capital purchases and interest on debt are also the farms that perform poorly in terms of the NPV indicator. It is possible that the high proportion of these costs is responsible for the poor performance. A test that would help confirm the suspicion that the high capital costs are responsible for the poor performance of the other systems is a correlation test between the two.

The following investigation tests the correlation between the proportion of capital cost of the system relative to total cost, and the average NPV for the 10 year study period. The decision to use the average NPV is made because it gives an indication of the farms' performance over the entire study period. The values for the farms are shown in table 6 below.

Table 6 Calculations to determine the correlation between the net present value (NPV) of various farms

	Average of NPV over 10 years	% of Capital Cost to Total Costs
Farm 1	R 18 749.25	12.13%
Farm 2	R -137 490.74	21.17%
Farm 3	R -338 225.13	29.50%
Farm 4	R -224 642.76	41.54%
		Correlation between the data arrays
		-0.745767124

As shown in the table, the correlation between the proportion of capital cost to total cost and the average NPV over 10 years is approximately -0.75. This substantiates the fact that in order to design a system that will perform better, the ratio of capital costs to total costs should be minimised. The correlation of -0.75 signifies that there is reasonable inverse relation between the two parameters, but it also suggests that there are other factors that could contribute to the poor performance of the farms. This warrants a further investigation into the poor performance of these farms.

Therefore, the first step in designing a potentially successful aquaponics system is to determine an appropriate proportion of the cost of capital to total cost of sales. This can be done by either increasing the production of the system, decreasing the capital cost, or both.

5.3.4 Comparison between the results of the case studies and the literature

According to research (Rakocy, Masser & Losordo 2006), the economic potential of aquaponic systems looks promising based on the studies at their system in the UVI. They warn, however, that it would be inaccurate to make sweeping statements about the economic potential because many aspects of an aquaponics system vary by location. An outdoor system such as the one at the UVI requires a lower capital cost to construct; this affects the economic feasibility of the operation. This corresponds with the result found in section 5.3.1.2., where farms 2, 3 and 4 performed considerably better when capital costs were reduced.

Selling prices for fresh fish and vegetables at the UVI are relatively high. This is because of the cost associated with transporting fresh produce to the island. The UVI capitalises on the high prices caused by transport and importing costs. The success of the UVI system corresponds to the analysis in 5.3.1.4., where it is found that the performance of the system is sensitive to the selling price of the fish. The research at the UVI indicates that aquaponics systems can be profitable in certain niche markets.

A feasibility study on operating an aquaponics system in conjunction with an ethanol plant was conducted in the USA (Hansen, Hardy 2008). The waste heat energy is used to heat the water in the aquaponics system. The study found that the system is economically viable, and theoretically produces a 19.06 % return on investment. However, this system farms with a genetically superior species of tilapia, in a country where there is an established market, and the system receives free heat energy. Therefore, comparisons between this case and the case studies are not applicable.

Two South African authors have also commented on the feasibility of aquaponics in South Africa. They claim that the systems described in their manuals are economically feasible, granted that the correct management practises are maintained (Konschel 2009, Cuthbert 2007). These statements do not correspond with the research done in this thesis. Rather, the income figures they quote are overly optimistic, and various costs are overlooked.

5.4 Recommendations for the case studies

The stocking densities, pond sizes, and area of hydroponic growth should be calculated scientifically, so that the space and resources are used efficiently. This is not always the case and some of farmers have received information from sources that do not use well-established or scientific information in order to base their recommendations upon.

The following section lists some recommendations to the farmers operating the case study farms. These recommendations are based on the study of aquaculture and aquaponics in the literature study, as well as the results of the feasibility study and sensitivity analyses on the case study farms.

5.4.1 Fish stock

The farmers should change from growing out mixed-gender tilapia to all-male stock. Mixed-sex tilapia reach sexual maturity when they are between 9 and 15cm total length, at which stage they are between the ages of 5 and 10 months (Duponchelle, Panfili 1998, Konschel 2009). At this stage, they have not yet reached market size and weight. Once sexual maturity is reached, growth is severely stunted amongst the female tilapia. Both genders expend energy on reproduction instead of growth in biomass. Male tilapia are said to grow at approximately twice as fast as females (Popma, Masser 1999).

The sensitivity analysis performed in section 4.3.1.5 shows that growth rate is a factor that influences the NPV to a large extent. Unless reproduction is controlled, more than 75 % of the fish biomass may be too small for public acceptance (Phelps, Popma 2000).

Furthermore, the offspring produced by the reproduction will compete for food, space and resources, subsequently decreasing the productivity of the operation.

Buying or producing an all-male fish stock is a relatively simple process, and the effect thereof on the profitability of the operation is substantial. Further reading on the methods of acquiring an all-male fish stock and the sex-reversal process are described by (Phelps, Popma 2000).

5.4.1.1 ***Growth of fish relative to temperature***

This section shows the importance of maintaining the temperature within a suitable range on the growth rate of the fish.

According to research (Timmons, Ebeling 2007), a way to define fish growth is based upon a temperature unit approach. The following formula is used to calculate the growth rate of a fish species.

$$growth\left(\frac{cm}{month}\right) = \frac{T - T_{base}}{TU_{base}} \quad (41)$$

The symbol T in the equation is the temperature that the fish are grown at. T_{base} and TU_{base} are constants that are supplied by (Timmons, Ebeling 2007). Using equation 41, a graph can be draw representing the number of months that it would take for a tilapia to reach market size at varying temperatures (figure 56).

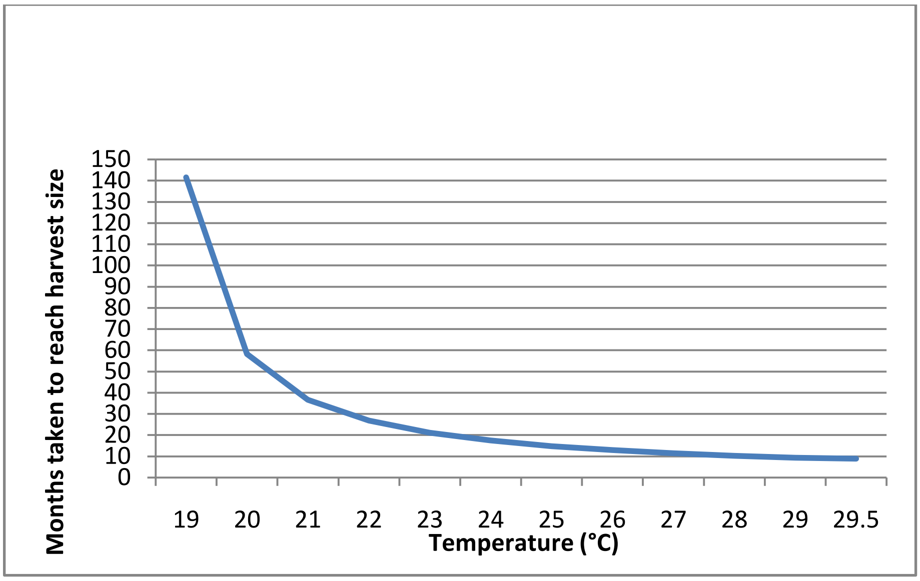

Figure 56 Months taken to reach harvest size at varying temperatures (Timmons, Ebeling 2007)

Figure 57 shows the time taken to reach harvest size for a smaller range of temperature to get a better idea of the time taken under a likely range of temperature.

