INTERACTION BETWEEN AQUACULTURE AND WATER QUALITY IN ON-FARM IRRIGATION DAMS

Report to the

Water Research Commission

on a project titled

"Interaction Between Aquaculture and Water Quality in On-Farm Irrigation Dams: Extended Monitoring and Mitigating Procedures to Manage Environmental Impact"

by

K Salie, A Lansdell, N du Buisson, B Snyman, K Holm & L de Wet
Department of Animal Sciences (Division of Aquaculture)
Stellenbosch University

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Water Research Commission
Private Bag X03
GEZINA, 0031

orders@wrc.org.za or download from www.wrc.org.za

EXECUTIVE SUMMARY

Motivation and background

This study served as a second phase of investigations into the impact of fish farming on the water ecology of small farm dams. It was commissioned as a follow up to the first phase of research in which the fitness-for-use of irrigation dams and canal systems for floating net cage aquaculture and the fitness-for-use of fish farming effluent for irrigation was evaluated. Both fitness-for-use investigations had a positive outcome in relation to the envisaged utilisation of farm dams for fish farming. The second phase encompassed continuing the monitoring and evaluation of a larger sample of Western Cape Province (WCP) dams. Practising intensive fish farming operations in existing open water bodies can increase the nutrient levels of the water via the addition of organic material as by-products from fish feed and metabolic waste. Under such conditions the primary usage (irrigation, drinking water and recreation) of these water resources can be compromised. The prevailing Mediterranean conditions in the WCP study area provide marginal fish farming conditions for both warm and cold water species due to seasonal fluctuations in water quality. Therefore, research was required to quantify and qualify the impact over a longer period of exposure. The acquired knowledge can then be used to propose management and mitigation measures to minimise the existing impact and to ensure an ecologically balanced system for integrated agriculture-aquaculture initiatives. It was further required that the impact of fish farming on water bodies within the context of a history of commercial plant crop farming be described by the authors.

Objectives of the research were:

1. To draw up a monitoring and evaluation water sampling protocol to quantify environmental impact.
2. To develop guidelines to improve management procedures and practices for pollution prevention and minimization.
3. To evaluate environmentally-friendly aquafeeds.
4. To implement mitigating measures (i.e. mechanical and biological waste removal) by which farmers can minimize aquacultural waste.

The following research questions were structured around the research:

a. What were the longer term (over four years) water quality dynamics of smaller irrigation dams associated with periods of fish farming and non-fish farming?

Small water bodies are dynamic structures which undergo erratic changes according to seasonal patterns and climatic conditions. Repeated measurements and assessments provided sufficient sample size to explore the dynamics and the fitness-for-use of irrigation water for both fish and land-based crops.

b. *What was the effect thereof on parameters most likely to be affected by aquaculture (i.e. dissolved oxygen, total ammonia nitrogen, phosphorous, total suspended solids) and parameters most likely not to be affected by aquaculture (i.e. temperature, total dissolved solids, alkalinity, hardness)?*

It is difficult to partition the influence of aquaculture for irrigation dams that are subject to multiple influences. Therefore we grouped the water quality parameters in categories most likely to be or not to be influenced.

c. *To what extent do surface and bottom water differ?*

Dams can undergo stratification and form distinctive layers which separate surface and bottom waters. The bottom of dams is also characterised by bio-accumulation.

d. *What was the occurrence of phytoplankton and diversity in irrigation dams?*

Phytoplankton blooms are linked to mesophylic water conditions including enough nutrients as well as favourable temperatures and oxygen. Harmful algae, such as blue-green algae, can lead to off-flavours in taste in commercial fish species, whilst algae not harmful to fish can influence oxygen levels and can lead to fluctuating concentrations associated with oxygen production (photosynthesis) and consumption (respiration and decomposition).

e. *What is the role and function of historical commercial agriculture in farm dam dynamics?*

Most of the farm dams in the WCP have a history of fertilizer and pesticide application on the surrounding land. This phenomenon was considered in the description of the water body's water ecology dynamics.

f. *Can negative as well as positive impacts be identified?*

Aquaculture in irrigation dams can have a negative as well as a positive impact on the water quality and terrestrial land-use. A balanced approach was followed to describe the ecosystem health and trophic status.

g. *How does fish production data compare with water quality parameters?*

Fish production output is the economic driver behind successful aquaculture. To what extent prevailing water quality influences fish yield, was assessed.

h. *What are the land-use changes and interactions associated with catchments in fish farming projects?*

Aquaculture is one of a myriad of activities within a catchment ecosystem; *inter alia*, commercial and subsistence agriculture, light industry, housing developments, recreation, etc. Aquaculture needs to be described within this context of multiple-use resources.

i. *Does freshwater aquaculture add value to the livelihood strategies of rural and peri-urban farming communities?*

It is important to address the socio-economic contribution of aquaculture in the context of conservation and management of our natural resources. The research and development of sustainable aquaculture should provide the building blocks for the preservation of resources.

j. *Are there feasible mitigation measures to reduce point and non-point sources of pollution in farm dams?*

Introducing mitigating measures to reduce organic pollution, could improve the water ecology. However, mitigating measures should be feasible if farmers are expected to make them work.

k. Can eutrophied water bodies be used for plant production?

Hydroponic systems in enclosures produce vegetable- and fruit crops successfully. Nutrient rich water bodies could be considered as major hydroponic systems and we need to assess the success of plant production in these large open water systems.

l. What are the challenges associated with technology and knowledge transfers?

In order to practise good management, both fish and land-based crop farmers need to understand the functioning of aquaculture systems in larger open water irrigation dams.

m. What is the public's understanding of aquaculture?

The broader public's understanding of aquaculture requires attention to enable awareness of the potential for sector development and the associated environmental impact.

n. What are the key issues for regulators and decision makers?

The government provides the implementation and policing of legislation and policy. Their decisions are based on information which comes from applied research.

Methodology

For the purpose of addressing the objectives and consequent research questions, 29 irrigation dams were commissioned for research in three distinct geographical areas including, Grabouw/Caledon, Stellenbosch/Franschhoek and Ceres/Worcester. All the dams were smaller than 20 ha and had a history of fish farming at some stage during the period under investigation. Production cycles varied from one to four. The dams used for fish farming were all seasonal producers of high value rainbow trout (*Oncorhynchus mykiss*) destined for the retail market. Water samples were collected once during each of the seasons (winter, spring, autumn and summer) over a period of 40 months (starting in June 2008 and ending in August 2011). The water samples were analysed for a range of physico-chemical parameters as well as for biological parameters (phytoplankton). The water quality data were analysed with statistical software packages including Statistical Analysis System and Statistica for Least Square Mean (LSM) estimates and Analysis of Variance (ANOVA) for repeated measures among groups as well as for Logistic Regression and Frequency of Occurrence. In 2009 nineteen fish farming projects were monitored and production data were collected. An ANOVA was run on the production data to determine the variance among the groups for the total amounts of fish harvested against other production- and water quality parameters.

Feed management issues were addressed through participatory appraisals via questionnaires and workshops to ascertain the level of awareness of the feed suppliers and trout producers (large scale and small scale commercial farms); to weigh the level of concern; and determine the ability of the industry's role players in the supply chain to address these concerns. To manufacture environmentally friendly aqua feeds, faecal stability is important in order to reduce dissolving. Furthermore, the longer the faeces remain intact, the more waste can be removed from suspension with mechanical systems and the less feed will dissolve in the water column. The research investigated the effect of increasing levels of a guar gum based pellet binder on the feed and faecal stability of Mozambique tilapia *Oreochromis mossambicus.* Results were evaluated for significant differences using ANOVA with Tukey's multiple comparison tests.

Two investigative mitigation measures were evaluated. These included one mechanical measure (demand feeder) and one biological measure (floating gardens). Both trials were conducted at farm dams with a history of fish farming. Due to the short duration of both trials, only preliminary results were described.

Results and conclusions

1. To draw up a monitoring and evaluation water sampling protocol to quantify environmental impact.

Any form of intensive agriculture will have an impact on the ecology of the natural environment. Therefore intensive aquaculture is assumed to be no different. Animals are farmed in high stocking densities and fed high volumes of artificial diets, with resultant organic waste. In the process farming is driven to maximize profits and optimize feasibility in a sustainable manner. However, the very operation is threatened if farmers cannot foresee long term environmental sustainability. In general, results indicated that the classical physico-chemical parameters, such as dissolved oxygen, nitrogen and phosphorous concentrations, have been impacted. However, the commercial farms that accommodate these fish farming projects have a history of applying fertilizers (i.e. superphosphates) and pesticides (i.e. endosulfan) to the crops and soils. This practice could lead to eutrophication if not well-managed. The impact of fish farming on the water quality of farm dams was evaluated within this context of multi-purpose usage.

The analysis for the minimum and maximum concentrations of the physico-chemical parameters indicated that the water quality is conducive to trout farming. The fact that these trout operations were conducted during the colder, winter months when the water temperatures were low and the dam levels were high supported the notion that the impact is minimal. The least square mean (LSM) values were indicative of the low impact. The analysis of variance between groups indicated that difference in bottom and surface samples and the site location is more important than the absence or presence of fish farming. The difference in bottom and surface is directly linked to the ecological status of the sediment, which serves as nutrient sinks. In monomictic dams found in Mediterranean areas, mixing occurs during the winter turnover phase. Nutrients are released due to surface and bottom water mixing, brought about by torrential rains and wind turbulence. Thus, the organic state of the sediment and bottom waters is a function of the nutrient loading over time, irrespective of whether the point source is fish farming or past agricultural activities. Therefore, it can be postulated that the initial selection of site is very important in order to sustain trout farming. Many dams in the WCP are already eutrophic due to a history of collecting effluent and runoff from different sources. When sites of this nature are used for fish farming, the nutrient status is directly influenced.

Dissolved oxygen (DO) levels differed significantly between surface and bottom samples ($p<0.05$). Furthermore, there were no statistically significant differences found in oxygen concentration in dams with and without fish farmed ($p>0.05$). However, phosphorous concentrations differed significantly between surface and bottom samples and between fish farmed and non-fish farmed sites ($p<0.05$). Phosphorous is the single most important parameter influenced by the presence of fish farming. There was a significance difference in the TAN level between surface and bottom samples ($p<0.05$). Furthermore, there was no difference in the TAN between sites or between fish farmed and non-fish farmed dams ($p > 0.05$). Nitrate-nitrogen readings indicated no significant difference between surface and bottom samples among sites or between fish farmed and non-fish farmed dams ($p>0.05$), whilst Nitrite-Nitrogen differed significantly among sites, between surface and bottom samples as well as between fish farmed or non-fish farmed sites ($p<0.05$). The Secchi disk reading, which is indicative of water transparency, indicated significant differences among sites and between fish farmed and non-fish farmed dams ($p<0.05$).

The occurrence and phytoplankton biomass distribution fluctuated with dam water levels and nutrient concentrations. The prevailing phytoplankton communities are important to fish farmers for two reasons*, inter alia*, 1. Influence on dissolved oxygen concentrations through users (respiration and decomposition) and producers (photosynthesis), and 2. Algal taint of trout flesh due to geosmin producing species. The anticipation of the impact of existing phytoplankton on the quality of trout production requires reinforcement. It was evident that phytoplankton biomass and diversity can be controlled by ensuring sub-optimal conditions through reducing nutrient input. The frequency of occurrence indicated that the Group Chlorophyta (including genera, *Chlamydomonas, Closterium, Oocystis, Scenedesmus, Staurastrum, Tetraedron*, etc.) occurred most often (371) with Chrysophyta (including genera, *Dinobryon, Mallomonas, Synura*, etc.) least often (34). The type of genus as well as the prevailing season had a significant influence on the occurrence of phytoplankton ($p<0.05$). However, the geographical location of the research site had no significant influence on the occurrence of phytoplankton ($p>0.05$).

There was no direct link between physico-chemical parameters for water quality (DO, pH, TAN, PO_4, Secchi disk) and production yield of harvested fish at the different sites ($p>0.05$). The yields of farms were directly linked to the quality of juveniles as supplied by different hatcheries and the feed conversion ratio (FCR) achieved by the respective fish farming projects. In this study the importance of good management for optimal yields and the maintenance of good water quality, is discussed. Compliance with such management guidelines and strategies will ensure sustainability.

2. To develop guidelines to improve feed management procedures and to prevent and minimize pollution.

To achieve better feeding management procedures requires not only good on-farm management but also consideration of what happens off the farm and in feed manufacturing. It is important that farmers start looking at the how the aquafeed is made and where the ingredients come from in order to address the end consumers' concerns. In addition on-farm management of the aquafeed is essential not only to optimize the use of the aquafeed but also to maintain an optimal aquatic environment for the farmed species. Mismanagement of aquafeed can have a damaging effect on the water quality of the farming system.

To ensure that the aquafeed is used correctly, procedures have been written that can be used by farmers to ensure that aquafeeds are correctly handled. At the conclusion of this project, 60 procedures were written for aquafeed manufacturing as well as for feeding fish. Seven record sheets can be used on farms were provided. This initiative will be an on-going concern in that procedures will continually be written and adapted in our strive for environmentally friendly and sustainable aquaculture that can be achieved on any size farm from extensive subsistence farming to intensive commercial farming. Information on responsible aquaculture practices for feeding management can be obtained on the internet. The website address is: http://academic.sun.ac.za/aquafeeding/documents/Section%203.%20Practices/RAP%20Practices%20for%20responsible%20aquafeed%20manufacturing%20and%20feeding.pdf.

3. To evaluate environmental-friendly aquafeeds.

Treatments consisted of a control diet with increasing levels (0, 9, 17.5, 35.0 and 70.5 g kg^{-1}) of a commercial animal feed binder Duracube® (Bitek, Midrand) containing 170 g kg^{-1} guar gum. Water analysis and visual assessment of faecal length and colour showed no significant difference ($p>0.05$) between treatments. The tendency of faecal matter to become lighter with an increasing level of binder inclusion may possibly be explained by increased gut emptying rate due to the viscous nature of the soluble fibre component of the binder. In addition, the level of binder did not influence the digestibility of the experimental diets.

4. To implement mitigating measures (i.e. mechanical and biological waste removal) so that farmers can minimize aquaculture waste.

Floating gardens:

Due to the nature of the project it was impossible to collect sufficient data on the growth of the plants. The growth of the lettuce was very slow due to the harsh production conditions. It was suggested that other more hardy crops such as basil and parsley would grow better under these conditions. However, it was possible to collect data and practical knowledge on the design and construction of floating rafts to withstand turbulent conditions, especially during winter. The preliminary findings indicated that it was possible to construct a low cost raft system like a hydroponic system that is easy to operate and manage and that can produce plant crops. The plant growth on farm dam water provided support for the premise that the water quality can be improved via extraction of nutrients for crop production. It was found that the removal rate of TAN for lettuce was 0.27 g/m^2/day. Thus, for the production of 3.5 kg/m^2 lettuce, a ratio of 109 plants/fish (1.84 g feed/day/plant) is recommended to limit the accumulation of residual nutrients in a fish farming system. The P concentration decreased from 0.157 mg/L to 0.071 mg/L over a nine week period, which amounts to 0.001 mg/L/day. The extent, to which water quality is improved via extraction of nutrients for plant growth, needs to be further quantified.