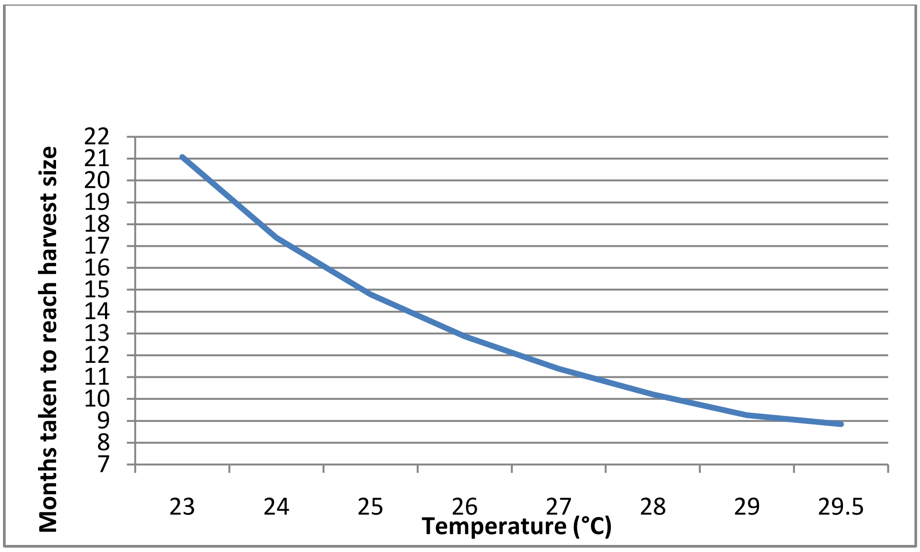

Figure 57 Months taken to reach harvest size at varying temperatures (for smaller range of temperatures) (Timmons, Ebeling 2007)

This formula is an approximate calculation and the actual growth rate is dependent on other aspects such as water and feed quality, stocking density and the species of tilapia farmed.

The growth rates calculated by this approximated formula are higher than those observed in the case studies.

However, the figures demonstrate the importance of maintaining the water temperature within a suitable range. The current farmers must ensure that they maintain their water temperatures using the heating devices at their disposal. From the study it was determined that the farmers would only need to heat their water for a number of months in the year. Other measures that can be taken are to insulate the fish tanks and greenhouse to minimise the loss of heat.

5.4.1.2 *Production staging*

Using a staggered production system such that the crops and fish are harvested at regular intervals (as opposed to harvesting the entire system at the same time), is recommended (Rakocy *et al*. 2003). This eliminates the problem of experiencing nutrient deficiencies in the system towards the end of the plants' life cycles. More information on this topic is available from (Rakocy *et al*. 2003). Staggering production also provides the farmer with produce at regular intervals. This makes the harvesting process more manageable and cost-efficient. It is also preferable to have a regular produce for marketing and sales purposes as the products are perishable and markets prefer a regular supply of goods (Rakocy, Masser & Losordo 2006).

In a well-designed system, both the aquaculture and hydroponic components of the system operate at near-maximum efficiency (Rakocy, Masser & Losordo 2006). Operating a system with fish stocking densities near the maximum stocking density is advantageous because it uses space efficiently which maximises production, and reduces the variation in the daily feed input in the system. The latter advantage is an important factor for the hydroponic component (Rakocy, Masser & Losordo 2006). The system's production staging should be designed in such a way that the nutrient production by the fish and nutrient uptake by the plants are matched.

5.4.2 System design

5.4.2.1 *Filtration*

The filtration used in some of the farms needs to be improved in order to improve water quality. If the farm operators intend on stocking the ponds at stocking densities that are in line with other operations overseas (Rakocy, Masser & Losordo 2006), the filtration systems must be improved. A solids capture device is needed in some of the systems, as this is a vital component of RAS (Timmons, Ebeling 2007). Some technically feasible aquaponics designs operate without solids capture devices, but this in often to the detriment of the aquaculture component of the system. These systems have a high ratio of hydroponics component relative to aquaculture component. Further reading on these systems is available from (Rakocy, Masser & Losordo 2006, Diver, Rinehart 2006). However, solids capture devices can be relatively expensive, so this factor needs to be taken into account. A study determine to what extent the farmers need to improve their filtration would reveal more information.

5.4.2.2 *Grading*

A practice that can help to increase the productivity of the systems is grading the fish at certain stages. Grading is a process where the fish are sorted according to size, and the smaller fish are removed. These fish are removed because they are not converting feed into biomass efficiently (Timmons, Ebeling 2007). Fish that grow slower than the ideal growth rate are known as genetic runts. These fish do not have the potential to grow at an efficient rate, and should be identified and removed from the system as early in the production cycle as possible (Timmons, Clark 2009). Grading can be performed by drawing a mesh grid with holes of a specific size though the water body. At the stage when grading is performed, the majority of the fish should be of such a size that they cannot fit though the mesh screen. The genetic runts are smaller and fit though the screen, after which they should be removed from the system and culled and discarded of humanely. The case study farms do not grade their fish. This decreases productivity and increases the number of smaller, un-marketable fish harvested.

5.4.2.3 *Construction*

The current farmers have evidently already constructed their farms, so little can be done in the way of improving this aspect. However, at a later stage when the assets must be replaced as a result of wear and tear, or if the farmer decides to expand on the system, the farmers could construct the components in a slightly differently. For example, larger growout tanks or cheaper growbeds could be installed.

An example of how the farmers could improve the financial performance of the farms by altering the construction is demonstrated below. The construction of the growbeds could be done in a more cost-effective manner. Figure 58 and 59 shows the growbeds of farms 2 and 4 respectively. Note the costly materials used for the support of the growbeds, as well as the inefficient usage of space.

Figure 58 Farm 2 growbeds

Figure 59 Farm 4 growbeds

An alternative construction method is shown (figure 60 and 61); this technique of growbed construction is cheaper and can be designed such that it is more efficient in terms of space utilization. The growbed is constructed by digging and levelling a hole in the shape of the desired growbed. The plumbing is then installed, and the formation is lined with a tough plastic material. In the case below, the growbed is used for raft hydroponics, but medium hydroponics could also be practised in this manner.

Figure 60 Construction of an alternative growbed

Figure 61 Alternative growbed in operation

Decreasing the cost of constructing the assets will increase the financial performance of the farm (section 5.3.3).

5.4.3 Other recommendations

These recommendations have been uncovered during the course of the study. The author acknowledges that these recommendations could cause the aquaponics system to move away from its core objective, which is to produce and sell products (i.e. fish and plants), but the recommendations should be mentioned nonetheless.

5.4.3.1 *Value-adding*

The farmer could add value to the produce of the system by processing the products. Ways in which to do this include:

- packaging the produce into marketable size packages;
- filleting, smoking or breading the fish; and
- processing the vegetables or herbs into chutney, salsa, pesto or jam.

Value-adding can increase the value and shelf-life of the produce considerably, but often the costs involved in value-adding are neglected. The labour and facility requirements of performing such tasks can be considerable.

5.4.3.2 *Agritourism*

Agritourism is often practised in conjunction with aquaponics. It appears that the concept of aquaponics is intriguing to many people. The farm operator can give a group of tourists a guided tour of the facility and explain how the aquaponics farm operates. Some aquaponics farmers also offer courses on aquaponics. These activities can generate some extra income for the operation. A factor that needs to be taken into account when allowing large numbers of visitors into an aquaponics facility is that of bio-security. The visitors could cause a disease to be introduced into the system, which could cause a number of problems. The time taken to give the tourists the tour should also be taken into account. The author concedes that this aspect is off course from the actual study, but numerous cases of these activities taking place are observed; for this reason, the prospect of these activities is stated.

5.4.3.3 *Niche marketing*

This aspect could improve the profitability of the aquaponics system to a large extent. The profitability of the systems is highly sensitive to the selling price of the produce.

5.4.3.4 *Diversification*

A noteworthy recommendation that makes financial sense is that of diversification of the income streams. Strictly, diversification refers to a strategy that reduces the exposure to risks by combining a variety of investments that are unlikely to all move in the same direction (Firer *et al*. 2008). These strategies can help prevent unfavourable situations from occurring. For example, if a component of the system is not producing the expected income, the other products can mitigate the loss incurred to the system. A situation like this can occur for a number of reasons, such as the market price for a certain product unexpectedly dropping to below the cost of production, or a disease wiping out a whole crop or species of plant or animal.

Suggestions for diversification are listed below:

- the farm operator could incorporate chickens into the system as in the operations on farm 4;
- a number of different vegetables or herbs could be planted so that if one vegetable type performs badly, the income from the other vegetables can mitigate the loss.;
- algae can be grown in order to feed chickens or fish or harvest spirulina; and
- the batches of fish could be isolated to as to prevent the spread of disease from one batch to the next.

5.4.3.5 ***Conclusion on other recommendations***

The recommendations in section 5.4.3 have been found to increase the revenue of aquaponics operations. These recommendations have been made by (Konschel 2009, Cuthbert 2007). The author is however suspicious that these activities are suggested to make an aquaponics venture seem more profitable than it is. The author found no evidence of an economically viable aquaponics system in operation in South Africa. Therefore, care should be taken not to overestimate the increased revenue received from these recommendations.

6 Near-ideal system

The following section investigates the possibility of designing and specifying a system that is theoretically better than the current farms in South Africa. The logic behind this investigation is that using the information gathered from the literature study, case studies, feasibility studies, sensitivity analyses and recommendations to the farmers, a system could be designed or specified that is more profitable than the current farmers'. Favourable characteristics of aquaponics systems that would cause them to be more profitable can be indentified and incorporated into the so-called "near-ideal" system.

6.1.1 Methods for designing near-ideal system

The feasibility model is used to calculate the performance of the near-ideal system. The process of designing or specifying a near-ideal aquaponics system investigates whether a favourable arrangement of model input parameters could improve the chances of success for a system of this sort. The input parameters are subject to a number of constraints, which need to be taken into consideration.

In the same way that the operating objective for financial management is to maximise the net present worth of a venture or share (Firer *et al*. 2008), the purpose of this section is to maximise the expected NPV of a potential aquaponics venture.

An objective function can be formulated that achieves this aim. This function is shown below. The components that make up the objective function are individually broken down until each component is directly constrained by an external factor. These constrained entities are typed in bold.

$$Maximum\big(Average(NPV\ from\ 1\ to\ 10\ years)\big) = fn(cash\ flows) \ldots\ldots\ldots\ldots\ldots (42)$$

$$Cash\ flows = fn(sales, costs) \ldots\ldots\ldots\ldots\ldots (43)$$

$$Sales = fn(production\ rate\ aqu, production\ rate\ hydro, \boldsymbol{sale\ prices}) \ldots\ldots\ldots\ldots\ldots (44)$$

$$Costs = fn(capex, opex) \ldots\ldots\ldots\ldots\ldots (45)$$

$$capex = fn(system\ design) \ldots\ldots\ldots\ldots\ldots (46)$$

$$Opex = fn(cost\ of\ sales, overheads) \ldots\ldots\ldots\ldots\ldots (47)$$

$$Cost\ of\ sales = fn\begin{pmatrix} \boldsymbol{feed\ price}, \boldsymbol{FCR}, \boldsymbol{additives}, \\ \boldsymbol{hydroponic\ component\ costs} \end{pmatrix} \ldots\ldots\ldots\ldots\ldots (48)$$

$$Overheads = fn\begin{pmatrix} electricity\ costs, \boldsymbol{insurance}, \boldsymbol{labour}, \\ \boldsymbol{interest\ on\ debt}, \boldsymbol{capital\ purchases} \end{pmatrix} \ldots\ldots\ldots\ldots\ldots (49)$$

$$Electricity\ costs = fn(\boldsymbol{electricity\ price}, \boldsymbol{inflation\ on\ electricity}, \boldsymbol{power\ consumption}) \ldots\ldots\ldots\ldots\ldots (50)$$

$$Production\ rate\ aqu = fn(biological\ growth, system\ design) \ldots\ldots\ldots\ldots\ldots (51)$$

$$Production\ rate\ hydro = fn\begin{pmatrix} \boldsymbol{expected\ production}, \\ \boldsymbol{temperature}, \boldsymbol{water\ quality} \end{pmatrix} \ldots\ldots\ldots\ldots\ldots (52)$$

$$Biological\ growth = fn(\boldsymbol{species}, \boldsymbol{feed\ quality}, \boldsymbol{water\ quality}, \boldsymbol{temperture}) \ldots\ldots (53)$$

$$System\ design = fn(\boldsymbol{physical\ constraints}, \boldsymbol{budget\ constraints},) \ldots\ldots\ldots (54)$$

Figure 62 shows the formulas in a break-down arrangement.

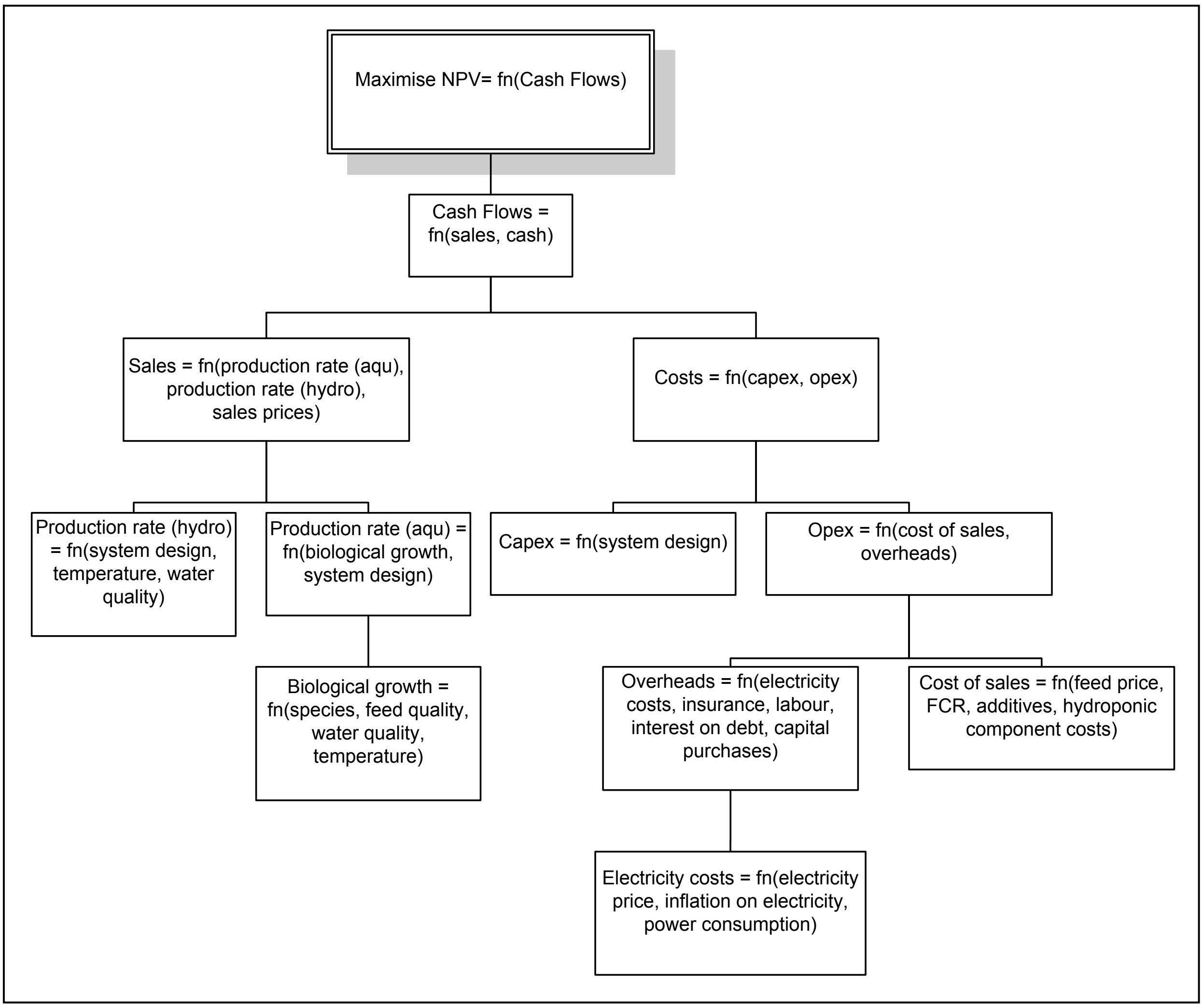

Figure 62 Chart of the entities and parameters that affect the objective function of the near-ideal system

The group of formulas above show the relation between the objective (to maximise the NPV over the 10-year scope), and the constrained parameters which can be optimised in favour of the goal.