Pendulum demand feeders:

A possible feeding technique to reduce the impact of wasted uneaten feed is to use a demand feeder, where the fish control their feed supply according to their appetite. Widely-used sensor-operated demand feeders function well on a cage system for they are robust and insensitive to adverse weather conditions. However, they are too expensive, thus they are almost inaccessible to smaller scale farmers. Furthermore, pendulum demand feeders are an inexpensive type of demand feeders; they are maintenance free and easy to operate. An investigative experiment was applied to see if the pendulum demand feeder could withstand the physical elements associated with cage systems and provide a feasible feeding management method that could reduce wastage. Although the pendulum demand feeder provided an affordable option to farmers for feed management, it was found to be too sensitive to wind and wave action to operate effectively. This resulted in the unnecessary release of feed that ended in additional uneaten feed and subsequent wastage.

5. Research questions which were structured around the research, and answers.

a. What was the longer term (over four years) water quality dynamics of smaller irrigation dams associated with periods of fish farming and non-fish farming?

Small water bodies are dynamic structures with erratic changes according to seasonal patterns and climatic conditions. Repeated measurements and assessments provided sufficient sample size to explore the dynamics and the fitness-for-use of irrigation water for both fish- and land-based crops.

b. *What was the effect thereof on parameters most likely to be influenced by aquaculture (i.e. dissolved oxygen, total ammonia nitrogen, phosphorous, total suspended solids) and parameters most likely not to be influenced by aquaculture (i.e. temperature, total dissolved solids, alkalinity, hardness)?*

The concentration of the parameters most likely not to be influenced by fish farming (depth, temperature, pH, TDS, Na, K, Ca, Mg, Fe, Cl, CO_3, HCO_3, Mn, B, Cu, Zn, Al, SO_4, alkalinity and hardness) indicated a strong affinity to regional patterns. The process is mainly influenced by geology and the prevailing climate in terms of temperature and rainfall. Soils in the WCP are mainly from weathered Table Mountain Sandstones and shales from the Malmesbury Group. The Mediterranean climate of the WCP provides winter rainfall and subsequently diluted waters, whereas in summer higher temperatures lead to increased evaporation and concentrated waters. Thus, major ions in the water fluctuate according to the changing weather patterns.

The concentrations of the parameters most likely to be influenced by fish farming (Secchi disk, DO, P, TAN, NO_3-N, NO_2-N, and TSS) can be influenced by fish farming activities. There can be a primary influence where organic particles emanating from excess feeds and faeces are suspended in the water column, changing the TSS concentration and consequently the water transparency observed in the Secchi disk reading. Secondarily, nitrogenous compounds are released into the water environment through nitrification by aerobic micro-organisms (*Nitrosomonas* and *Nitrobacter* spp), as well as through denitrification. Dissolved oxygen levels are influenced by the rate of photosynthesis and the decomposition of organic material. Phosphorous is mainly released from the feed. The ratio of fish farming to non-fish farming ranges from 0.8 (TAN) to 2.06 (P). These ratios are relatively low and are indicative of good water resource management by both fish- and crop farmers.

c. To what extent do surface and bottom water differ?

Irrigation dams generally indicated no levels of stratification, thus showing adequate mixing of surface and bottom waters. This can be ascribed to relatively shallow dams with an average depth of 7 m. Dams with low Secchi disk readings (transparency) also indicated lower oxygen levels in bottom strata. The following parameters, DO, pH, Fe, P, PO_4, TAN, NO_2, TSS, TDS and alkalinity, indicated statistical significance between surface and bottom. The following parameters Na, K, Ca, Cl, SO_4, B, Mn, Cu, Zn, NO_3, AL and hardness, did not indicate statistical significance between surface and bottom.

d. What was the occurrence of phytoplankton occurrence and diversity in irrigation dams?

The occurrence and phytoplankton biomass distribution fluctuated with dam water levels and nutrient concentrations. The prevailing phytoplankton communities are important to fish farmers for two reasons*, inter alia*, namely: 1. They have an influence on dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis), and 2. There may be an algal taint of trout flesh due to geosmin producing species. The anticipation of the impact of existing phytoplankton on the quality of trout production requires attention. It was evident that phytoplankton biomass and diversity can be controlled by ensuring sub-optimal conditions through reducing nutrient input. The frequency of occurrence indicated that the Group Chlorophyta (including genera, *Chlamydomonas, Closterium, Oocystis, Scenedesmus, Staurastrum, Tetraedron*, etc.) occurred most often (371) with Chrysophyta (including genera, *Dinobryon, Mallomonas, Synura*, etc.) occurring least often (34). The type of genus as well as the prevailing season had a significant influence on the occurrence of phytoplankton ($p<0.05$). However, the geographical location of the research site had no significant influence on the occurrence of phytoplankton ($p>0.05$).

e. What is the role and function of historical commercial agriculture in farm dam dynamics?

The general water quality indicated that irrigation dam water quality is relatively well-managed by the commercial crop farmers in the WCP. However, in studies elsewhere in South Africa, e.g. KwaZulu-Natal and Mpumalanga, dams in the area were classified as eutrophic and in certain cases hypertrophic. Thus, the concern remains that our water resources as a whole lack appropriate management and compliance with better management practices. Aquaculture has been proven to provide real benefits to rural and urban communities and co-existence and integrated aquaculture-agriculture will only prosper when both primary and secondary users of irrigation dams apply practices to sustain good water.

f. Can negative as well as positive impacts be identified?

It was found that aquaculture in irrigation dams has a negative impact on the water quality due to organic enrichment via excess feeds and faeces. Some farmers also reported clogging of irrigation systems. Positive impacts were identified as an increase in diversity in aquatic plant and animal occurrence. The post-fish farm zone showed the establishment of additional wetland plant species. Prominent plant genera of *Typha, Phragmites, Zantedeschia* and *Restio* were observed. An increase in birdlife, rodents and small mammals was also observed in and around dams where fish farming activities took place.

g. How does fish production data compare with water quality parameters?

Fish production output (total kg fish yield) from farms was closely associated with the quality of juveniles/juveniles for stocking. The other important parameter determining harvest quality was the farm's FCR. Thus, management of the operation is considered to be more important than the prevailing water quality. The water quality parameters, including, DO, pH, TAN, PO_4 and Secchi disk did not influence the yield of farms. However, it is important that these parameters are always closely monitored to ensure good water quality for farming.

h. What are the land-use changes and interactions associated with catchments in fish farming projects?

Aquaculture is conducted in irrigation dams. The land-use is primarily affected by the volume of water released below the dam. The below-dam ecology has adapted to these flow patterns. Light industry and agriculture around the dam area are more aware of potential pollution from their operations and are generally more cognisant of harming the aquaculture operations.

i. Does freshwater aquaculture add value to the livelihood strategies of rural and peri-urban farming communities?

Peri-urban and rural communities are in dire need of economic activity to present income and livelihood opportunities. These communities support aquaculture in their areas for it has been found to lead to job creation.

j. Are there feasible mitigation measures to reduce point and non-point sources of pollution in farm dams?

Mechanical mitigation measures were found to be impractical or too costly. Extraction of nutrient from dams via floating gardens has been found to have potential to reduce organic pollution arising from feed, faeces and surrounding land.

k. Can eutrophied water bodies be used for plant production?

Nutrient rich water bodies can be considered as hydroponic systems e.g. floating gardens on farm dams. In our investigation it was found that certain vegetables can be successfully grown on floats incorporated next to net cages for fish.

l. What are the challenges associated with technology and knowledge transfers?

To achieve technology transfer, we need to understand the following elements:

a. What information is available?
b. In which manner is the information accessed?
c. How is the obtained information used?
d. What constraints do fish farmers experience when accessing information?
e. What processes influence priority in information selection for implementation?
f. How much of farmer knowledge is based on existing or new information?
g. What is the cost-benefit of information access and dissemination?
h. How are our farmers managing the mass influx of information?

Thorough understandings of these elements will provide a measure to the success of technology transfer.

m. What is the public’s understanding of aquaculture?

The broader public’s understanding of aquaculture in South Africa is limited and mainly associated with large-scale operations with shrimp and salmon. The public needs to be made aware of the potential of aquaculture to contribute to food security and socio-economic development. Aquaculture can provide individuals and communities the opportunity to run a sustainable enterprise and to participate in the aquaculture sector.

n. What are the key issues for regulators and decision makers?

Integrated aquaculture-agriculture systems provide an alternative strategy to optimise utilisation of South Africa's water resources. Our existing resources are continuously under pressure from the increasing demand from the public and industrial sectors. National government should be encouraged to:

a. Promote integrated farming systems in irrigation dams through incentives to farm owners
b. Develop strategies to optimise associated water resource management requirements
c. Regulate effluent discharge to reduce ecosystem pollution and ecological integrity
d. Facilitate captive markets for fish and crops
e. Encourage secondary and tertiary institutions to include aquaculture in their curricula
f. Support directed research programmes on farm dams.

Conclusion and future research

It was found that irrigation dams in the Western Cape Province (WCP) have a history of enrichment through external factors such as agriculture (fertilizers and pesticides), runoff and storm water from the surrounding areas and effluent from infrastructure extension (housing and informal settlements). The incorporation of aquaculture into such dams adds additional nutrients to the water column and sediment although the nutrients are not very concentrated. Irrigation dams can play a role in providing water bodies for floating net cage farming systems. However, the research found that water quality analyses over the research period indicated that farm dams in the WCP overall had good water quality, indicating that commercial crop farmers are exercising better management practices. The water quality was generally within the South African Water Quality Guidelines for agriculture, aquaculture and recreational use. The introduction of aquaculture under the prevailing farm dam water quality guidelines generally did not pollute the water to such an extent that crop farming was compromised. Thus, there is a case to be made for promoting integrated aquaculture-agriculture farming. Sustainability for both uses can be maintained through robust site selection and diligent hands-on management of both fish and crop farming operations. This approach will ensure that commercial crop farmers' irrigation regime and yield quality is not negatively affected. Therefore future research needs to be focused on:

- Prevention and minimisation of pollution deriving from aquaculture through improved management. This can be achieved by optimising technology transfer.
- Monitoring catchment as a continuum with all the external factors affecting the ecology of farm dams. This can be achieved through qualifying the point source and presenting guidelines to minimise it.
- Quantifying the impact of aquaponics on improving the water quality of farm dams.
- Understanding the sediment processes and dynamics needs. This can be achieved through incorporating monitoring programmes on the ecological status of the bottom waters of the dams.

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TABLE OF CONTENTS

APPENDICES

LIST OF ACRONYMS

ANOVA	Analysis of Variance
ASCE	American Society of Civil Engineers
BEMLAB	Private analysis Laboratory, situated in Somerset West
BOD	Biological Oxygen Demand
DAFF	Department of Fisheries and Forestry (formerly DWAF)
DEAT	Department of Environmental Affairs and Tourism
DST	Department of Science and Technology
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FCR	Food Conversion Ratio
HACH	Company that manufactures and distributes analytical instruments and reagents used to test the quality of water and other aqueous solutions
IDPH	Illinois Department of Public Works
LSM	Least Square Means
NSP	Non-starch polysaccharides
SAS	Statistical Analysis System
SAWS	South African Weather Service
SGR	Specific Growth Rate
SOFIA	The State of World Fisheries and Aquaculture
TAN	Total Ammonia Nitrogen
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

GLOSSARY

Ad libitum

Performed freely or at the discretion of the administer or performer of the duty

Alkalinity

Alkalinity is a measure of the presence of bicarbonate, carbonate or hydroxide constituents. Concentrations less than 100 mg/L are desirable for domestic water supplies. The recommended range for drinking water is 30 to 400 mg/L. A minimum level of alkalinity is desirable because it is considered a “buffer” that prevents large variations in pH. High alkalinity (> 500 mg/L) is usually associated with high pH values and hardness.

Allogenic and autogenic

Successional change can be caused by either endogenous or exogenous factors. If the change is caused by endogenous factors (within the organism itself) it is termed autogenic. In cases where the changes are caused by exogenous factors (external factors), it is termed allogenic.

Ammonia

Ammonia is a pungent, colourless highly soluble gas mainly used in the manufacture of fertilizers, nitric acid, and other nitrogenous compounds. The chemical formula is $NH_{3.}$ The term ammonia refers to two chemical species which are in equilibrium in water (NH_3, un-ionized and NH_4^+, ionized). Tests for ammonia usually measure total ammonia (NH_3 plus NH_4^+). In general, more NH_3 and greater toxicity exist at higher pH and temperature. The free ammonia form is considerably more toxic to organisms such as fish. The un-ionized form is a gaseous chemical, whereas the ionized form remains soluble in water.

Anoxia

Anoxia refers to very low oxygen or absence of oxygen. In most farm dams the water is relatively stagnant or stationary and huge water movement usually occurs when the dam overflows or during extraction through irrigation. The hypolimnium is the anoxic layer (due to decomposition of accumulated organic material and a lack of mixing).

Aquafeeds

Aquafeeds is a short form of aquaculture feeds and refers to the manufacturing of aquatic species’ specific diets based on a ration of ingredients that are utilised cost-effectively and provide for the optimal growth rates with minimal environmental impact.

Aquaponics

Aquaponics is an integrated aquaculture (growing fish) and hydroponic (growing soilless plants) system that mutually benefits both environments.

Biological oxygen demand (BOD)

This is the amount of dissolved oxygen in a body of water needed by aerobic biological organisms to break down (oxidate) organic matter.

Cages

These are fish farming systems comprise of floating structures/devices in the form of net cages and anchored in fresh or marine water bodies.

Catchment area

Catchment describes the area from which surface runoff is carried away by a single drainage system (river, basin or dam).

Dam (Reservoir)

A dam is either a barrier constructed across a waterway to control the flow or raise the level of water or the body of water that is contained by such a barrier. Another term for reservoir would be dam. In South Africa, small farm dams mostly serve the purpose of storing water for irrigation or drinking

Epilimnion

This layer occurs at the surface of the dam above the deeper hypolimnion. It is warmer and has a higher pH and DO concentration than the hypolimnion. Being exposed at the surface, it becomes turbulently mixed as a result of surface wind-mixing. It exchanges dissolved gases (O_2 and CO_2) with atmosphere.

Eutrophication

This refers to the enrichment of a water body with chemical compounds through non-point sources such as agricultural runoff, industrial and household effluent and stormwater. Eutrophication is a natural phenomenon and can be exacerbated by anthropogenic activities.

Food conversion ratio (FCR)

The FCR is the amount of feed it takes to grow a kilogram of fish. Wasted feed and mortalities are included in this ratio.

Google earth

Google Earth is a virtual globe map and geographical information programme which maps the Earth by the superimposition of images obtained from satellite imagery aerial photography and GIS 3D globe.

Hardness

Hard water is high in dissolved inorganic constituents such as magnesium and calcium.

Holomictic

The term holomictic refers to the mixing regime of the water body. A holomictic lake or dam is completely mixed during a turnover event, whereas in some very deep lakes the deepest layer might not be involved in the mixing (meromictic). Most water bodies are holomictic.

Hypolimnion

The layer of water in a thermally stratified dam that lies below the thermocline, is usually non-circulating, and can remain perpetually cold. Being at depth, the hypolimnion is isolated from surface wind-mixing, and usually receives insufficient irradiance (light) to enable photosynthesis and oxygen exchange. The layer is characterised by high concentrations of carbon dioxide, ammonia and hydrogen sulphide.

Monomictic

Monomictic dams mix from top to bottom during one mixing period each year. These dams usually become destratified during the mixing cycle. In Mediterranean and subtropical regions, the temperatures of epilimnion and hypolimnion are isothermal (of the same temperature) in winter, so that there is only one mixing phase per year, lasting from two to several months.