There are a number of constraints which cannot realistically be changed. These include the electricity price, species, insurance rate and inflation. The other parameters can be changed, but a change in one parameter will likely affect a number of the other parameters. For this reason, it is not possible to use a software package to determine an ideal set of input parameters. The objective function, however, shows which entities should be maximised, and which should be minimised. The sales element of the function should be maximised, and the costs element minimised.

The following recommendations can help to accomplish this.

- Capital cost should be minimised such that it comprises a smaller percentage of the cost of sales of the system.
- The system should make maximum use of cheap or available energy such as solar or wood-burning to replace electricity.
- The system should be designed such that it is less sensitive to an increase in daily operating costs, to accommodate for unforeseen costs.
- Throughout the entire function, the risk factor should be minimised. This should be done to minimise the likelihood of an unfavourable situation taking place that adversely affects the objective function, and also to reduce the cost of capital.
- The effect of economies of scale should be taken into account.

6.2 Designing of the near-ideal system

6.2.1 Capital cost

Capital cost is an important consideration in the design of a near-ideal system. Before designing a near-ideal system, the author must decide upon a suitable amount for the capital cost. If no constraints are set out, the economies of scale would dictate that the larger the system is, the better it would perform. It was therefore decided to limit the capital cost to within the range of those of the case study farms i.e. between R100 000 and R 250 000.

The near-ideal system should maximise the productivity of the system using this capital cost. This can be achieved by:

- using low-cost materials with acceptable wear and tear rates; and
- personally overseeing the construction of the system instead of outsourcing it.

Also important when constructing the system is the following factors:

- maximising the utilization of the greenhouse space; and
- designing the system such that it makes efficient use of energy.

6.2.2 System design

Using the appropriate ratio between the aquaculture component and hydroponic component is a key aspect of the system design. This ratio is described in terms of water volume or surface area of the components, and depends on the stocking densities of the aquaculture component, and the method of hydroponics used.

The method of hydroponics most commonly used in systems that strive to be commercially viable is the raft hydroponics technique. For that reason, this method is chosen for the near-ideal system.

For raft hydroponics, the recommended ratio of surface area of the hydroponic component relative to the aquaculture component is 7.3:1 (Rakocy, Masser & Losordo 2006). This ratio will be used for the near-ideal system. Using this recommended ratio will result in a large majority of the system's water being in the hydroponic component.

As a result of the recommendation to diversify the system's income streams, the near-ideal system could have a variation of different hydroponic growbeds. An NFT or gravel component could be constructed and integrated into the system at relatively low cost.

6.2.3 Summary of near-ideal system characteristics

A near-ideal system would have the following characteristics:

- correct component ratio;
- low-cost construction;
- maximised space utilization i.e. maximised productivity of the system;
- optimal water temperatures using solar and fire-powered water heating if possible;
- sufficient flow rates and aeration for solids removal, DO levels, and TAN removal;
- sufficient surface area for bacteria to biologically filter the compounds;
- diverse income streams (separate fish stocks, various vegetables, various hydroponic techniques, possible incorporation of chickens);

- consider substituting pelleted feed with duckweed and chicken droppings;
- minimised system risk (sensitivity to daily operating costs, bio-security, power failure, monitoring equipment);
- tilapia *O. mossambicus* with strong genetics farmed ;
- efficient electrical usage;
- guaranteed market for goods, with potential price premium; and
- correct management practices.

Using similar construction methods as those in farm 1 could allow the capital costs to be relatively low. A realistic amount for the capital costs is estimated at R180 000. Using this budget, the volume of water in the growout tanks should be maximised. The surface area of the hydroponic growbeds should also be maximised. As in farm 1, the fingerlings should be bred in-house as this is theoretically more cost-effective. Figure 64 shows the breeding tanks specified for this process.

The near-ideal system has a separate solids capture component as this aspect is emphasised in RAS (Timmons, Ebeling 2007.

A number of the input parameters remain the same as with the case studies as they are constrained by external factors.

6.2.4 A potential layout for a near-ideal system

Figure 63 shows a potential layout for the near-ideal system. The figure is simply to illustrate that a near-ideal system should use the greenhouse space efficiently, and that the component ratios should be designed appropriately.

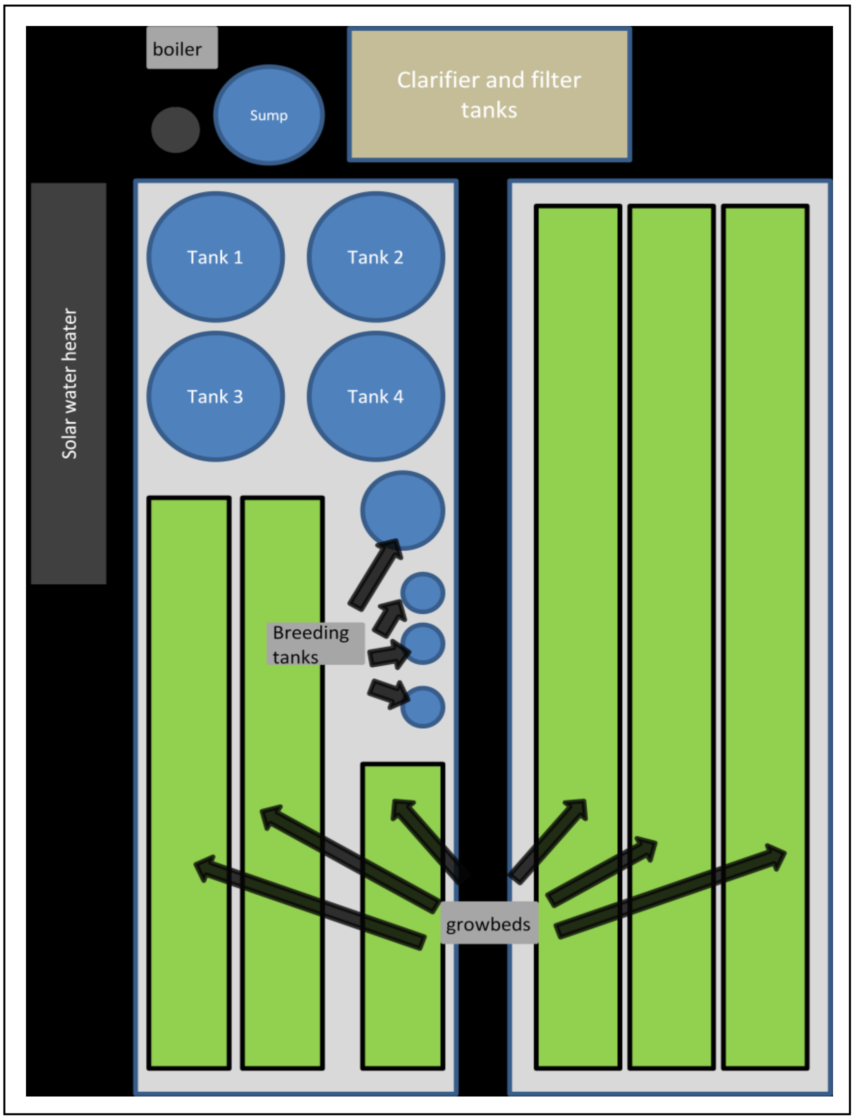

Figure 63 A potential layout for a near-ideal aquaponics system (approximately drawn to scale)

6.2.5 Near-ideal system performance according to feasibility model

The parameters are entered into the model. A larger daily operating cost value has been used to account for labour charges and unexpected costs. Figure 64 shows the projected NPV for the near-ideal system.