Non-point source

Non-point source pollution to water bodies generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification.

Phytoplankton

Phytoplanktons are photosynthesizing free-floating microscopic organisms that inhabit the upper sunlit layer of almost all bodies of fresh water.There are mostly autotrophic (photosynthetic) organisms in aquatic systems.

Poikilothermic

The internal body temperature of the organism is detemined by the temperature of its surrounding i.e. by the water temperature.

Polyculture

In aquaculture polyculture refers to the association of fish species of different food habits (feeding at different trophic levels) for the effective use of available fish foods in the pond, where wastes produced by one species may be inputs for other species.

Ponds

Land-based rectangular dug-outs, also called earthen ponds. They can also comprise circular water containers constructed in series or parallel with water flowing through the system, or recycled. Ponds are usually constructed along contour lines where water is gravity-fed to ponds.

Pycnocline

A pycnocline is layer in a body of water where the density of algae is the greatest.

Raceways

Rectangular water containers constructed in series either as in earthen dams or plastic/concrete containers with water flowing through the system.

Recirculation systems

These systems generally refer to cement or plastic containers where the water is re-used through recirculation.

Runoff

Surface runoff is the water flow that occurs when the soil is infiltrated to full capacity and excess water from rain or other sources flows over the land to collecting structures such as dams. Included are not only the waters that travel over the land surface and through channels to reach a dam but also interflow, the water that infiltrates the soil surface and travels by means of gravity toward a stream channel (always above the main groundwater level) and eventually empties into the dam. Runoff also refers to groundwater that is discharged into a stream. The total runoff is equal to the total precipitation less the losses caused by evapotranspiration (loss to the atmosphere from soil surfaces and plant leaves), storage (as in temporary dams), and other such abstractions.

Secchi disk

A Secchi disk is usually a 20 cm diameter disk with alternating black and white quadrants. It is lowered into the water of a water body until the observer cannot differentiate between the lighter and darker colouring. The depth at which this differentiation is nullified is called the Secchi depth and it is a measure of the transparency of the water.

Shoreline

It indicates the edge of a body of water e.g. a dam. The shoreline distance is usually calculated when dams are full to capacity.

Specific growth rate (SGR)

The rate at which fish grow is dependent on a number of factors including species, age, genetic potential, water temperature, health, and quantity and quality of food. The simplest modes for fish growth can be obtained by saying that all newly laid-down tissue is itself capable of equal growth thereby producing an exponential growth curve. However this only holds true if the percentage of body weight gained per unit time remains constant throughout the life of the fish. This is not the case – young fish are capable of doubling their weight in a much shorter time than when they are older due to a decrease in potential growth rates. It is therefore useful to be able to ascertain the rate at which fish are growing by referring to the instantaneous growth rate which is based on the natural logarithm of body weight. The formula most commonly used to express fish growth is indicated below (Steven et al., 2006):

SGR = (In FBW – in IBW) / D, where
FBW is the final body weight (g)
IBW is the initial body weight (g)
D = no of days

Stagnation phase/Stratification

In Mediterranean and subtropical climates, a thermocline develops during the summer months and divides the upper water layer (epilimnion) from the lower water layer (hypolimnion). Due to reduced water exchange by prevented mixture of water, this phase is called the stagnation phase. During this phase the deeper layers of the dam is low in DO concentration and the overall productivity of the dam for fish farming is reduced. As a result the stocking density of fish is also lowered.

Total dissolved solids (TDS)

A test for TDS includes the measurement of inorganic salts, organic matter and inorganic constituents. The solids can be iron, chlorides, sulphates, calcium or other inorganic constituents found on the earth’s surface. The dissolved inorganic constituents can produce an unpleasant taste or appearance and can contribute to scale deposits on piping and conduits in aquaculture production systems.

< 500 mg/L	Satisfactory
501 to 1000 mg/L	Less than satisfactory
1001 to 1500 mg/L	Undesirable
> 1500 mg/L	Unsatisfactory

Total suspended solids (TSS)

Total suspended solids (TSS) include both suspended sediment and organic material collected with the water sample. Suspended solids in water reduce light penetration in the water column, can clog the gills of fish and invertebrates, and are often associated with toxic contaminants because organics and metals tend to bind to particles (e.g. phosphorus, bacteria). They also cause the build-up of sediments in water bodies and can lead to anoxic conditions in the bottom waters of farm dams.

Turnover phase / Destratification phase

Mixing in lakes and dams is largely controlled by stratification. Stratification reduces vertical exchange and can drive horizontal exchange by enforcing a preferred vertical structure. During the winter months the temperature in the WCP‘s water bodies tends to be similar throughout the whole water body, and the whole water body (depending on overall depth) can undergo mixing.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: Overview and background setting of the investigation

1.1 General introduction

The use of irrigation dams for cage aquaculture is not a new concept, internationally or in South Africa. This practice is becoming increasingly widespread and represents a farming system that can alleviate the pressure on the demand for primary water usage and increase the productivity of dams. Nationally, the total storage capacity of the major dams in the country currently amounts to about 33 900 million m^3, which is equal to approximately 70% of the mean annual runoff from the land surface of the country. This storage has been created by the construction of 252 large dams. In addition, some 3 500 dams with a height of greater than 5 m have been registered with the Department's Dam Safety Office (Roberts, 2012).The WCP is an important agricultural area in South Africa and has a history of more than 350 years of commercial agriculture. The first constructed masonry dam is the Woodhead Dam under Table Mountain which was completed in 1897 (American Society of Civil Engineers, [s.a]). This scenario led to the development of a network of storage dams for the drier season irrigation of agricultural crops. Aquaculture is non-consumptive of water and therefore these dams pose good potential for the implementation of cage culture operations. This is particularly important where access to primary water resources for aquaculture is limited as the single most important environmental limiting factor for freshwater aquaculture development in South Africa is the lack of suitable freshwater resources (DWAF, 1996).

South Africa is mostly a semi-arid country with an average rainfall of only 450 mm per annum compared with the world average of about 860 mm (DWAF, 2004). Predicted climatic changes for the WCP will result in an even worse scenario as rainfall is expected to decrease and temperatures are expected to rise (SAWS, 2007). The utilization of land and water resources for livelihood creation forms an integral part of the cultural and economic lives of coastal and inland communities in South Africa. Such utilization is based on tradition and to a large extent survival strategies brought about by the socio-economic situation in South Africa. Planning for the water needs of the country in the future is a complex task, and non-conventional areas must now be addressed to supplement the two major areas of: water resource management and water demand management (Grobicki & Cohen, 1999). These strategies have to be environment specific, low risk, eco-friendly and have to be sustainable with respect to time- and resource usage. Such attributes conserve and enrich the aquatic natural capital. With increasing industrial development, the demand on the country's water is nearing the point where conventional supplies for human use will soon be exceeded. Due to the increasing demand, utilisation has created more potential sources of pollutants to the water. As it stands, most of South Africa's major rivers have been dammed to provide water for the increasing population. In some areas over 50% of the wetlands have been converted for other land-use purposes; industrial and domestic effluents are polluting the ground- and surface waters, and changes in habitat have affected the biotic diversity of freshwater ecosystems (DEAT, 1999).

Eutrophication is a serious problem in a number of catchment areas in South Africa. This phenomenon can be directly linked to nutrient enrichment in freshwater resources and therefore the most important management approach involves minimising the influx of nutrients into receiving waters (Van Ginkel, 2011). Aquaculture in the form of fish farming can contribute to eutrophication through the accumulation of unutilized feed and excretory products in dissolved and solid form dispersed in the water column and accumulating in the bottom sediment. The challenge is to manage fish farming operations within the target range that will maintain the water quality integrity for crop irrigation and recreational usage. Apart from any potentially negative impact of fish farming on the environment, cognizance has to be taken of the potentially positive impact. Boyd & Salie (2011) postulated that where irrigation is the main purpose of the dam, enrichment can be beneficial for crop fertilization. Earlier researchers (Maleri, 2008; Salie et al., 2009) conducted various research projects on the viability of tilapia and rainbow trout production in irrigation dams in the WCP. Other countries, such as Pakistan and Iran, have successfully cultured rainbow trout in cages (Kayim et al., 2007; Moogouei et al., 2010). Turkey and Iran are two of the major countries also producing trout in cages (Alpaslan & Pulatsü, 2008).

The production potential of any fish water body, including irrigation dams, is determined by a number of factors/variables such as species of fish (in monoculture or polyculture), the water environment (water quality, oxygen levels, microbiological load, etc.) and the stocking density / production system as well as the feeding regime (mostly intensive feeding, including 100% feeding of an artificial balanced fish diet) used. The effect of cage fish farming on the water quality in the storage structure was investigated in several studies (Cornel & Whoriskey, 1993; Pulatsu et al., 2004; Kayim et al., 2007; Du Plessis 2008, Maleri et al., 2008; Moogouei et al., 2010; Maleri 2011; Mirrasooli et al., 2012) and it was concluded that biochemical enrichment is occurring, specifically with regard to the increasing concentration of the nitrogenous and phosphorous compounds. Of all the research conducted to date in South Africa, none of the investigations included adequate descriptions of the socio-ecological interaction within the agriculture-aquaculture landscape and its surrounding environment. An understanding of such dynamics could help development authorities decide on whether or not to include aquaculture on irrigation dams as a priority farming system to contribute to resource management and sustainable utilization. An ecological balanced farming system in irrigation dams will provide viable fish farming operations and simultaneously maintain ecological integrity of the water resource. Aquaculture-agriculture is a dynamic system with different internal and external factors contributing to the ecological balance. In Appendix 1 there is an organogram depicting the interaction of biotic and abiotic factors in an aquaculture system.

1.2 Motivation for this study

The motivation for this study is embedded in the need to continue and extend the research programme on the assessment of the interaction between cage aquaculture and water quality in on-farm irrigation dams (Du Plessis, 2007; Maleri et al., 2008). Recent research programmes established the agenda and protocol to conduct monitoring and evaluation schedules to provide baseline data on the impact of aquaculture on open water systems, and storage dams for irrigation in particular. Studies on the effect of aquaculture on the water quality and the fitness-for-use have to be maintained to ensure environmental integrity (Maleri, 2011).

Inland freshwater aquaculture development is dependent on the sustainable utilisation of the available resources and prevailing micro-climate (Boyd, 2002). Aquaculture provides a unique opportunity to contribute towards socio-economic development, food security and human resource development, through multiple and sustainable utilisation of water resources, both for rural and peri-urban communities in South Africa (Brink, 2003; Rana et al., 2005). The opportunity has been identified for the integration of aquaculture into existing agricultural development without an increased consumptive demand on water resources, and limited impact on water quality through best management practices for all users (Salie et al., 1998). At present, with the global emphasis on sustainable development particularly in the agricultural sector, more effort is being put into optimising resource use rather than exploiting new resources. Due to the nature of operation of floating net cage aquaculture systems, they allow for the discharge of waste such as uneaten food, faeces, fish scales, mucus and organic soluble waste, directly into the surrounding water environment (Stirling & Dey, 1990). During cage aquaculture the cultured species are confined, but organic and soluble wastes fall from the cages and mixes with the water column and sediment (Cornel & Whoriskey, 1993; Beveridge, 1996). Critical concepts that were described in the previous research included timing and implications of turnover phases, water retention times and the self-cleansing ability of the dams (Callebaut, 2000; De Groeve, 2003; Maleri et al., 2008; Maleri, 2011). Feeding management is an important challenge facing small-scale farming aquaculture from a cost-optimization and water quality management point of view. Sub-optimal feeding management practices often overshadow feed development efforts as they oppose an even bigger threat to economic and environmental optimization of aquaculture. Various projects are proposed (towards achieving) in order to achieve more responsible aquafeed and feed management practices (De Wet, 2007). Therefore the project focused on these main topic areas. The above-mentioned interventions are crucial in order to secure long-term sustainability of aquaculture in irrigation dams and to stabilise small-scale fish farming enterprises as viable livelihood opportunities. Although previous research initiatives have given a detailed description of the expected impact of fish farming on water quality, and proposals were also made regarding guidelines for biological and economic sustainability, the need exists to investigate the socio-ecological interaction and provide information based on a multi-ecosystems approach. It is envisaged that the outcomes of the study will complement previous work and benefit strategic decision making for farm dam utilization and management.

1.3 Objectives of the study

The objectives of the research (as adapted from original project proposal) are:

1. To draw up a monitoring and evaluation water sampling protocol to quantify environmental impact.
2. To develop guidelines to improve management procedures and practices for pollution prevention and minimization.
3. To evaluate environmental-friendly aquafeeds.
4. To implement mitigating measures (i.e. mechanical and biological waste removal) for farmers to minimize aquaculture waste.

1.4 Approach followed to address the objectives

In Chapter 1 an overview and background setting for the study is provided. The fieldwork conducted to quantify the environmental impact was spread across three geographical areas in the WCP (Grabouw/Caledon, Stellenbosch/Paarl and Ceres/Worcester). The sampling was performed from June 2008 until August 2011. The phytoplankton was also included and evaluated for frequency of occurrence, dominant classes and interdependence. Furthermore fish production data for 2009 were evaluated to determine the interrelationship of water quality parameters with production data. The findings are described in **Chapter 2.**The objective to describe feasible mitigation measures to reduce organic pollution is discussed in **Chapter 3**.

Mitigation measures such as improved feed manufacturing and management, integrated plant-fish systems (floating gardens) and demand feeders are investigated. In **Chapter 4** a summary of conclusions is provided and the contribution of our findings to the aquaculture sector is emphasized. Recommendations to farmers and policy makers are made and areas to be considered for future research are listed.

1.5 Structure of the report

Hypotheses are not tested in heuristic research such as this; it is considered not to be necessary. This type of research employs a "discovery approach." Although the research does not use a formal hypothesis, focus and structure are maintained. Therefore, after reviewing the relevant literature and consulting the aquaculture sector, clear research questions are formulated. The structure of the report follows the conventional outline of a scientific publication. It comprises of five chapters of which two are research chapters.

1.6 Research questions

The following research questions were probed:

a. *What were the longer term (over four years) water quality dynamics of smaller irrigation dams associated with periods of fish farming and non-fish farming?*

   Small water bodies are dynamic structures with erratic changes according to seasonal patterns and climatic conditions. Repeated measurements and assessments provided sufficient sample size to explore the dynamics and the fitness-for-use of irrigation water for both fish and land-based crops.

b. *What were the effects thereof on parameters most likely to be influenced by aquaculture (i.e. dissolved oxygen, total ammonia nitrogen, phosphorous, total suspended solids) and parameters most likely not to be influenced by aquaculture (i.e. temperature, total dissolved solids, alkalinity, hardness.*

   It is difficult to partition the influence of aquaculture on irrigation dams which are subject to multiple influences. Therefore we grouped the water quality parameters into categories of “most likely to be influenced” or “most likely not to be influenced”.

c. *To what extent does surface and bottom water differ?*

   Dams can undergo stratification and form distinctive layers which separate surface and bottom waters. The bottom of dams is also characterised by bio-accumulation.

d. *What was the occurrence of phytoplankton occurrence and diversity in irrigation dams?*

   Phytoplankton blooms are linked to mesophylic water conditions namely enough nutrients, favourable temperatures, and oxygen. Harmful algae, such as blue-green algae, can lead to off-taste in commercial fish species, whilst algae not harmful to fish can influence oxygen levels and can lead to fluctuating concentrations associated with producing (photosynthesis) and using (respiration, decomposition).

e. *What is the role and function of historical commercial agriculture in farm dam dynamics?*

   Most of the farm dams in the WCP have a history of fertilization and pesticide application on the surrounding land. These agricultural practices were considered in the description of the water body’s water ecology dynamics.

f. *Can negative as well as positive impacts be identified?*

Aquaculture in irrigation dams can have a negative as well as positive impact on the water quality and terrestrial land-use. A balanced approach was followed to describe the health and trophic status of the ecosystem.

g. *How does fish production data compare with water quality parameters?*

Fish production output is the economic driver behind successful aquaculture. To what extent prevailing water quality influences fish yield was assessed.

h. *What are the land-use changes and interactions associated with catchments where there are fish farming projects?*

Aquaculture is one of a myriad of activities within a catchment ecosystem; *inter alia* commercial and subsistence agriculture, light industry, housing developments, recreation, etc. Aquaculture needs to be described within this context of multiple-use resources.

i. *Does freshwater aquaculture add value to the livelihood strategies of rural and peri-urban farming communities?*

It is important to address the socio-economic contribution of aquaculture in the context of conservation and management of our natural resources. The research and development of sustainable aquaculture should provide the building blocks for preservation of resources.

j. *Are there feasible mitigation measures to reduce point and non-point sources of pollution in farm dams?*

Introducing mitigating measures to reduce organic pollution, could improve the water ecology. However, it should be possible for farmers to make these measures work.

k. *Can eutrophied water bodies be used for plant production?*

It is possible to produce vegetables and fruit crops successfully using hydroponic systems in enclosures. Nutrient rich water bodies can be considered as major hydroponic systems and we need to assess the application of plant production on these large open water systems.

l. *What are the challenges associated with technology and knowledge transfers?*

In order to practice good management, both fish and land-based crop farmers need to understand the functioning of aquaculture systems in larger open water irrigation dams.

m. *What is the public's understanding of aquaculture?*

It is necessary to improve the broader public's understanding of aquaculture in order to make them aware of the potential for sector development and the associated environmental impact.

n. *What are the key issues for regulators and decision makers?*

The government provides the implementation and policing of legislation and policy. Their decisions are based on information coming from applied research.

1.7. Concluding remarks

The approach to the study is well supported by previous research, local and international literature and consultation with key persons in the aquaculture sector. This provided a research agenda and enabled the authors to formulate and address clear research questions. During the investigation it was possible to reflect on these benchmarks and revisit research priorities. The envisaged outcome is to provide additional knowledge complementing our understanding and interpretation of aquaculture in local farm dams.

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CHAPTER 2: Description and analysis of water quality and production parameters to quantify environmental impact

2.1 Introduction

Farm dams have proven to be viable water bodies for selective fish production. However, both extensive and intensive fish farming can contribute to eutrophication of these dams. The main wastes derived from fish production are fish faeces and uneaten feed. The waste is rich in phosphorous and nitrogen which have the potential to alter the trophic state of the water (Temporetti & Pedrozo, 2000; Daou, 2012). The value of water is compromised and therefore eutrophication of South Africa's water resources will continue to decrease the benefits to household and commercial use (Oberholster & Ashton, 2008). Thus, the challenge to fish farmers is to manage their water quality within the South African Water Quality Guidelines described in DWAF (1996) in order to maintain a healthy environment for fish production and ensure that the water quality for crop irrigation is sufficient.

Excessive pressure on water utilization has necessitated the revisiting of traditional approaches to the management of South Africa's water resources. Planning for the water needs of the country in the future is a complex task, and non-conventional areas must now be addressed to supplement the two major areas of: water resource management and water demand management (DEAT, 1999; Grobicki & Cohen, 1999). The use of irrigation water bodies for aquaculture is becoming increasingly common worldwide and provides a system to alleviate the pressure on the demand for primary water usage. South Africa has a network of more than 5000 registered dams of which a large number have been utilized for aquaculture.

An ecologically balanced farming system in irrigation dams will provide viable fish farming operations and simultaneously maintain the ecological integrity of the water resource. Aquaculture-agriculture is a dynamic system with different internal and external factors contributing to the ecological balance (Fernando & Halwart, 2000; Ingram et al., 2000). The monitoring and evaluation of the physico-chemical water quality parameters are the first steps leading to the management and conservation of aquatic resources (Garg et al., 2010). In this chapter the impact of aquaculture on the water quality of irrigation dams is monitored and evaluated.

2.2 Research scope

Earlier studies established a water sampling and monitoring protocol to build up baseline data on the impact (negative & positive) of aquaculture on the water quality of storage dams. Outcomes from the previous studies highlighted the critical concepts and agents influencing the water quality of these systems, as well as areas of impact. In these studies a limited number of sites were reported on and the need for more research sites over a wider geographical area was identified (Maleri et al., 2008; Maleri 2011). This can extend and validate findings from previous research. More research sites will also allow the identification of patterns and processes in dam systems with different characteristics and associated ecological interaction. The collection of a larger database will furthermore allow the classification criteria of dams for site selection procedures. Therefore the number of research sites in this study was extended to an additional 29 sites. The research site information, including production years, geography, hydrology and land-use of respective farms is shown in Appendix 2.

2.3 Fieldwork setting

All farm dams monitored and evaluated are situated along catchments located within a radius of 150 km of Stellenbosch. The general location of the sites is indicated on the Google Earth maps. Pictures of some of the sites in each geographical grouping are also included. Figure 2.1. indicates the overall geographical distribution of dams monitored.

Figure 2.1. Google Earth™ satellite photograph of the overall geographical distribution of dams monitored in WRC project K5/1802.

The dams were grouped, as follows, according to their geographical distribution:

- Eight in the Grabouw/Caledon area.
- Ten in the Stellenbosch/Paarl area.
- Eleven in the Ceres/Worcester area.

For each group, two sites were randomly selected and information was provided on each. The selected sites served as an approximate indication of site characteristics for that particular area. Additional comments were also included for each site. The geographical distribution of dams monitored in the Grabouw/Caledon area is indicated in Figure 2.2.

Analysed sites in the Grabouw/Caledon area:

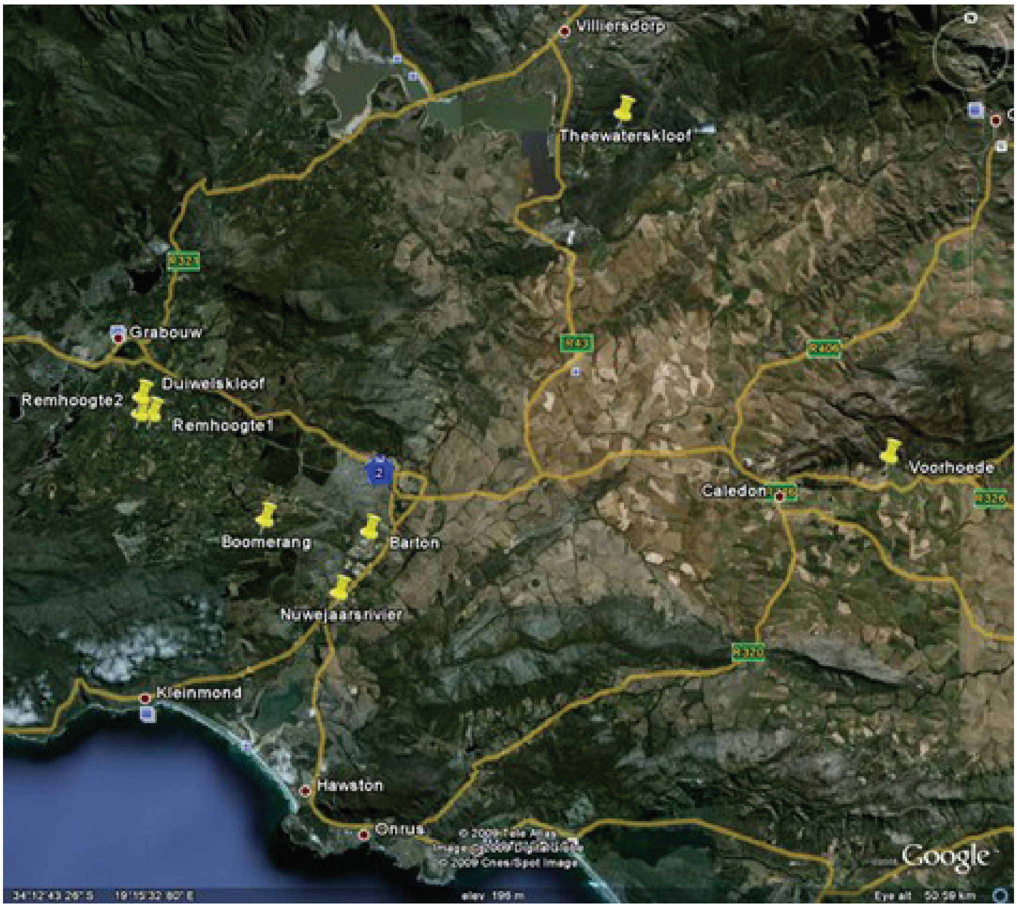

Figure 2.2. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Grabouw/Caledon area.

Figure 2.2.a. Wide-angled picture of the Nuwejaarsrivier experimental site.

The Nuwejaarsrivier site is one of two projects that were farmed for all four years (2008-2011) of the research period. The dam receives water from a spring source and from runoff. The surrounding landscape is covered with Fynbos vegetation. The agricultural land has vegetables and fruit trees under irrigation. The dam has a high turnover rate (more than twice a year) and there is a continuous flow from the dam. Figure 2.2.a. indicates a relatively small surface area, but due to the high turnover rate, the project has been farmed successfully for the whole research period, except for 2011, when there was a total biomass kill. The reason for the mortalities was not fully understood and no conclusive evidence could be provided. It was believed that rising pH could have been a contributing factor.

Figure 2.2.b. Wide-angled picture of the Voorhoede experimental site.

The Voorhoede site has a relatively short aquaculture history (2008 & 2009). The dam receives runoff water for the surrounding catchment. Water is also pumped to the dam. The vegetation type is Mountain Fynbos with pockets of pine plantation. In Figure 2.2.b. it can be noticed that the farmer is stocking the cages with juvenile trout via a pipeline from the truck to the cage. The water is used for the irrigation of vineyards and fruit trees.

Analysed sites in the Stellenbosch/Paarl area

The geographical distribution of dams monitored in the Stellenbosch/Franschhoek area is indicated in Figure 2.3. The Nietvoorbij site has the longest aquaculture history of all the dams in the monitoring program. The first fish farming was started in 1996. During the monitoring period it was only farmed during 2008 and 2009. It receives water from runoff as well as pumped from the Plankenbrug River. The water is used for irrigation of vineyards. Long term monitoring and evaluation indicated that the dam might have reached its threshold for continued aquaculture. Additional enrichment of the dam in future will be caused by wine cellar effluent as well as a large population of Egyptian geese. Figure 2.3.a. indicates the location of the floating cage system anchored in the deepest part of the dam, and the surrounding vineyards under irrigation.

The Mountainvineyards site is one of the recent aquaculture projects .Fish farming was started in 2009 and the site was farmed during 2010 as well as during the monitoring period. The dam receives water via streams from the Simonsberg catchment and from a pipeline from higher dams. It has a large surface area and the water is used for the irrigation of vineyards and fruit trees such as oranges and pears. Figure 2.3.b. shows the Simonsberg Mountains in the background with the vineyards stretching from the foot of the mountains to the dam. The damwall is covered with well-established Fynbos vegetation.

The research sites for Wijzersdrift and Hexron were not monitored from winter 2009 onwards for the quality of the assessment has been compromised. Both dams were almost pumped dry and the sites were difficult to sample in the muddy conditions. The geographical distribution of the dams monitored in the Paarl/Worcester is shown in Figure 2.4. This area has many dams higher in the catchment and presents good potential for future aquaculture activities.

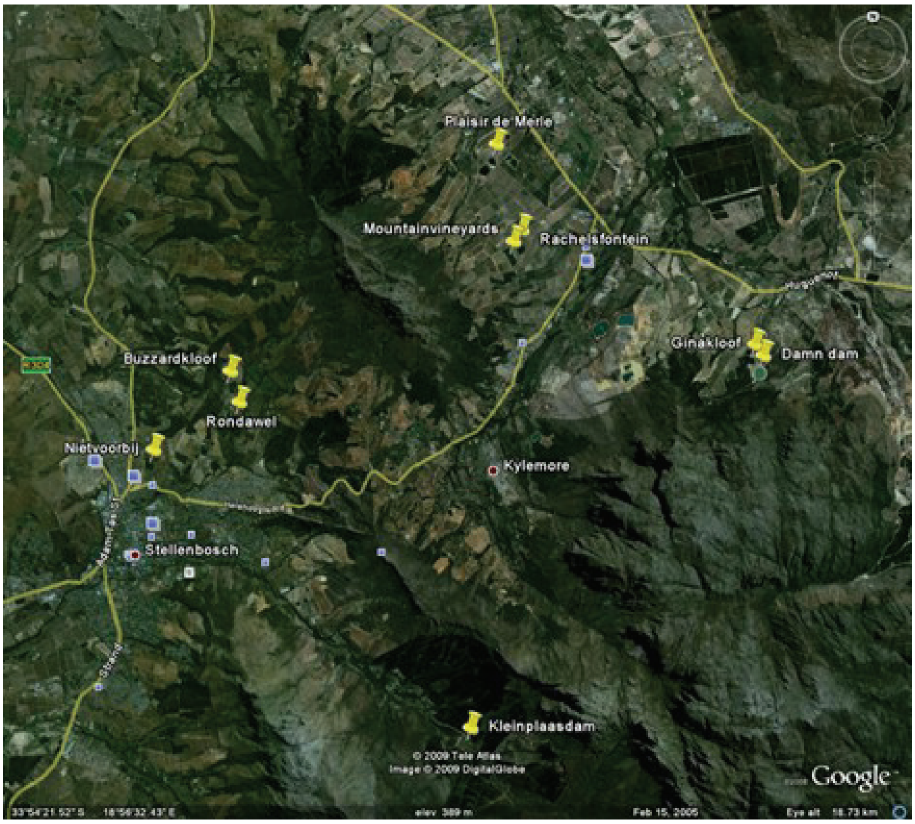

Figure 2.3. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Stellenbosch/Paarl area.

Figure 2.3.a. Wide-angled picture of the Nietvoorbij experimental site.

Figure 2.3.b. Wide-angled picture of the Mountainvineyards experimental site.

Analysed sites in the Paarl/Worcester Area

Figure 2.4. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Paarl/Worcester area, with the exception of Wijzersdrift and Hexron which were omitted from winter 2009 onwards.

Figure 2.4.a. Wide-angled picture of the Goedgeloof (new) experimental site.

A start was made with aquaculture at the Goedgeloof site in 2008 and trout farming took place there for three consecutive years. The dam receives water which is pumped from an irrigation scheme as well as runoff from the surrounding landscape. The surrounding agricultural land is covered with vineyards and fruit trees under irrigation. It is a relatively newly constructed dam. Goedgeloof is the best-performing small-scale fish farming project. In Figure 2.4.a. it can be seen that the vegetation is still being established on the damwall.

Figure 2.4. b. Wide-angled picture of the Worcester experimental site.