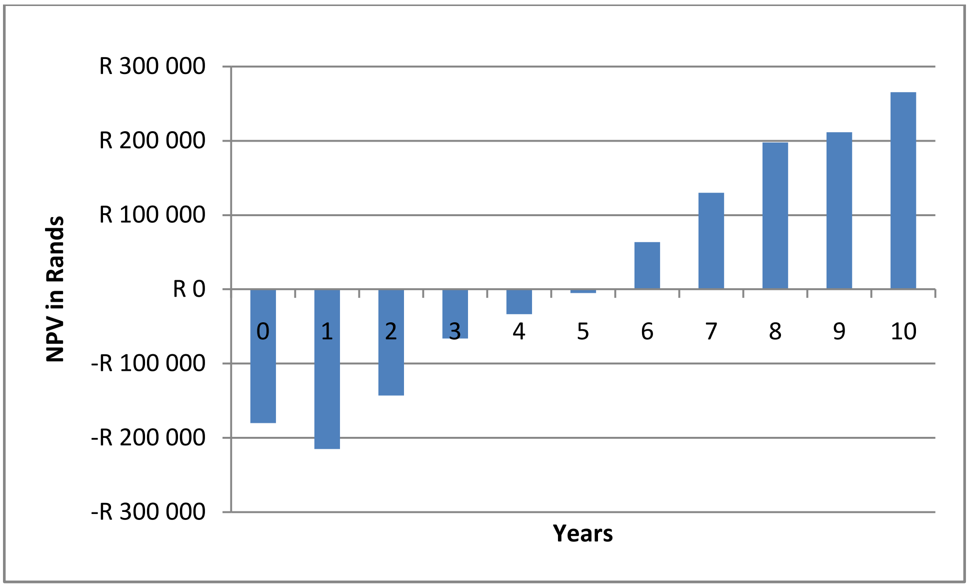

Figure 64 Net present value (NPV) for 10 years of a near-ideal system

The performance of the near-ideal system draws a slight resemblance to that of farm 1 when comparing the NPVs. The difference between the two is that the near-ideal system incurs a cost for labour. The breakeven additional operating cost for farm 1 is R65.

If a species such as *O. Niloticus* were hypothetically allowed to be farmed with, and the time taken to reach harvest size is decreased from 365 days for *O. Mossambicus* (Cuthbert 2007, L De Wet 2010, pers. comm., 27 Jan) to 280 days (Chapman 2000), the system's performance would improve considerably. Figure 65 shows the NPV of the near-ideal system when farming with a superior tilapia species. The performance of the system differs as a result of the higher growth rate of the *O. Niloticus*, which increases the productivity of the system.

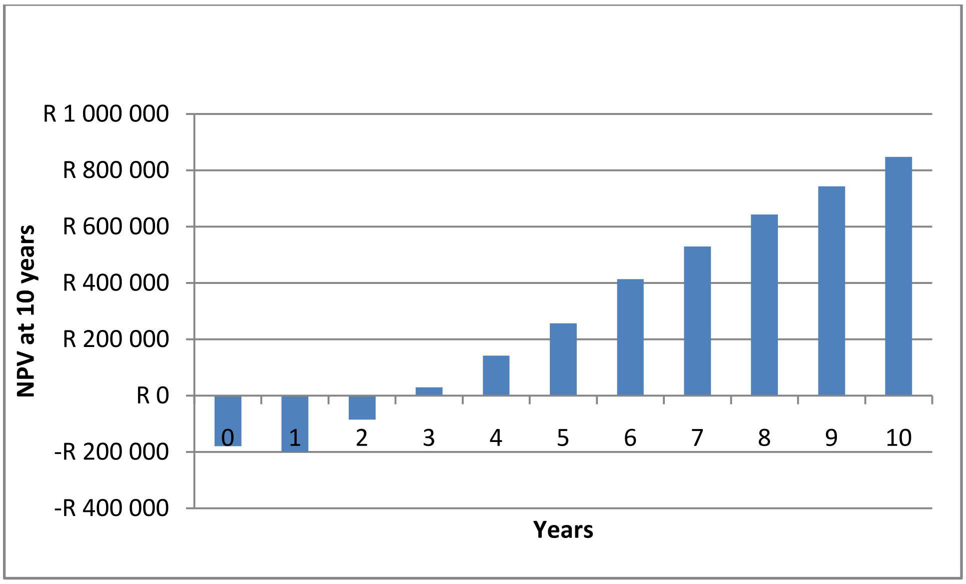

Figure 65 Net present value (NPV) of near-ideal system farming a superior tilapia species

The figure shows that the discounted payback period for the system is approximately in the fourth quarter of the second year. This represents a much more favourable investment. A way to quantify the improvement between farming *O. mossambicus* compared to genetically superior species could be to look at the difference in return on investment. Farming *O. mossambicus* provides a 7 % annual return on investment over 10 years. The genetically superior species would provide an 18.07 % annual return on investment over 10 years. Hypothetically, farming with a superior tilapia species would not increase the risk of the operation; however, stringent safety precautions would have to be put in place to prevent the fish from escaping into the wild. Additional research into this subject would establish the practical implications of farming with an alien species.

7 Conclusion

After studying the state of the aquaculture industry, tilapia farming, the constraints limiting the development of aquaculture and the aquaponics “industry”, the information needed to build a techno-economic model for the case studies in South Africa was gathered. The case studies were then documented, and the data was used to populate the techno-economic model and determine the feasibility of the case studies. The sensitivity analysis uncovered some facts about the systems’ dependence on and interrelationships between a number of constraints. Recommendations for the current farms were then made based on the conclusions from the techno-economic model and other information gathered. The study then examined whether a near-ideal system could be designed such that it performs better financially compared to the current systems. This virtual system combined all known best practices and values; this hypothetical system was entered into the techno-economic model and showed that it was borderline viable.

The study concludes that the aquaculture industry is a very difficult one to successfully enter into. This statement was reaffirmed when one of the case study farms closed down half way through the study, citing the lack of financial viability as the reason for terminating operations.

The feasibility study of the case studies concluded that the majority of the farms would make particularly unfavourable investments under the current circumstances. One farm did perform reasonably well, but a number of assumptions were made which positively influenced the outcome of the system’s performance. These assumptions do not reflect the reality of an aquaponics system in South Africa; they merely reflect the best-case actual operations at the farm.

The case studies could not be used to completely verify the model as they are not nearly as productive as the model predicts; yet, the model still predicts that most of the case studies would not be financially viable.

The recommendations given for the case study farms would help the farmers to improve the profitability of the farms, but not necessarily to such an extent that they result in the farms becoming financially viable.

The section studying the prospect of designing a near-ideal system based on the information gathered during the rest of the study did not bring forward any astonishing results. The constraints that the small-scale aquaponics industry is placed under restrict the operations to such an extent that only marginal improvements could be made in a few aspects. The near-ideal system benefits from improvements made with respect to the productivity, risk reduction and efficiency of the operations.

There are a number of factors that could transform aquaponics from a risky venture with low returns to an economically feasible venture. Increasing the scale of the operation may decrease the proportional cost of capital and operation, thereby making it more profitable. The species constraint could also play a significant role in the viability of the operations. If the superior, faster-growing species of tilapia were permitted to be farmed in South Africa, the operations would benefit significantly from this, as shown in section 6. Niche marketing could also be instrumental to the success of aquaponics. If the farmers could fetch higher prices for their produce, this would have a substantial effect on the feasibility.

Aquaponics is a viable concept when viewed from a technical perspective. The symbiotic relationship between the plants and fish makes it a sustainable food production method. However, from an economic perspective, the odds are stacked against it in the form of high capital and operating costs, high risk, and low profit margins. Extreme caution should be practised when considering an aquaponics venture and, as stated by (Timmons, Clark 2009), “Only invest what you can afford to lose”.

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Appendix A – Trend of tilapia in the U.S.A.