The Worcester site has an aquaculture history of approximately six years. The project produced trout in 2008 and 2009 during the period under research. The area surrounding the dam is characterized by Fynbos and semi-Karoo vegetation. Dam levels are maintained through runoff from winter rains as well as water supply via a pipeline from a drinking water dam located higher up. The dam has been used for more than a century by local fly-fishing clubs. The water is also used for the irrigation of a nearby golf course. In case of uncontrolled veld fires in the Worcester area, water is extracted from this dam to extinguish these fires. Figure 2.4.b. indicates the natural vegetation surrounding the dam and two well-maintained access roads.

Analysed sites in the (Ceres) Koue Bokkeveld Area

The geographical distribution of dams monitored in the Ceres District (Koue Bokkeveld) is indicated in Figure 2.5. The dams Slangboskloof and Helpmekaar were not monitored from winter 2009 onwards due to challenging research logistics. The Koue Bokkeveld area is deemed to be the future focal point for trout production. The area is characterized by a network of irrigation dams with cooler summer water temperatures which can accommodate year-round production.

The Rocklands site was densely stocked during 2008 and produced marketable trout in the production year of 2009. The dam receives water from three feeder streams from the surrounding catchment. The area is characterized by mountainous outcrops and luscious Fynbos vegetation (Figure 2.5.a). Allegedly the project was terminated due to the blocking of irrigation systems. It is postulated that the fish farming had an impact on the phytoplankton abundance and diversity and it is linked it to a drop in water level depth and the ready availability of nutrients (F. du Plessis, personal communication, 30 August 2007). The water is used for the irrigation of fruit trees.

The Môrester site has a very short history of aquaculture. It only produced trout in 2009. Water is supplied to the dam via runoff from the surrounding mountains. This seems to be the only source of water. The site is remotely located in mountains and is difficult to access during rainy conditions (Figure 2.5b). It is one of a few sites with a constructed weir which can be monitored for overflow volumes. It is noticed that the dam was overflowing during this site visit. The water is used for the irrigation of fruit trees and vegetables, as well as serving as a drinking hole for wild animals.

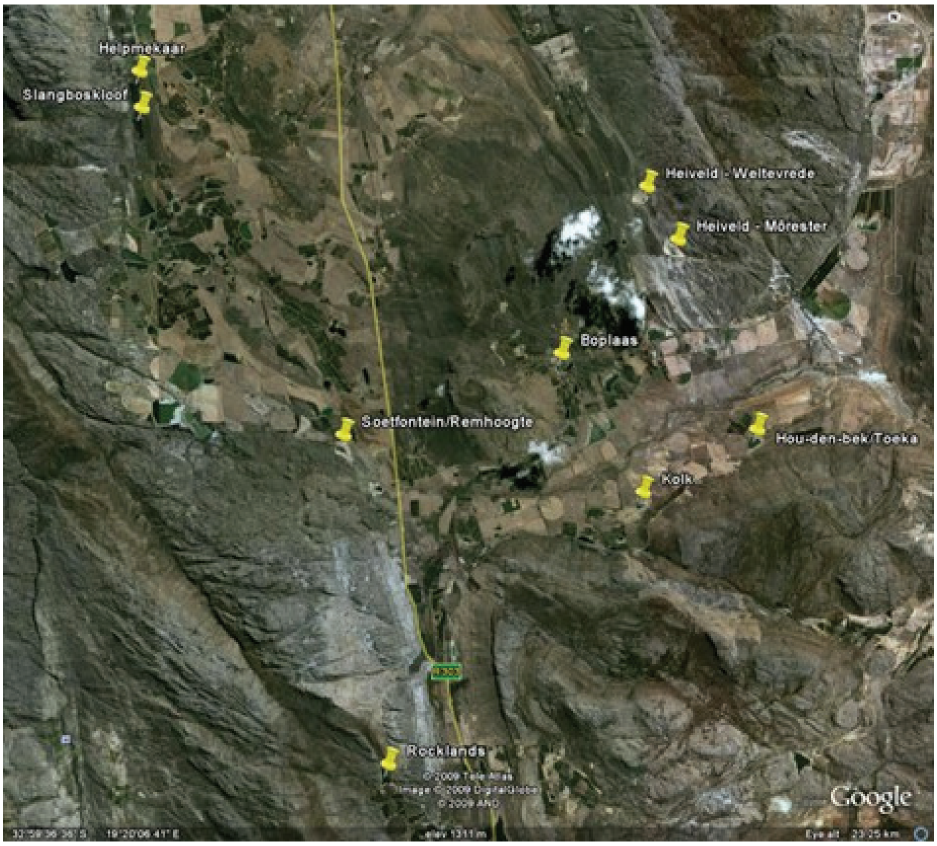

Figure 2.5. Google Earth™ satellite photograph of the geographical distribution of dams monitored in the Ceres area (Koue Bokkeveld), with the exception of Slangboskloof and Helpmekaar which were omitted from winter 2009 onwards.

Figure 2.5.a. Wide-angled picture of the Rocklands experimental site.

Figure 2.5. b. Wide-angled picture of the Môrester experimental site.

2.3.1 Location of sites

The commissioned sites were located in the WCP of South Africa within a 200 km radius of Stellenbosch University in Stellenbosch. Sites were limited to this area to facilitate visiting farms and collecting water samples in short periods of time. For the purpose of data analysis, the sites were grouped into three regions. The regions are Grabouw/Caledon, Stellenbosch/Paarl and Ceres/Worcester. The regional distribution of the commissioned research sites is indicated in Table 2.1.

Table 2.1. Regional distribution of commissioned research sites.

Grabouw/Caledon	Stellenbosch/Paarl	Ceres/Worcester
Remhoogte 1	Nietvoorbij	Ezelsfontein
Remhoogte 2	Rondawel	Rocklands
Duiwelskloof	Buzzardkloof	Soetfontein
Boomerang	Jonkershoek Kleinplaas	Boplaas
Theewaterskloof	Rachelsfontein	Morêster
Nuwejaarsrivier	Damn Dam	Weltevrede/Tweefontein
Barton	Ginaskloof	Toeka
Voorhoede	Plaisir de Merle	Westland/Kolk
	Cape Olive	Worcester
	Mountain vineyards	Goedgeloof (old)
		Goedgeloof (new)

2.3.2 Suitability of sites

Sites were selected as per recommendations stipulated in Maleri et al., (2008). All the research sites were simultaneously investigated for fish farming potential. The research team had regular communication with farm owners and informed them about the progress of the research as well as developments in the aquaculture sector. Furthermore, information was obtained on geochemistry and hydrology (e.g. soil types, erosion, depth, surface area, volume replacement, mixing regimes, etc.), on vegetation (e.g. dominant vegetation type, physiognomy, etc.), and on agricultural activities in the surrounding catchment. This enabled the researchers to identify trends and processes for water ecology in farm dams in relation to the different characteristics of a specific region, and agricultural history.

2.4. Materials and methods

Water samples were collected from 29 sites four times a year over a period of 40 months (June 2008 to August 2011). All the dams were irrigation water bodies. The sizes of the dams were all in the range of 2-12 ha in surface areas. The depths varied from 6 to 18 m. One farm produced fish during all four the years and one farm did not produce at all. On all the other farms production was intermittent. Only one cycle of trout production was completed during one year and projects had a dormant period over summer. The production season is generally from April to November in the WCP (Salie et al., 2008).

All the research sites had a designated sampling point to ensure uniformity of sampling areas. The point was marked with a buoy. Samples were transported from these buoys with a canoe. Samples were also taken in more or less the same time period. Sampling was scheduled to coincide with the different seasons i.e. summer, winter, spring and autumn. Surface and bottom samples were taken at each sampling point.

The surface samples were taken in the dams within the first metre of water and the bottom samples within the first metre from the bottom of the dam. Samples were stored in transparent 350 mL plastic bottles and all the bottles were free of headspace where air could be trapped. A combination of new and re-used bottles was used. Both type of bottles were thoroughly washed and rinsed with the particular dam's water to eliminate the possibility of contamination with water from other research sites. The samples were immediately stored in a cooler container at temperatures below -5°C. The samples were delivered to an accredited water analysis expert laboratory the same day or early the following day (Lind, 1979; Wetzel & Likens, 2000). Table 2.2 provides a summary of the field measurements taken at each site.

Table 2.2. Summary of the field measurements taken at each site

Parameter	**Unit**	**Method**	**Reference**
Temperature	°C	Oxyguard MK III oxygen meter, OxyGuard Polaris	
Turbidity	cm	Secchi disk (diameter 25 cm)	(Wetzel & Likens 2000)
Dissolved Oxygen	mg/L	Oxyguard MK III oxygen meter, OxyGuard Polaris	
Oxygen saturation	%	Oxyguard MK III oxygen meter, OxyGuard Polaris	
Water depth	m	Measuring tape with a weight at lower end	

The following list of parameters was included for analysis:

Depth, Secchi disk, Temperature, Dissolved Oxygen (DO), pH, Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Chloride (Cl), Carbonate, Bicarbonate, Manganese (Mn), Copper (Cu), Zinc (Zn), Boron (B), Phosphorous (P), Orthophosphate (PO_4), Total Ammonia Nitrogen (TAN), Ammonia-Nitrogen (NH_3-N), Nitrate-Nitrogen (NO_3-N), Nitrite-Nitrogen (NO_2-N), Aluminium (Al), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Alkalinity, Hardness, Sulphate.

Although all the listed parameters, except depth, can conceivably be influenced by rainbow trout farming (hereafter called trout farming), the underlined parameters should increase most in association with trout farming (C.E Boyd, personal communication, 10 August 2012).

Phytoplankton samples were also collected at the sites at the following times:

Sample 1, taken during the spring season of 2010.

Sample 2, taken during the summer season of 2011.

Sample 3, taken during the autumn season of 2011.

Sample 4, taken during the winter season of 2011.

Sample 5, taken during the spring season of 2011.

The samples were collected by inserting a 2 m long tube with a weight on the end to cut a 2 m deep phytoplankton sample from the surface of the water (Harding, 1992). Phytoplankton samples were fixated in the field and Lugol's acetic solution (1 mL to 100 mL of sample) was added for preservation and dyeing of the planktonic material (Lind, 1979; Entwisle et al., 1997; Hötzel & Croome, 1999). Samples were stored in a cool, dark place until identification and quantification were carried out. Samples were shaken vigorously to ensure proper mixing of material before decanting 20 mL of the sample into a self-constructed chamber (2 mL). The chambers with the sample were then allowed to settle for 24 h. After settling, cell counts and species identification by groups and genus were done (Utermöhl, 1958; Van Vuuren et al., 2006; Van Ginkel et al., 2007). A Zeiss inverted microscope with a 100 x oil immersion objective were used for the cell counts and species identification (Young, 1986; Wetzel & Likens, 2000). The biovolume of each specimen was taken from the literature or calculated via the nearest geometrical shape. Biomass was calculated from the volume data using factors of 1.02 to 1.30 kg/m^3 (Sommer, 1996).

Data were analysed statistically by one-way analysis of variance (ANOVA) for repeated measures at the same site at different times (Steel & Torrie, 1980). It was generated using PROC LOGISTIC of SAS software, Version 9.3 of the SAS System for Windows (SAS, 2010). Differences were considered statistically significant if $p<0.05$. All means are given with ± standard error (S.E.). The data for the phytoplankton was not homoscedastic (equal variances) or normally distributed and therefore it was not possible to analyse it with ANOVA or general linear models. Therefore non-parametric methods were used i.e. logistic regression and odd ratio analyses. Logistic regression analysis per group with genus, geographical location and season as dependent variables in the model, was conducted. A total of 2600 observations and six groups were used for the statistical analysis. A separate analysis was done per group including genus, geographical location and season as dependent variables in the model. For purposes of analysis the group Cryptophyta was omitted for it had only genus. Production data were only captured from the small-scale fish farmers in 2009. Of the 29 sites, 15 trout farms could provide a full set of data. The production data of the selected sites were compared with water quality parameters. An ANOVA was performed where the production data such as the total kg of fish harvested were run against the physico-chemical parameters (DO, pH, TAN, PO_4 and Secchi) and production data (fingerling source, date of stocking, date harvested, days in water, kg stocked, average stocking weight, average harvested weight, number of fish stocked, number of fish harvested, fish mortalities, feed conversion ratio [FCR] and specific growth rate [SGR]). Production data of trout farms for 2009 with associated physico-chemical water quality parameters are presented in Appendix 3.

2.5. Results and discussion

The results of the analysis of specific parameters for both **fish farmed and non-fish farmed dams** are discussed in this section**.** First the group of parameters **most likely not be influenced** by the presence of aquaculture is discussed and thereafter the group **most likely be influenced**. The range of specific parameters (the minimum, maximum, mean and standard deviation) is shown in Table 2.3. The summary of the LSM values with standard errors are indicated in Table 2.4. The summary of ANOVA (Wald F-statistics & p-values) for physico-chemical parameters is shown in Table 2.5. All the water quality parameters are discussed, starting with a basic description, occurrence and possible pathways of entering water systems. Through the discussion reference is made of the interaction of the prevailing agricultural activities and its role and function in nutrient loading. It emphasizes that irrigation water bodies are dynamic systems undergoing seasonal changes in its physical and chemical character.

2.5.1 Parameters most likely not to be influenced by the presence of aquaculture

a. Depth

The depth of the dam used for cage culture is usually determined by the suspended length of the cage bag in whether it can hang freely without touching the bottom. A minimum depth of less than 1.20 m (see Table 2.3.) is unlikely to support any form of cage culture, except when this depth was recorded during or just after the summer season when trout farming is not taken place. Irrigation dams are primarily used for the summer irrigation of agricultural plant crops when the rainfall is relatively low or absent. The research was conducted in a winter rainfall area (Mediterranean) when dams are filled. The same dam will serve as a dam for irrigation during the summer. The minimum depth will increase as the dam fills, but huge fluctuations are not conducive to trout farming.

A maximum depth of 21.60 m (see Table 2.3) results in a slower environmental impact in larger, deeper water bodies because of the larger physical buffering maintained (Baily-Watts & Duncan, 1981). Fish farmers making use of cage culture appreciate deeper dams. The depth of dams ranged between 6-10 m. The mean value of 7.65 ± 3.27 m indicated that most of the selected dams were deep enough to support the cage culture of trout. The widely used net cages are usually suspended 4 m in the water and require a free-space of at least 1 m for sufficient lateral flow through the netting (Beveridge, 2004; Salie et al. 2008). The physical criteria of surface area and depth are important values for sustainable site selection. Maleri (2011) emphasizes the importance of the threshold values of suitable parameters (e.g. surface area, maximum dam depth, surface phosphorous concentrations, dominant rock type of catchment area and dam basin) to be defined in order to understand the conditions that make a minimal impact on net-cage aquaculture.

No two sites will have the same depth. There is a statistically significant difference between sites for depth ($p<0.05$) as indicated in Table 2.5. Dams range in size from pond-like to large lakes, but with regard to natural lakes, the range of dam types and morphological variation is generally much greater (Chapman, 1996). The profiling of dams was designed according to contours and draining channels, thus creating a unique bathometry for each dam. The geology and soil type also influence the dam profiling. The dams under research were all used for irrigation and the inflow and extraction dynamics resulted in fluctuating depths during the year.

Table 2.3. Twenty eight physico-chemical water parameters with range of variation, mean and standard deviation, for the 29 sampled dams (*n*=524).

	Range of variation			
Parameter	**Min**	**Max**	**Mean**	**Standard deviation**
Depth (m)	1.20	21.60	7.65	3.27
Secchi disk (cm)*	10	510	139	94
Temperature (ºC)	6.20	28.30	16.48	4.78
Dissolved Oxygen (mg/L)*	0.30	16.40	8.07	2.49
pH	4.50	9.20	7.11	0.85
Total Dissolved Solids (mg/L)	4.00	550	101.4	94.88
Sodium (mg/L)	1.56	105.30	16.27	14.60
Potassium (mg/L)	0.06	9.11	1.74	1.46
Calcium (mg/L)	0.07	38.42	5.77	6.58
Magnesium (mg/L)	0.11	23.63	3.86	3.83
Iron (mg/L)	0.010	14.380	0.453	1.205
Chloride (mg/L)	0.18	251.60	30.50	26.93
Carbonate (mg/L	9.04	330.70	7.68	32.15
Bicarbonate (mg/L	3.06	180.30	29.11	24.03
Sulphate (mg/L)	0.300	86.390	8.081	10.280
Boron (mg/L)	0.010	0.150	0.018	0.016
Manganese (mg/L)	0.001	2.199	0.066	0.235
Copper (mg/L)	0.001	0.083	0.003	0.007
Zinc (mg/L)	0.001	0.141	0.011	0.018
Phosphorous (mg/L)*	0.001	0.735	0.065	0.223
Total Ammonia Nitrogen (mg/L)*	0.015	6.480	0.475	0.682
Orthophosphate (mg/L)*	0.003	2.253	0.198	0.684
Nitrate-Nitrogen (mg/L)*	0.009	7.360	0.535	0.851
Nitrite-Nitrogen (mg/L)*	0.001	0.200	0.024	0.024
Aluminum (mg/L)	0.010	1.014	0.233	0.232
Total Suspended Solids (mg/L)*	2.00	1396	53.28	114.40
Alkalinity (mg/L)	1.51	92.87	20.23	20.60
Hardness (mg/L)	1.89	98.07	26.85	25.74

* – parameters most likely to be influenced by aquaculture

Table 2.4. The comparison of physico-chemical water parameters with LSM and standard errors for non-fish farmed and fish farmed sites (*n*=684). The ratio of fish farming (FF) to non-fish farming (NF) is indicated.

Parameters	**Non-fish farming (NF)**		**Fish farming (FF)**		**Ratio of FF to NF**
	LSM	Standard error	LSM	Standard error	
Secchi disk (cm)	116	5	147	4	1.27
Temperature (ºC)	15.85	0.31	17.18	0.24	1.08
Dissolved Oxygen (mg/L)	8.21	0.148	8.09	0.12	0.99
pH	6.54	0.04	7.28	0.03	1.11
Sodium (mg/L)	13.45	0.61	17.15	0.47	1.28
Calcium (mg/L)	4.80	0.31	6.37	0.24	1.33
Magnesium (mg/L)	3.25	0.13	4.06	0.10	1.25
Iron (mg/L)	0.59	0.11	0.68	0.09	1.15
Chloride (mg/L)	26.32	1.22	32.31	1.07	1.23
Carbonate (mg/L	0.17	3.18	12.11	2.62	71.24
Bicarbonate (mg/L	26.94	1.23	30.60	1.00	1.14
Sulphate (mg/L)	10.589	0.668	6.980	0.387	0.64
Boron (mg/L)	0.020	0.002	0.020	0.001	1.00
Manganese (mg/L)	0.042	0.016	0.087	0.013	2.07
Copper (mg/L)	0.002	0.001	0.002	0.001	1.00
Zinc (mg/L)	0.012	0.002	0.012	0.002	1.00
Phosphorous (mg/L)	0.049	0.011	0.101	0.021	2.06
Orthophosphate (mg/L)	0.185	0.042	0.168	0.034	0.91
Total Ammonia Nitrogen	0.593	0.088	0.476	0.050	0.80
Nitrate-Nitrogen (mg/L)	0.493	0.073	0.503	0.057	1.02
Nitrite-Nitrogen (mg/L)	0.017	0.002	0.023	0.001	1.35
Aluminum (mg/L)	0.245	0.014	0.245	0.014	1.00
Total Suspended Solids	23.76	7.86	55.94	6.75	2.35
Total Dissolved Solids	69.47	4.54	99.34	3.76	1.43
Alkalinity (mg $CaCO_3$/L)	23.93	2.81	23.47	1.29	0.98
Hardness (mg $CaCO_3$/L)	26.80	1.15	26.63	1.80	0.99

During site selection for fish farming, the deeper dams (> 6 m) were always selected for fish farming. Therefore it was found that there is a statistically significant difference between fish farmed and non-fish farmed with regard to depth ($p<0.05$). Cage culture is based on the water body being deep enough to provide sufficient space underneath the suspended cages. This practice is beneficial for dispersing accumulated waste under the cages through lateral movement and flow of the water. It has been found that deeper dams have a greater chance of successfully hosting sustained fish farming than shallower dams as the volume is larger and the capacity to diffuse oxygen increases (Isyagi et al., 2009). The bottoms of dams are generally associated with anoxic conditions and can be detrimental to fish farming if regular mixing does not occur. Therefore it is important for fish farmers to understand the dynamics of the prevailing stratification patterns in their dams and what needs to be done to manage it.

Table 2.5. The influence of surface or bottom sampling location, different sites and whether there was fish farmed or not on the physico-chemical parameters in different dams. Differences are considered statistically significant if $p<0.05$ (ANOVA, Wald F-statistics). The highlighted (light grey) rows indicate significant differences.

Parameter	Source of variation	F-value	P-value
Depth	Surface/Bottom	0.00	Not Applicable (NA)
	Site	21.51	<0.001
	Fish farmed/Non-fish farmed	15.94	<0.001
Secchi	Surface/Bottom	NA	NA
	Site	14.49	<0.001
	Farmed/Non-fish farmed	27.77	<0.001
Dissolved oxygen	Surface/Bottom	161.56	<0.001
	Site	2.39	<0.001
	Farmed/Non-fish farmed	0.38	0.535
Oxygen saturation	Surface/Bottom	162.78	<0.001
	Site	2.47	<0.001
	Farmed/Non-fish farmed	0.10	0.747
pH	Surface/Bottom	7.12	0.008
	Site	22.60	<0.001
	Farmed/Non-fish farmed	192.53	<0.001
Sodium	Surface/Bottom	3.80	0.054
	Site	71.02	<0.001
	Farmed/Non-fish farmed	21.06	<0.001
Potassium	Surface/Bottom	1.38	0.244
	Site	60.81	<0.001
	Farmed/Non-fish farmed	18.07	<0.001
Calcium	Surface/Bottom	2.33	0.130
	Site	50.61	<0.001
	Farmed/Non-fish farmed	14.67	<0.001
Iron	Surface/Bottom	34.98	<0.001
	Site	2.35	<0.001
	Farmed/Non-fish farmed	0.34	0.556
Chlorine	Surface/Bottom	0.81	0.369
	Site	47.57	<0.001
	Farmed/Non-fish farmed	12.23	<0.001
Sulphate	Surface/Bottom	3.30	0.072
	Site	18.32	<0.001
	Farmed/Non-fish farmed	19.64	<0.001
Boron	Surface/Bottom	5.51	0.020
	Site	4.19	<0.001
	Farmed/Non-fish farmed	0.01	0.937

Parameter	Source of variation	F-value	P-value
Manganese	Surface/Bottom	3.31	0.072
	Site	15.39	<0.001
	Farmed/Non-fish farmed	4.07	0.046
Copper	Surface/Bottom	0.16	0.684
	Site	1.27	0.165
	Farmed/Non-fish farmed	0.02	0.889
Zinc	Surface/Bottom	0.69	0.405
	Site	1.04	0.417
	Farmed/Non-fish farmed	0.01	0.912
Phosphorous	Surface/Bottom	6.51	0.012
	Site	1.64	0.022
	Farmed/Non-fish farmed	4.44	0.037
Orthophosphate	Surface/Bottom	6.39	0.012
	Site	1.46	0.061
	Farmed/Non-fish farmed	0.09	0.762
Total Ammonia Nitrogen	Surface/Bottom	8.98	0.003
	Site	1.08	0.353
	Farmed/Non-fish farmed	1.19	0.277
Nitrate-Nitrogen	Surface/Bottom	2.30	0.132
	Site	1.31	0.135
	Farmed/Non-fish farmed	0.01	0.914
Nitrite-Nitrogen	Surface/Bottom	17.39	<0.001
	Site	2.90	<0.001
	Farmed/Non-fish farmed	9.17	0.003
Aluminium	Surface/Bottom	1.06	0.309
	Site	9.52	<0.001
	Farmed/Non-fish farmed		
Total suspended solids	Surface/Bottom	0.43	0.509
	Site	1.63	0.025
	Farmed/Non-fish farmed	8.90	0.003
Total dissolved solids	Surface/Bottom	8.35	0.004
	Site	26.60	<0.001
	Farmed/Non-fish farmed	23.34	<0.001
Alkalinity	Surface/Bottom	8.07	0.005
	Site	32.36	<0.001
	Farmed/Non-fish farmed	0.02	0.873
Hardness	Surface/Bottom	0.26	0.609
	Site	33.37	<0.001
	Farmed/Non-fish farmed	0.01	0.934

b. Temperature

Temperature, together with DO, are the two most important water quality parameters to consider when choosing sites for fish farming and predetermining the chances of sustainable production and culture success (Pillay & Kutty, 2005; Maleri, 2008). Fish are poikilothermic animals, therefore their rate of metabolism, growth, energy consumption and absorption of feed nutrients are strongly influenced by water temperature (Hinshaw, 1990; Azevedo, 1998). Trout prefer temperature ranges of 9-18ºC for optimal growth in Mediterranean conditions (FAO, 2011). The spread of this range over the year will determine the number of months available for production. A minimum water temperature reading of 6.20ºC is slightly below the lower limit for good trout farming, thus this can result in a decrease of oxygen uptake due to the slowing metabolism. The maximum value of 28.30ºC is well above the upper limit for trout production, and is indicative of water temperatures for summer months (see Table 2.3). The nature of Mediterranean climate lends itself to a limited period of trout production for most of the experimental sites. It is sometimes possible to farm trout at elevated sites, such in Ceres (Koue Bokkeveld) where summer water temperature seldom rises above 21ºC. The mean value of 16.48 ± 4.78ºC is within the optimal temperature range where trout has the lowest mortality rates and highest growth rate (Figure 2.6).

The LSM values for non-fish farmed and for fish farmed are 15.85 and 17.18 respectively (see Table 2.4). The small difference in temperatures is expected to have a negligible effect on the overall trout performance. Both values are within the temperature range for trout farming (about 7-18 C), where the appetite of the fish is optimal (Woynarovich et al., 2011).

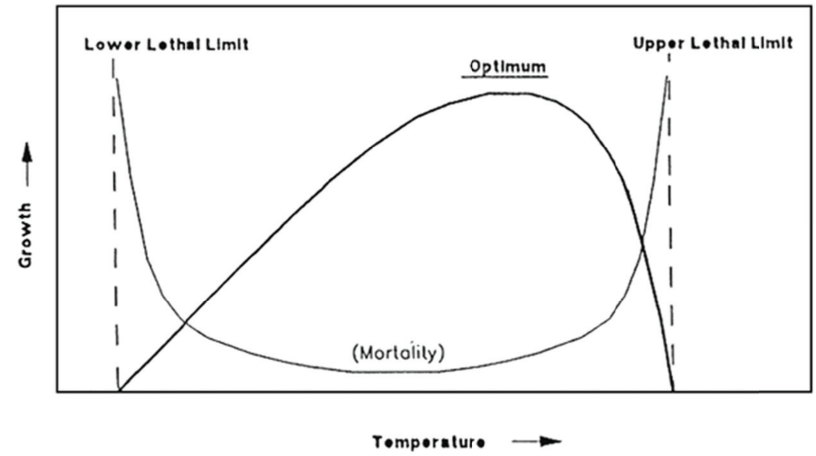

Figure 2.6. The relationship between fish growth and temperature (Akrout & Belkhir, 1994).

c. pH

The pH levels requirements are different for different life stages of trout. For developing and embryo stages 6.5 to 8 are proposed and for older fish the range can be wider (FAO, 2011). The minimum pH value of 4.50 is not conducive to trout farming (see Table 2.3). The maximum of 9.20 is also slightly outside the optimum range. The mean pH for the total number of sites is 7.11 ± 0.85. Such fluctuation is indicative of a water body weakly buffered to withstand pH fluctuations (Kristensen et al., 2009). They can also have a secondary effect on the toxicity levels of other parameters such as ammonia which becomes more toxic with an increase in pH and temperature. The mean pH value of 7.11 ± 0.85 is in the desirable range for successful trout farming. Although the maximum value is relatively high for freshwater bodies, it is in line with the highest value of 9.38 which Maleri (2011) found in her study.

The LSM value of 6.54 for the pH of the non-fish farmed sites was significantly lower than for the fish farmed sites which had a LSM value of 7.28 (see Table 2.4). In non-fish farmed sites the pH of water can be influenced by waste water (storm, sewage, industrial), inorganic constituents (from surrounding soils) and acid rain (Factors that affect the pH of water in wetlands, [s.a.]). In fish farmed sites the pH changes can be ascribed to organic loading via fish farming in addition to the same influences for non-fish farmed sites. Fluctuating pH values in dams are usually due to changes in the OH^- or H^+ ion concentration in the water, and both aspects associated with non-fish farmed and fish farmed sites can contribute to these concentrations. This is a reasonable initial assumption, given that photosynthesis causes pH to rise, whereas respiration causes pH to decline. With strong illumination and healthy algal populations, photosynthesis predominates over respiration (Lewis & McCutchan, 2009), thus resulting more often in an alkaline environment and rise in pH. Thus, the higher value in the fish farmed sites could be attributed to an increase in algal growth as a result of increased nutrient. The algae can increase the utilization of CO_2.

The results indicate a significant difference in pH ($p<0.05$) between the surface and bottom (see Table 2.5). The bottom of a dam is characterised by both inorganic and organic sediment accumulation. In monomictic dams where regular mixing does not occur, NH_3, H_2S and CO_2 increases in the bottom layer due to anoxic conditions and lowers the pH of the hypolymnion. The pH shifting between acid and alkaline ranges is a dynamic process in dams, thus presenting differences among sites ($p<0.05$). The microclimate (precipitation and evaporation) as well as geology of the dam can also result in different values for sites. The difference in pH in dams with and without fish farming activities can be linked to the secondary effect fish farming has on the values ($p<0.05$). An increase in nutrient loading, specifically in N and P, can result in excessive algal growth in a freshwater body. High algal biomass release carbon dioxide through respiration or use it during photosynthesis. The fluctuating CO_2 concentrations influence the pH levels. Another contributing factor is the built-up of organic waste as sediment on the dam floor. This is associated with cage culture where the net cages are not routinely rotated and instead of gradual dispersal, waste accumulates in one area. Under anoxic conditions H_2S and CO_2 are released and this influences the pH. In other studies it was found that trout farming has no significant impact on the pH values (Cornel & Whoriskey, 1993; Pulatsu et al., 2004; Maleri, 2011). However, when comparing the LSM of dams with and without fish farming activities, there was a significant difference and fish farmed dams exhibit a lower value (6.54) than non-fish farmed dams (7.28). The LSM values for alkalinity were 23.9 and 23.5 for farmed and non-fish farmed dams respectively. Alkalinity values < 75 mg/L have a low buffering capacity and lead to fluctuating pH levels. The desired total alkalinity level for most aquaculture species lies between 50-150 mg/L $CaCO_3$, but no less than 20 mg/L (Wurts, 2002).

d. Total dissolved solids (TDS)

Total Dissolved Solids (TDS) is a measurement of inorganic salts, organic matter and inorganic constituents in the water (USEPA, 1986; IDPH, 2012). The solids can include chlorides, sulphates, calcium and other inorganic constituents found on the earth's surface. The dissolved inorganic constituents can produce an unpleasant taste or appearance and can contribute to scale deposits on piping and conduits in aquaculture systems. TDS is also an indication of the salinity of the water environment. The mean salinity of the world's rivers is approximately 120 mg/L and the major anion found in natural waters is bicarbonate (Weber-Scannell & Duffy, 2007). Day and King (1995) explained that ground waters in the southern and south-western Cape were shown to be low in TDS (< 1000 mg/L). The mean of 101.40 ± 94.88 mg/L is close to the world average for rivers and natural waters. Water with values above 1000 mg/L is considered to be brackish (Weber-Scannell & Duffy, 2007). The range of TDS values from a minimum of 4.00 mg/L to a maximum of 550 mg/L is indicative of waters that are not saline (see Table 2.3). This result presented a wider habitat range and production opportunities for both stenohaline (e.g. common carp) and euryhaline (e.g. trout) as aquaculture species. Higher levels > 1000 mg/L can also lead to a decrease in the propagation of wetland plants such as *Typha* sp. Derry et al. (2003) reported that salinity and aquatic biodiversity are inversely related in lake water. Wetland plant species are important for treating aquaculture effluent in the post-farm zone. Here harmful accumulated ammonia can be broken down into less harmful compounds such as nitrate through nitrification and mesophyllic, aerobic bacteria *Nitrosomonas* and *Nitrobacter spp*.