Table 7 The growing trend in tilapia consumption in the US

	2007		1995	1990	
species	rank	kg / capita	kg / capita	rank	kg / capita
shrimp	1	1.86	1.13	2	0
canned tuna	2	1.22	1.54	1	0.68
salmon	3	1.07	0.54	5	0.33
pollock	4	0.78	0.69	4	0.58
tilapia	5	0.52	0	not ranked	0
catfish	6	0.40	0.39	6	0.32
crab	7	0.31	0.15	10	0.13
cod	8	0.21	0.44	3	0.63
clams	9	0.20	0.26	7	0.28

Appendix B - Old feasibility model outline

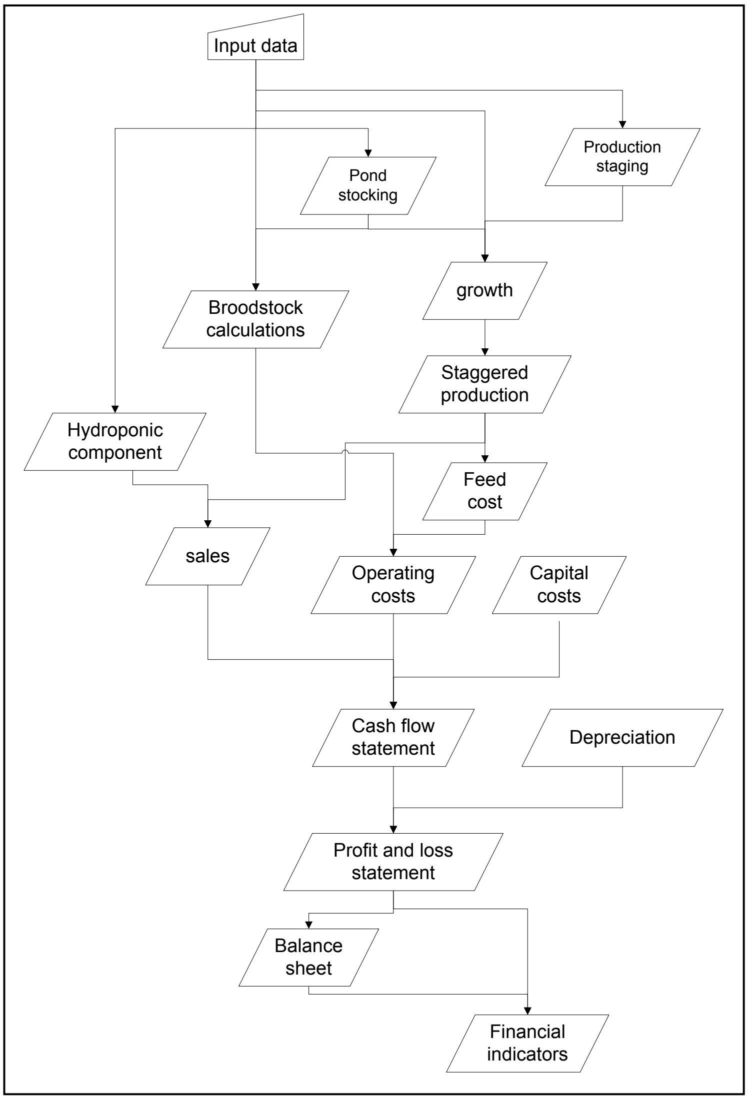

Figure 66 Outline of the old feasibility model that predominantly uses VBA programming

Appendix C - Description of financial indicators

Net present value

An investment is seen as being worth undertaking if it creates value for its owners. In a general sense, this is defined as an operation that creates value and is therefore worth more in the marketplace than it costs to acquire. The net present value (NPV) is defined as the difference between an investment's market value and its cost (Firer *et al*. 2008). The rule for NPVs is that an investment should be accepted if the NPV is positive, and rejected if the NPV is negative.

The NPV is calculated by discounting all of the cash flows of an investment (including the investment cost) to the present time, using a discount rate. The calculation of the NPV is a relatively simple one, but task of determining the appropriate discount rate, as well as predicting the future cash flows, is much more challenging (Firer *et al*. 2008). The formula for the NPV is as follows.

$$NPV = \sum_{t=1}^{T} \frac{cash\ flow\ (t)}{(1+discount\ rate)^t} \qquad (55)$$

Payback rule

The Payback rule is defined as the amount of time taken for an investment to generate an accumulated cash flow that equals the initial capital cost. The rule used with this financial indicator is that an investment should be accepted if it has a payback period that is less than a pre-determined number of years.

The payback period is one of the simpler and more widely understood ideas when it comes to measuring the performance of an investment, yet it has a number of pitfalls. The method does not take into account the time value of money, as well as risk. The method also ignores any cash flows that take place after the cut-off period (i.e. the predetermined number of years as above). Perhaps the biggest problem with this method is that it is difficult to decide on the right cut-off period. There is no economic rationale behind looking at the cut-off period in the first place, which often results in the analyst choosing a cut-off period arbitrarily.

In the case studies, the payback period may be misleading as a result of the second disadvantage mentioned above. The farmers incur large sums of capital costs at various stages in the projects' life cycles. Changing the timing of these capital costs would alter the result of the payback period, but it may not necessarily mean that the investment is more favourable in the long term.

Discounted payback rule

This variation of the payback rule takes into account the time value of money, and is therefore a better indication of whether an investment is attractive.

The discounted payback rule is a compromise between two other financial indicators, namely the regular payback rule, and the NPV indicator. It incorporates elements of both, which causes it to lack the simplicity of the former, and the conceptual rigour of the latter. However, it is still a better indicator than the regular payback rule, as it recognises that the investment money could have been used elsewhere, thereby earning a return on it.

Average accounting return

The average accounting return is calculated by taking the average net profit after tax and dividing it by the average book value of the investment. This indicator has a relatively high level of use in South Africa (Firer *et al*. 2008), and is therefore discussed in order to point out its strengths and weakness as a decision-making rule. The formula for calculating average accounting return is as follows.

$$average\ accounting\ return = \frac{average\ net\ profit\ after\ tax}{average\ book\ value} \dots\dots\dots\dots\dots (56)$$

This indicator is easy to calculate, as the necessary information is usually available. However, the rule has a number of weaknesses. It is not a true rate of return in any meaningful economic sense, as it is the ratio of two accounting numbers. As in the payback rule, the average accounting return relies on an arbitrary cut-off rate to decide the investment's fate.

Internal rate of return

The internal rate of return (IRR) is defined as the discount rate that makes the NPV of the investment zero. In investments with multiple cash flows (which is the case in the investments considered in this thesis), the IRR cannot be solved for algebraically, and must be solved using trial and error.

$$0 = \sum_{t=1}^{T} \frac{cash\ flow\ (t)}{(1 + discount\ rate)^t} \rightarrow solve\ for\ discount\ rate \ldots\ldots\ldots\ldots..(57)$$

The rule for making decisions using the IRR indictor is to accept an investment if the IRR exceeds the required return.

A problem with the IRR rule as a decision-making tool is that, when determining the IRR of an investment that produces multiple, irregular cash flows, an event may occur where there are multiple rates of return.

Another problem that arises with the IRR rule occurs when a comparison between two investments that are mutually exclusive (implying that taking the one investment prevents the taking of the other) is made. The IRR rule can sometimes return misleading results, causing an investment to be chosen over another that has a higher NPV. Therefore, when considering mutually exclusive investments, the IRR rule should not be used.

Owing to its close relation to NPV, and the ease with which the indicator can be understood and communicated, the IRR rule is very popular in practice.

Profitability index

Also called the benefit/cost ratio, this ratio is determined by dividing the present value (PV) of the future cash flows by the investment cost. It is closely related to the NPV, and generally leads to the same decisions being made.

$$Profitability\ index = \frac{PV\ of\ future\ cash\ flows}{capital\ cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(58)$$

Appendix D - People interviewed for the thesis

Kevin Cuthbert

Kevin is an aquaculture consultant in the Garden Route area. Contact was made with Kevin in the early stages of the literature study. Kevin provided many valuable contacts to aquaponics farmers. He also made available a handbook on aquaponics which he wrote himself, which provides a good background on the design, construction methods and operating practices of some of the farms operating in South Africa.

Tanner Georgiou

Tanner is an aquaculture specialist and has worked on many fish farms during his career. He provided a selling price for tilapia that is realistic as he signed a contract with a fishery to sell tilapia in South Africa.

Ken Konschel

Ken is an aquaponics expert from the KZN region, and has been working in the aquaponics industry for many years. He has also written a handbook on aquaponics in South Africa, which provides a lot of information on the topic as gained through Ken's person experience. He received an award for innovative work from the International Institute of Inventors in 2003.

Dr. Charles Johnson

Dr. Johnson is an aquaponics specialist from the U.S.A., and the interview with him brought forward some interesting details. He is of the opinion that small-scale aquaponics can be successful and helped with some conceptual aspects of the thesis.

Gareth Lawrence

Gareth is an aquaculture professional and specialises in making business plans and feasibility studies for aquaculture ventures. He assisted by outlining the methods to perform the feasibility study, as well as providing information on some intricacies of how to model an aquaculture venture. He also helped in verifying that the model is in fact working correctly.

Lourens de Wet

Lourens is an aquaculture specialist from the University of Stellenbosch. He helped by outlining the factors that constrain the culture of tilapia culture in South Africa, and providing a realistic outlook on the project.

Leslie Ter Morshuizen

Leslie is an aquaculture specialist, and helped to provide contact with people involved in aquaponics in South Africa. He provided some insight into the selling of tilapia in South Africa.

Appendix E – Financial indicators of the case study farms

The tables below show the financial indicators for the case study farms under the conditions as described in section 5.1.1. The average accounting return (AAR) and internal rate of return (IRR) performance indicators cannot be used in these cases as they do not supply valuable information. The AAR requires a book value for the system, and this value is difficult to calculate correctly as a result of depreciation. The irregular cash flows received by the system cause the IRR to give misleading results as there are a number of discount rates where the NPV is zero. Therefore, only the NPAT, net cash flow, NPV, profitability index and payback periods are given below. The payback period column shows the years in which the system has paid back its capital cost. The table shows each year subsequent to the year that the system has accumulated more profit than its capital cost as it is possible that the systems produce negative earnings during a year and no longer satisfy the payback test.

Farm 1 Financial Indicators

Table 8 Financial Indicators of Farm 1

	NPAT	net cash flow	NPV	profitability index	regular payback period	disc. payback period
Year 0		-R 100 000	-R 100 000			
Year 1	-R 28 172	-R 15 005	-R 113 641	-13.64 %		
Year 2	R 29 508	R 43 596	-R 77 611	22.39 %		
Year 3	R 38 747	R 53 864	-R 37 142	62.86 %		
Year 4	R 16 644	R 32 776	-R 14 756	85.24 %	Year 4	
Year 5	-R 3 370	R 13 892	-R 6 130	93.87 %	Year 5	
Year 6	R 46 324	R 64 794	R 30 445	130.44 %	Year 6	Year 6
Year 7	R 64 473	R 84 292	R 73 700	173.70 %	Year 7	Year 7
Year 8	R 68 087	R 89 238	R 115 330	215.33 %	Year 8	Year 8
Year 9	R 35 080	R 57 711	R 139 805	239.81 %	Year 9	Year 9
Year 10	R 28 652	R 52 730	R 160 135	260.13 %	Year 10	Year 10

Farm 2 Financial Indicators

Table 9 Financial Indicators of Farm 2

	NPAT	net cash flow	NPV	profitability index	regular payback period	discounted payback period
Year 0		-R 250 000	-R 250 000			
Year 1	-R 65 964	-R 33 048	-R 282 567	-13.03 %		
Year 2	R 16 049	R 51 270	-R 238 222	4.71 %		
Year 3	R 47 695	R 85 488	-R 171 236	31.51 %		
Year 4	R 9 281	R 49 613	-R 136 447	45.42 %		
Year 5	-R 44 903	-R 1 749	-R 138 734	44.51 %		
Year 6	R 11 303	R 57 478	-R 105 396	57.84 %		
Year 7	-R 12 136	R 37 412	-R 85 630	65.75 %		
Year 8	-R 46 654	R 6 222	-R 82 907	66.84 %		
Year 9	R 2 160	R 58 737	-R 56 873	77.25 %		
Year 10	-R 207 679	-R 147 484	-R 119 327	52.27 %		

Farm 3 Financial Indicators

Table 10 Financial Indicators of Farm 3

	NPAT	net cash flow	NPV	profitability index	regular payback period	disc. payback period
Year 0		-R 250 000	-R 250 000			
Year 1	-R 82 408	-R 49 491	-R 297 688	-19.08 %		
Year 2	-R 28 032	R 7 189	-R 291 478	-16.59 %		
Year 3	-R 1 046	R 36 747	-R 262 870	-5.15 %		
Year 4	-R 34 152	R 6 180	-R 258 971	-3.59 %		
Year 5	-R 87 487	-R 44 332	-R 288 940	-15.58 %		
Year 6	-R 35 957	R 10 218	-R 283 514	-13.41 %		
Year 7	-R 48 444	R 1 104	-R 283 167	-13.27 %		
Year 8	-R 77 491	-R 24 615	-R 295 532	-18.21 %		
Year 9	-R 29 654	R 26 923	-R 283 620	-13.45 %		
Year 10	-R 221 899	-R 161 704	-R 351 783	-40.71 %		

Farm 4 Financial Indicators

Table 11 Financial Indicators of Farm 4

	NPAT	net cash flow	NPV	profitability index	regular payback period	disc. payback period
Year 0		-R 200 000	-R 200 000			
Year 1	-R 43 742	-R 17 409	-R 216 959	-8.48 %		
Year 2	-R 17 690	R 10 487	-R 207 758	-3.88 %		
Year 3	-R 7 861	R 22 373	-R 190 025	4.99 %		
Year 4	-R 20 129	R 12 136	-R 181 247	9.38 %		
Year 5	-R 48 612	-R 14 088	-R 191 344	4.33 %		
Year 6	-R 41 050	-R 4 109	-R 194 146	2.93 %		
Year 7	-R 14 299	R 25 340	-R 180 448	9.78 %		
Year 8	-R 44 619	-R 2 318	-R 181 891	9.05 %		
Year 9	-R 18 491	R 26 771	-R 170 009	15.00 %		
Year 10	-R 156 511	-R 108 355	-R 215 888	-7.94 %		