The LSM value of 69.47 mg/L for the non-fish farmed site is lower than the value of 99.33 mg/L for fish farmed sites (see Table 2.4). This is in line with the values explained by Mirrasooli et al., (2012). They found in their study that farm effluent has a significant effect on the TDS concentration. Dissolved organic carbon, in the form of humic acids derived from decaying vegetable matter may also contribute to TDS (DWAF, 1996 B). This chemical process is the cause of the characteristic brown colour to the WCP's freshwater in rivers and dams.

The statistically significant difference between TDS ($p<0.05$) at the surface and at the bottom could be due to solids containing inorganic constituents trapped in the sediment (see Table 2.5). The total dissolved solids test measures the total amount of dissolved inorganic constituents in water. This could be the reason for the higher concentration in the bottom layers of the dam. The difference in sites could be due to external environmental aspects such as geology, soil types and source of effluents entering the water body.

The statistically significant difference between fish farms and non-fish farms ($p<0.05$) is unlikely to be linked to fish production (C.E Boyd, personal communication, 10 August 2012). A possible explanation has been discussed, with reference to Mirrasooli et al., (2012).

e. Sodium (Na)

Sodium is a common element, the sixth most abundant, and present to some extent in most natural waters. Concentrations vary from negligible in freshwater to considerable in seawater and brackish water. The permeability of agricultural soil is harmed by a high ratio of sodium ions to total cations (Bartram & Balance, 1996). Most water supplies contain less than 20mg of sodium per litre, but in some countries, levels can exceed 250mg/L (Priyadarshi, 2005). The target water quality range for no adverse effect on livestock is between 0-2000 mg/L (DWAF, 1996 A). The mean value of 16.27 ± 14.60 mg/L is comparable to the value of 20 mg/L for most freshwater supplies in the world. The minimum reading of 1.56 mg/L and a maximum of

105.30 (see Table 2.3) is within water quality parameters for freshwater species, especially rainbow trout which can be rapidly transferred to two-thirds seawater and survive with gradual acclimation. Fish bred in water within this range have a low mortality rate and adapt within 7-0 days (Landless, 1979; Bath & Eddy, 1979). Higher concentrations of sodium can increase the energy requirement of fish for osmoregulation and affects overall growth performance of fish in production systems.

Fish do not always find themselves in isotonic environments. Thus, their body cells must have a means by which to adapt to changing salt concentrations in their bodies and environments. Osmoregulation controls this balance of water/salt concentrations. Freshwater fish are hypertonic to their water environment and therefore, water continually diffuses into the fish through the gill membranes and into the blood. The gills are also permeable to respiratory gases, ammonia waste products, and ions. Therefore, while water moves in towards the higher osmotic pressure of the blood, sodium and chloride ions also diffuse out of the fish, moving down their concentration gradients to the external environment. Freshwater fish must expend energy to regulate this ion loss and fluid uptake (Angelsplus, [s.a]). The lower value of 13.448 mg/L for non-fish farmed sites compared with the value of 17.154 mg/L for farmed sites could be due to Na leaching from uneaten feeds, and the accumulation of excretory products.

There was no statistically significant difference in Na ($p>0.05$) concentration between the surface and bottom of dams. There is significant difference in the Na concentration among sites ($p<0.05$). All the farm irrigation dams were different in physical and chemical structure. Aspects such as cost, geology, constructability, water table, foundation treatment, river volatility, river navigation, vegetation are considered before the construction of dams (Butler, 2011). The difference in Sodium concentration for farmed and non-fish farmed sites ($p<0.05$) could be ascribed to the accumulation of and subsequent organic enrichment via metabolic waste and excess feeds. Fish mortality could also contribute to increasing sodium levels in instances where dead fish are not regularly removed from the net cages by the farmers. Fish mortality rates are usually about 2-3% of the population, with many of the fish actually dying after handling during harvesting and test sampling (Kayim et al., 2007; Salie et al., 2008).

f. Potassium (K)

Potassium is a dietary requirement for nearly all organisms because it plays an important role in nerve functions. Potassium plays a central role in plant growth, and it often limits it. Potassium from dead plant and animal material is often bound to clay inorganic constituents in soils, before it dissolves in water. Consequently, it is readily taken up again by plants (Water treatment solutions, [s.a.]). The maximum value of 9.11 mg/L as well as the mean value of 1.74 ± 1.46 mg/L was well below the range for natural fresh waters (see Table 2.3). Excessive levels could be indicative of organic contamination of the water resource (Asante et al., 2008).

There is no statistically significant difference between the amounts of potassium ($p>0.05$) at the surface and at the bottoms of dams. The statistically significant difference in K concentration $p<0.05$) between dams could be explained by the heterogeneity of the landscape and spatial utilization where these farm dams were constructed. Each site has its own natural, climatic, anthropogenic and agricultural influences, and the interaction thereof is the reason for the homogeneity of the individual sites (Kumar et al., 2006; Butler, 2011). The statistically significant difference between fish farmed and non-fish farmed with regard to K could be explained by the accumulation of organic material ($p<0.05$). Although the K values for fish farmed sites are higher than for non-fish farmed sites, the maximum as well as the mean values are well below the range for natural fresh waters. Asante et al., (2008) also support the idea that excessive levels could be indicative of organic contamination of the water resource.

g. Calcium (Ca)

Calcium dissolves out of almost all rocks and is, consequently, present in practically all waters. Calcium concentrations derived from geological processes and fertilizer application, generally do not present high values in the water. In some places the climate is more prominent in influencing levels than the effect of geology. Typically, the concentration of calcium in freshwater is 15 mg/L (DWAF, 1996 A). The minimum value of 0.07 mg/L is indicative that this dam has been constructed on a granite geological formation. Many waters from limestone areas may contain 30-100 mg/L Ca and those associated with gypsiferous shale may contain several hundred mg/L. The maximum value of 38.42 mg/L is within the range for limestone areas. Calcium contributes to the total hardness of water and functions as a pH stabilizer due to its buffering capacity (Bartram & Balance, 1996). It is also important as it protects freshwater fish against osmotic and ionic gains and losses, as well as against most environmental toxicants (Çalta, 2000). Fish can absorb Ca directly from the environment or from food to serve these requirements. The mean reading of 5.77 ± 6.58 mg/L for the sites is too low for fish species to benefit optimally. The acceptable range for free Ca in culture waters is 25-100 mg/L, which is equal to 63-250 mg/L $CaCO_3$ hardness. In cases where fish lose salts to the environment, more energy is required to re-absorb salts and maintain osmoregulatory function (Wurts, 2000). Many algae species including *Chlamydomonas* and euglenoid species also thrive at a Ca concentration of 16.78 mg/L (Moss, 1973).

Most rainbow trout diets contain about 2-2.5% Ca during starter, juvenile and production phases. Calcium can leach from uneaten feeds. The difference in LSM values for farmed (6.37 mg/L, standard error 0.24) and non-fish farmed (4.80 mg/L, standard error 0.31) dams is attributed to the influence of uneaten feed in surrounding waters. The Ca concentration can also increase in areas where water losses are excessive due to evaporation causing an increase in the salt concentration of the water. Evaporation can be as high as 300 mm over the summer months (Dec-Feb) at the WCP's major dams (Western Cape water supply systems, [s.a.]).

There is no statistically significant difference between surface and bottom readings for Ca ($p>0.05$). The statistically significant difference between sites ($p<0.05$) with regard to Ca concentration could be explained by the heterogeneity of the landscape and spatial utilization where these farm dams were constructed. Each site has its own natural, climatic, anthropogenic and agricultural influences, including geological formations and soil types. The dynamics of these different factors that could occur in varying degrees have already been described (refer to Kumar et al., 2006; Butler, 2011).

Results indicated a significant difference in Ca concentration between dams where fish are farmed and those where no farming takes place ($p<0.05$) and could be ascribed to the biological activities of the fish. The difference in LSM values for farmed and non-fish farmed dams is too low to affect fish production.

h. Magnesium (Mg)

Magnesium is a relatively abundant element in the earth's crust and hence a common constituent of natural water. The Mg concentration in South African freshwater is generally between 4-10 mg/L (DWAF, 1996 A). The mean value of 3.86 ± 3.83 mg/L indicates that most of the sites are in predominantly granite or siliceous soils. Water in contact with dolomite or magnesium-rich limestone may contain 10-50 mg/L, and several hundred mg/L may be present in water that has been in contact with deposits containing sulphates and chlorides of magnesium. The maximum value of 23.63 mg/L is within this range. By a similar action to that of calcium, magnesium imparts hardness to water. This may be reduced by chemical softening or by ion exchange. It should be noted that the difference between total hardness and the calcium concentration can be used to calculate the magnesium concentration (Bartram & Balance, 1996).

The LSM value for non-fish farmed sites was 3.25 mg/L (standard error 0.13) and 4.06 (standard error 0.10) for fish farmed sites. There is no significant difference between the Mg concentrations for farmed and non-fish farmed sites.

i. Iron (Fe)

Iron is an abundant element in the earth's crust, but exists generally in minor concentrations in natural water systems. The form and solubility of iron in natural waters are strongly dependent upon the pH and the oxidation-reduction potential of the water. Iron is found in the $^{+2}$ and $^{+3}$ oxidation states. In a reducing environment, ferrous ($^{+2}$) iron is relatively soluble. An increase in the oxidation-reduction potential of the water readily converts ferrous ions to ferric ($^{+3}$) and allows ferric iron to hydrolyse and precipitate as hydrated ferric oxide. The precipitate is highly insoluble. Consequently, ferric iron is found in solution only at a pH of less than 3. The presence of inorganic or organic complex-forming ions in the natural water system can enhance the solubility of both ferrous and ferric iron. Surface waters in a normal pH range of 6 to 9 rarely carry more than 1 mg of dissolved iron per litre. However, subsurface water removed from atmospheric oxidative conditions and in contact with iron-bearing inorganic constituents may readily contain elevated amounts of ferrous iron (Bartram & Balance, 1996). In South Africa unpolluted surface water contains between 0.001-0.5 mg/L (DWAF, 1996 A). Iron as it exists in natural groundwater is in the soluble (ferrous) state but, when exposed to oxygen, it is converted into the insoluble (ferric) state with its characteristic reddish brown or rusty colour (IDPH, 2012). The following levels of iron (Fe) are expressed in mg/L (IDPH, 2012): 0-0.3 is acceptable, 3-1.0 is satisfactory (however, may cause staining and objectionable taste) and >1.0 is considered as unsatisfactory. The acceptable level for drinking water is 1 mg/L. (IDPH, 2012).

The maximum value of 14.38 mg/L is extremely high, and most probably an outlier. Other high values recorded were 5.93, 5.93 and 10.71 mg/L. According to DWAF (1996 A), values of <0.01 mg/L have no effect

on fish and the range of 0.01-0.50 mg/L is an indication of unpolluted surface water. All the above high readings were taken in the bottom layers of the dams, although the mean value is 0.453 ± 1.205 mg/L.
The statistically significant difference between surface and bottom concentrations of Fe ($p<0.05$) could be indicative of the heavy metals released from the sediment of dams. Under anoxic/reducing conditions metals can dissolve more readily and such metals introduced into the dam may be adsorbed to clay particles, organic matter and silt in the sediment and gradually released into the water column. Lee et al., (2008) found that trace metals such as Fe, Al and Mn adsorb to suspended metal hydroxides and are ultimately discharged into dams or lakes and thus affect the chemical composition of water and sediment. Their study further indicated that even a modest decrease in the pH of the sediment pore water from 6.4 to 5.9 caused a significant release of trace metals into the environment. The statistically significant difference between sites with regard to Fe concentration ($p<0.05$) could be explained by the heterogeneity of the landscape and spatial utilization where the farm dams were constructed. Dams are influenced by several extrinsic factors which may alter the structural and functional components of the ecosystem. Thus, each site in the study has its own natural, climatic, anthropogenic and agricultural influences. The dynamics of these different factors that can occur in varying degrees have already been described (refer to Kumar et al., 2006; Butler, 2011; Goswami, 2012).

j. Chloride (Cl)

Chloride anions are usually present in natural waters. A high concentration occurs in waters that have been in contact with chloride-containing geological formations. Otherwise high chloride content may indicate pollution by sewage or industrial wastes or by the intrusion of seawater or saline water into a freshwater body or aquifer. A salty taste in water depends on the ions with which the chlorides are associated. With Na ions the taste is detectable at about 250 mg/L Cl, but with Ca or Mg the taste may be undetectable at 1,000 mg/L. High chloride content has a corrosive effect on metal pipes and structures and is harmful to most trees and plants (Bartram & Balance, 1996). Chlorides in groundwater can be naturally occurring in deep aquifers or caused by pollution from sea water, brine, or industrial or domestic wastes. Chloride concentrations above 250 mg/L can produce a distinct taste in drinking water. Most freshwater species can survive adequately at 500 mg/L of Cl (DWAF, 1996 B). The maximum reading of 251.60 mg/L as well as the mean of 30.50 ± 26.93 mg/Lin the dams involved in this research is well within the range to support the survival of freshwater organisms. Where chloride content is known to be low, a noticeable increase in chloride concentrations may indicate pollution from sewage sources (IDPH, 2012).The following levels of chlorides are expressed in mg/L (IDPH, 2012): 0-250 is acceptable, 250-500 is lower than desirable, 500-1000 is undesirable and > 1000 is unsatisfactory.