Appendix F – NPV's of the case study farms with reduced capex

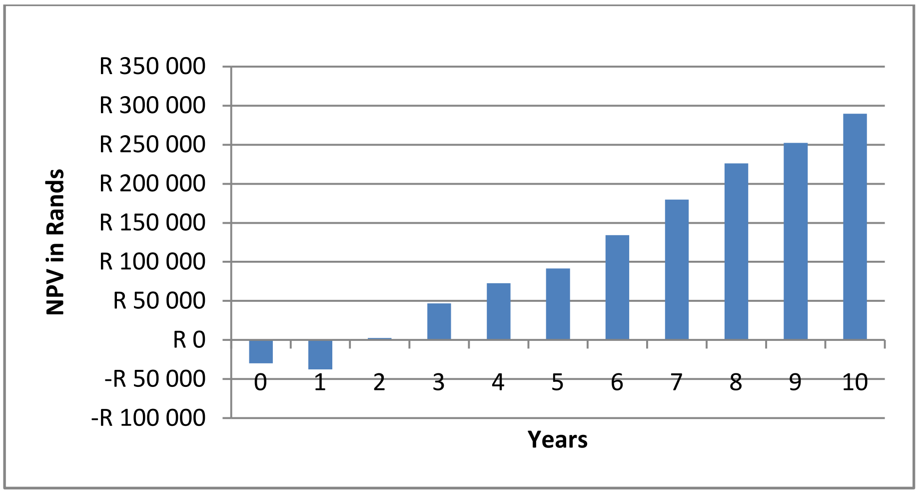

Figure 67 Net present value (NPV) of farm 1 with reduced capital expenditure

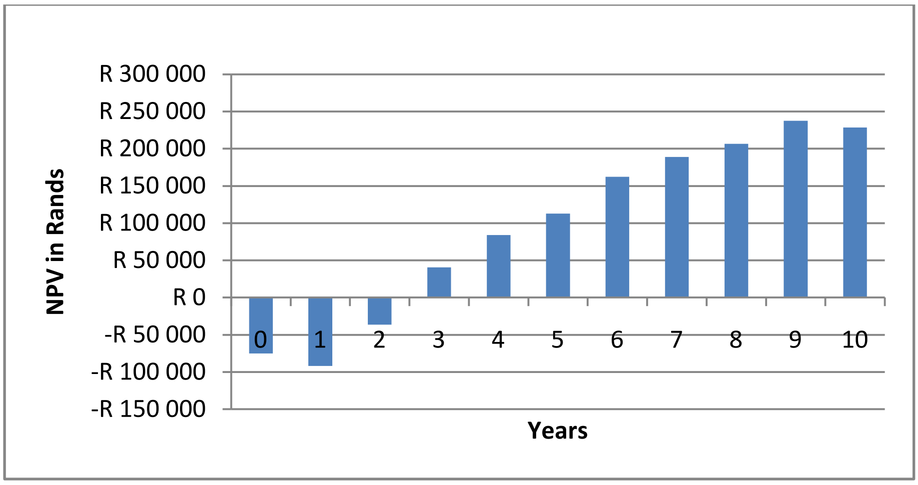

Figure 68 Net present value (NPV) of farm 2 with reduced capital expenditure

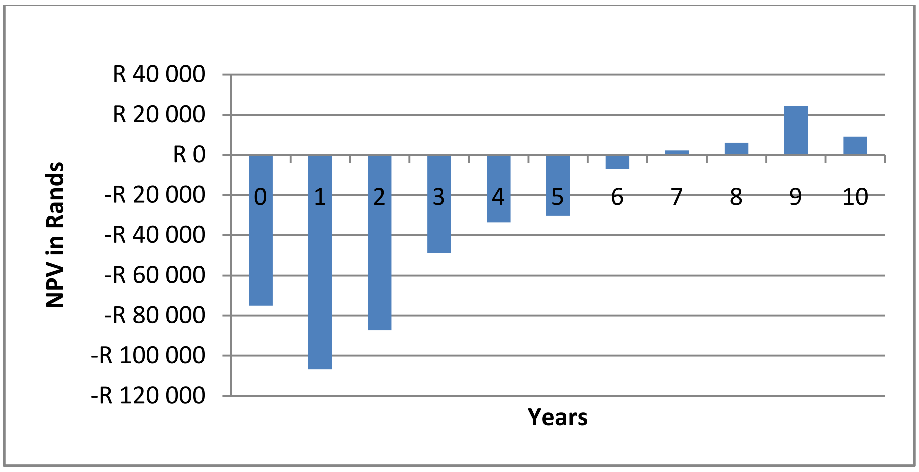

Figure 69 Net present value (NPV) of farm 3 with reduced capital expenditure

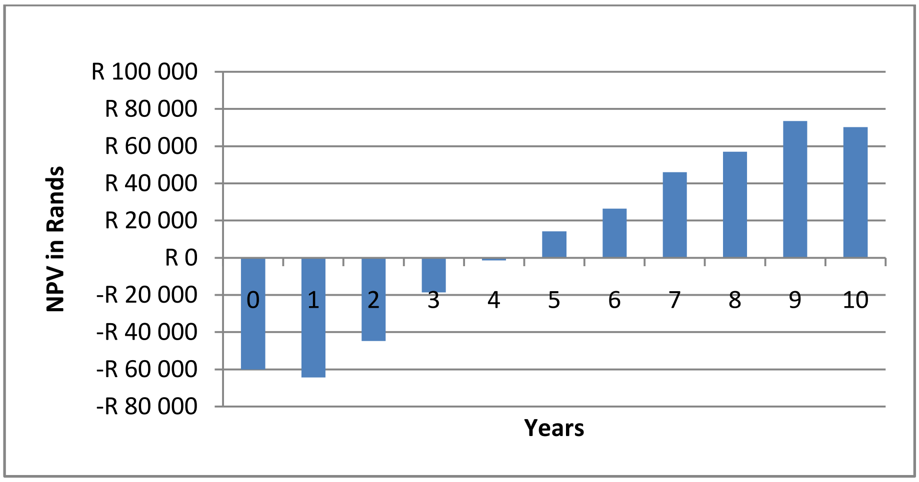

Figure 70 Net present value (NPV) of farm 4 with reduced capital expenditure

Appendix G – VBA code used in sensitivity analysis

Testing the effect of one parameter on a performance indicator

The following code runs a loop where an input parameter is set to a value, and the result of that change on a performance indicator is written into a cell. This process is repeated for a predetermined number of times as the input parameter is gradually incremented from the starting point to the end point.

```
Public Sub SensitivityCalc()

 Dim i As Integer
 Dim start As Double
 Dim last As Double
 Dim jump As Double
 Dim steps As Double
 Dim Parameter As Double

 start = Worksheets("Inputs").Range("Start").Cells(1, 1)
 last = Worksheets("Inputs").Range("Last").Cells(1, 1)
 steps = Worksheets("Inputs").Range("Steps").Cells(1, 1) + 1 ' fence pole dilemma
 Parameter = Worksheets("Inputs").Range("Parameter").Cells(1, 1)
 jump = (last - start) / (steps)

 For i = 1 To steps + 1
        'set selected variable value
        Worksheets("Inputs").Range("C5").Cells(Parameter, 1) = start + (i - 1) * jump
        ' run the model, then store the values
       Calculate
        ' store the values
```

```
        Worksheets("results").Range("C3").Cells(i, 1) =
Worksheets("inputs").Range("O99").Value

        Worksheets("results").Range("B3").Cells(i, 1) = start + (i - 1) * jump

    Next i

End Sub
```

Testing the effect of two parameters on a performance indicator

The following code runs two loops where two parameters are varied simultaneously and the result on a performance indicator is written into a cell. The end result is a matrix of values, which each represent a scenario where the two parameters are set at different values. As in the previous code, each input parameter is gradually incremented from the starting point to the ending point.

```
Public Sub SensitivityCalcTwoParameters()

 Dim i As Integer
 Dim start As Integer
 Dim last As Integer
 Dim jump As Long
 Dim steps As Integer
 Dim Parameter As Double

 start = Worksheets("Inputs").Range("Start").Cells(1, 1)
 last = Worksheets("Inputs").Range("Last").Cells(1, 1)
 steps = Worksheets("Inputs").Range("Steps").Cells(1, 1) + 1
 Parameter = Worksheets("Inputs").Range("Parameter").Cells(1, 1)

 Dim j As Integer
 Dim starttwo As Long
 Dim lasttwo As Long
```

```
Dim jumptwo As Long
Dim stepstwo As Integer
Dim Parametertwo As Double

starttwo = Worksheets("Inputs").Range("StartTwo").Cells(1, 1)
lasttwo = Worksheets("Inputs").Range("LastTwo").Cells(1, 1)
stepstwo = Worksheets("Inputs").Range("StepsTwo").Cells(1, 1) + 1
Parametertwo = Worksheets("Inputs").Range("ParameterTwo").Cells(1, 1)

jump = (last - start) / (steps)
jumptwo = (lasttwo - starttwo) / (stepstwo)

For i = 1 To steps + 1
For j = 1 To stepstwo + 1
        'set input parameters to the test values
          Worksheets("Inputs").Range("C5").Cells(Parameter, 1) = start + (i - 1) * jump
          Worksheets("Inputs").Range("C5").Cells(Parametertwo, 1) = starttwo + (j - 1) *
          jumptwo
       ' run the model, then store the values
       Calculate
          'store the values into a matrix with i and j as rows and columns
          Worksheets("results").Range("C3").Cells(i, j) =
Worksheets("inputs").Range("O99").Value
       Next j
   Next i
End Sub
```

Variations of this code are made to allow calculations where one of the input parameters increases whilst the other decreases. This is needed in certain situations where the two input parameters must be compared in this manner. Other variations to the code include situations where input parameters are used that are non-integers or percentages.