There is no statistically significant difference between surface and bottom concentrations of Cl ($p>0.05$). The LSM value for non-fish farmed sites was 26.32 mg/L with a standard error of 1.22. The value for the farmed sites was 32.31 mg/L with a standard error of 1.07. Although there is a statistical difference in Cl readings between farmed and non-fish farmed dams ($p<0.05$), the difference in LSM values indicates that the impact on the water quality is more or less similar. The statistically significant difference between sites ($p<0.05$) could be result of soil types containing different levels of Cl or concentrations of Fe.

k. Carbonate (CO_3)

The carbonate/bicarbonate interaction is fundamental to the maintenance of H+ concentrations, and therefore pH levels in a solution, and therefore, the concentration of carbonate/bicarbonate complexes are controlled to a large extent by the presence or absence of Ca and Mg, and these in turn help moderate, or 'buffer' pH (Kelly, 1998). There is a huge fluctuation between the minimum (9.00 mg/L) and the maximum (330.70 mg/L) concentration of CO_3 and this could be as a result of weakly buffered water. The mean value is 7.68 ± 32.15 mg/L. The LSM for non-fish farmed sites is 0.17 mg/L (standard error 3.18) and for fish farmed sites it is 12.11 mg/L (standard error 2.62). The fish farmed sites indicated a carbonate value of more than 12 times bigger and this can be ascribed to the secondary effect of fish farming. Enrichment caused by fish farming, together with the mesophyllic temperatures provides the ideal environmental cues for phytoplankton proliferation. Carbon dioxide, carbonates and bicarbonates can be utilized by plankton and could lead to increases in pH in weaker buffered waters (Moss, 1973).

l. Bicarbonate (HCO_3)

The carbonate/bicarbonate interaction is fundamental to the maintenance of H+ concentrations, and therefore pH levels in a solution. The concentration of carbonate/bicarbonate complexes are controlled to a large extent by the presence or absence of Ca and Mg. These in turn help to moderate or buffer pH fluctuations in water (Kelly, 1998).The minimum reading was 3.06 mg/L and the maximum was 180.30 mg/L. This indicates a mean value of 29.11 ± 24.03 mg/L.

The LSM value for non-fish farmed sites was 26.94 mg/L with a standard error of 1.23. The value for the farmed sites was 30.60 mg/L with a standard error of 1.00. There is no difference between the bicarbonate concentration for farmed and non-fish farmed sites ($p>0.05$). There is no statistically significant difference between surface and bottom concentrations of bicarbonate ($p>0.05$). There is a statistically significant difference between bicarbonate ($p<0.05$) readings at different sites. The statistically significant difference between sites have already been described (refer to previous discussion). There is a statistically significant difference between bicarbonate readings ($p<0.05$) from fish farmed and non-fish farmed dams. The difference in LSM values has little influence on the chemical value of the water.

m. Manganese (Mn)

Although manganese in groundwater is generally present in the soluble divalent ionic form because of the absence of oxygen, part or all of the manganese in surface waters (or water from other sources) may be in a higher valence state (Bartram & Balance, 1996). Fish manure has a higher content of manganese, cadmium, chromium and lead and lower concentrations of arsenic and selenium than other animal manures (Naylor et al., 1999). Manganese concentrations in the can be found in anaerobic bottom waters, where manganese has been mobilised from the sediments. The usual range for freshwater is 0.0002-0.130 mg/L and concentrations > 0.5 mg/L increases the risk of lethal effects (DWAF, 1996 B).The minimum reading was 0.001 mg/L and the maximum was 2.199 mg/L with a mean value of 0.066 ± 0.235 mg/L. The maximum value is relatively high and prolonged high concentrations can adversely affect fish species. High levels of Mn can disrupt metabolic pathways i.e. sodium regulation in fish, which could lead to mortalities (DWAF, 1996 B).

The LSM value for non-fish farmed sites was 0.042 mg/L with a standard error of 0.016. The value for the farmed sites was 0.087 mg/L with a standard error of 0.013. There is a statistically significant difference in Mn ($p<0.05$) concentrations between fish farmed and non-fish farmed dams. Although there is a difference between the two values, both were still below 2 mg/L for concentrations > 2 mg/L and could lead to changes in the water’s physico-chemical properties (Gantzer et al., 2009). The concentration of Mn in the water column is directly associated with the level of oxygen in the water. Gantzer et al. (2009) found that during oxygenation, Mn concentrations were very low in the hypolimnion (<0.05 mg/L), but high concentrations (> 2 mg/L) were still observed in the benthic region close to the sediment. The source water control of soluble Mn and Fe can be accomplished with hypolimnetic oxygenation in dams. It was further found that soluble Mn persisted until the sedimentation rate of detritus through the hypolymnion increased. Thus, the difference between fish farmed and non-fish farmed dams can be explained by saying that fish farming dams have a higher organic content due to higher detritus in the hypolymnion which results from suspended feed and faeces. Schenone et al., (2011) found that fish farm effluent has higher concentrations of Mn and Zn. Although the hypolimnion can contain higher levels of Mn, the analysis indicated that there is no statistically significant difference between Mn ($p>0.05$) readings at the .surface and the bottom. The statistically significant difference between sites has already been described (refer to previous discussion on geological and morphologically differences).

n. Boron (B)

In most natural waters boron is rarely found in concentrations greater than 1 mg/L, but even this low concentration can have deleterious effects on certain agricultural products, including citrus fruits, walnuts and beans. Water with boron concentrations in excess of 2 mg/L can adversely affect many of the more common agricultural common (Bartram & Balance, 1996). Soucek et al. (2011) postulated that most sensitive aquatic species have to be protected from concentrations >1 mg/L. The minimum reading in dams involved in the research was 0.010 mg/L and the maximum was 0.150 mg/L. This indicated a mean value of 0.018± 0.016 mg/L. The maximum value is below the target range for sensitive aquatic species and has no adverse effect on trout.

The LSM value for non-fish farmed sites was 0.020 mg/L with a standard error of 0.0012. The value for the farmed sites was 0.020 mg/L with a standard error of 0.001. There is no statistically significant difference between boron readings in fish farmed and non-fish farmed dams ($p>0.05$). The statistical significant difference between surface and bottom concentrations of B ($p<0.05$) could be the result of the release of the B as a trace metal trapped in the sediment of the dam. Thus, the bottom layer will have higher concentrations of B than the surface layer, unless mixing of the dam occurs, releasing higher concentrations in the water column. The statistically significant difference between sites has already been described (refer to previous discussion).

o. Copper (Cu)

Copper is a naturally occurring metal found in the earth's crust. Copper is also generally present in surface waters, with cupric ion (Cu^{+2}) as the primary form in natural surface waters. In freshwater systems, naturally occurring concentrations of copper range typically around 0.300mg/L (DWAF, 1996 B). It has been observed that Cu concentrations > 0.07 caused avoidance behaviour in rainbow trout (DWAF, 1996 B). The dietary requirement of Cu for rainbow trout has been reported to be 0.003 mg/L Cu g dry mass food (Ogino & Yang, 1980). Copper can also enter the aquatic environment through copper mining activities, agricultural activities (e.g. mildew-cide, fungicide, and/or algaecide), and manufacturing activities (e.g., manufacturing of leather and leather products), (EPA, 2012). Copper readily dissolve in acidic waters and higher levels can be found in these conditions (DWAF, 1996 A). Although high levels of Cu can be ascribed to the usage of fungicide, the concentrations recorded were low and not indicative of excessive usage of fungicide. The maximum value of 0.083 mg/L can lead to behaviour changes in trout, but the mean value of 0.003 ± 0.007 mg/L calculated across the study area is indicative that both fish farmed and non-fish farmed sites were well within the target ranges for fish farming.

The LSM for non-fish farmed sites was 0.002 mg/L with a standard error of 0.001. The value for the farmed sites was 0.002 mg/L with a standard error of 0.001, thus there was no statistically significant difference between fish farmed and non-fish farmed sites with regard to Copper ($p>0.05$). Furthermore, there was no difference in Cu concentrations ($p>0.05$) between surface and bottom samples, as well as between sites.

p. Zinc (Zn)

In surveys of river water in central and western Canada, it was found that the level of zinc varied widely both with regard to location and season. The range was 0.001 to 0.096 mg/L, with maximum levels observed in the Slave River in the Northwest Territories. In Canada, the concentrations in river water do not normally exceed 0.04 mg/L (Environment Canada. 1984). In South Africa, inland waters typically have concentrations of approximately 0.015 mg/L (DWAF, 1996 B). The Zn dietary requirement for rainbow trout is recommended to be between 15-30 mg/L (Ogino & Yang, 1978). There is still uncertainty as to what level of dietary Zn is toxic for rainbow trout (Read, 2012). Zinc toxicity increases with an increase in temperature, and a decrease in dissolved oxygen. An increase in hardness also increases the acute lethality of zinc as well as in corporation with zinc and copper sulphates. Under such conditions fish may show avoidance behaviour (DWAF, 1996 B). The maximum recorded value of 0.141 mg/L and the mean value of 0.011 ± 0.018 mg/L are within the target ranges for salmonids (0.03 to 0.2 mg/L) under conditions where the water hardness is between 10-50 mg/L $CaCO_3$.

The LSM value for non-fish farmed sites was 0.012 mg/L with a standard error of 0.002. The value for the fish farmed sites was 0.012 mg/L with a standard error of 0.002. Thus, the results indicated that there is no statistically significant difference between surface and bottom readings for Zn ($p>0.05$), as well as no statistically significant difference between sites for Zn ($p> 0.05$) and also no statistically significant difference between fish farmed and non-fish farmed sites for Zn ($p>0.05$).

q. Aluminum (Al)

Although aluminium is among the most abundant elements in the earth's crust, it is present in only trace concentrations in natural waters. Because it occurs in many rocks, inorganic constituents and clays, aluminium is present in practically all surface waters, but its concentration in waters at nearly neutral pH rarely exceeds a few tenths of a milligram per litre. It has been reported that there is no adverse effect on aquatic life at pH > 6.5 of Al concentrations of 0.03 mg/L. The toxicity of aluminium is strongly dependent on the degree of ionisation of aluminium present in the water (DWAF, 1996 B). In addition, in treated water or wastewater, it may be present as a residual from the aluminium coagulation process. The median concentration of aluminium in river water is reported to be 0.24 mg/L with a range of 0.01 to 2.5 mg/L (Bartram & Balance, 1996). Levels of >1.5 mg/L can be lethal to trout (DWAF, 1996 B). The mean value of 0.233 ± 0.232 mg/L is well within the target range, whilst the maximum recorded reading of 1.014 mg/L is acceptable as well.

The LSM value for non-fish farmed sites was 0.245 mg/L with a standard error of 0.014. The value for the farmed sites was 0.245 mg/L with a standard error of 0.014. Both values were the same, thus there is no statistically significant difference between Al ($p>0.05$) readings in fish farmed and non-fish farmed sites. Further, it was found that there is no statistically significant difference between surface and bottom concentrations of Aluminum ($p>0.05$). There is a statistically significant difference between sites and this is due to the heterogeneity of sites.

r. Sulphate (SO_4)

Sulphate is an abundant ion in the earth's crust and its concentration in water can range from a few milligrams to several thousand milligrams per litre. Industrial wastes and mine drainage may contain high concentrations of sulphate. Sulphate also results from the breakdown of sulphur-containing organic compounds. Sulphate is one of the least toxic anions and WHO does not recommend any guideline value for it in drinking water (Bartram & Balance, 1996). Hydrogen sulphides are found in the sediment of dams where organic materials accumulate in anaerobic conditions. Sulphates are formed through the oxidation of hydrogen sulphides (DWAF, 1996 B). Furthermore, sulphates in groundwater are caused by natural deposits of magnesium sulphate, calcium sulphate or sodium sulphate.

Concentrations should be below 250 mg/L. In areas where higher concentrations are present, they can cause ill-health when consumed as drinking water. (IDPH, 2012).The following levels of sulphates are expressed in mg/L: 0-250 is considered to be acceptable, 250-500 can be tolerated, 500-1000 is undesirable and >1000 the water is unsatisfactory for usage. The maximum value of 86.390 mg/L found in the study sites is well within the target range. This also indicates a mean value of 8.081 ± 10.280 mg/L across the study sites for the WCP region.

The LSM value for non-fish farmed sites was 10.589 mg/L with a standard error of 0.668. The value for the farmed sites was 6.980 mg/L with a standard error of 0.387.There is a statistically significant difference between fish farmed and non-fish farmed for sulphate ($p<0.05$). The higher value for the non-fish farmed sites can be a result of microbiological activity during the decomposition of organic material in the sediment of the dam, where disturbances of the bottom layers were caused by incrementally turbulent conditions. This activity releases sulphates into the water column and can occur in the absence of fish farming. Higher organic loading can be due to intensive feeding practices as well as natural leaf and tree litter in the area. There is no statistically significant difference in the sulphate ($p>0.05$) concentration between surface and bottom readings. The statistically significant difference between sites has been described ($p<0.05$). Further eutrophication can be caused by agricultural runoff and household and industrial effluent released in the receiving waters as well as other potential pollutants entering the system.

s. Alkalinity (mg $CaCO_3$/L)

Alkalinity is a measure of the presence of bicarbonate, carbonate or hydroxide constituents. Concentrations lower than 100 mg/L are desirable for domestic water supplies. The recommended range for drinking water is 30 to 400 mg/L. A minimum level of alkalinity is desirable because of its buffer capacity that prevents large variations in pH. High alkalinity (above 500 mg/L) is usually associated with high pH values, hardness and high rates of dissolved solids (IDPH, 2012). Water with low alkalinity (<75 mg/L), especially some surface waters and rainfall, is subject to changes in pH due to dissolved gasses (Wurts, 2002). Total alkalinity concentration should not be lower than 20 mg/L in production ponds for this can create unstable water chemistry. Fish production can be optimally achieved at target water quality ranges of 20-100 mg/L levels (DWAF, 1996 B). Pond pH can swing widely during the day, measuring from 6 to 10 at alkalinity concentrations < 75 mg/L. Large daily changes in pH can cause stress, poor growth and even death to fish. Most aquatic organisms can live in a broad range of alkalinity concentrations. At levels > 175 mg/L, the natural productivity of ponds decreases (DWAF, 1996 B). In areas where fish are farmed extensively, this could lead to lower production levels due to insufficient natural food being available. The desired total alkalinity level for most aquaculture species lies between 50-150 mg/L $CaCO_3$ (Wurts, 2002). The maximum reading of 92.87 mg/L falls within the desired range for good fish production. The mean of 20.33 ± 20.60 mg/L is relatively low and creates unstable water chemistry conditions at those specific sites. Such low alkalinity concentrations also decrease the natural productivity of dams.

The LSM value for non-fish farmed sites was 23.93 mg/L with a standard error of 2.81. The value for the farmed sites was 23.47 mg/L with a standard error of 1.29, thus there is no statistically significant difference between the alkalinity ($p>0.05$) at fish farmed and non-fish farmed sites. There is a statistically significant difference between the alkalinity readings ($p<0.05$) at the surface and bottom of the dam. This can be explained by the presence of CO_2 released from the sediment and bottom layers by the decomposition of organic material, and which affects the pH concentrations. Therefore alkalinity should be lower in the hypolymnion of dams due to acid complexes forming between CO_2 and tracer metals such as Fe, Mn, Cu being trapped in the sediment (Wurts, 2002). The statistically significant difference between sites ($p<0.05$) is linked to the chemical composition of rocks and soils. High alkalinities are associated with most rock formation types, except for weathered sandstones. Water bodies close to intensive agriculture may have a measurable phosphate-based alkalinity (DWAF, 1996 B).

t. Hardness (mg $CaCO_3$/L)

Water that contains more than 200 mg/L as $CaCO_3$ is considered to be hard (IDPH, 2012). The following is a measure of hardness (expressed in mg/L as CaCo3) as described in DWAF (1996 B):Hardness of 0-50 is considered as soft water, a levels of 50-100 is moderately soft, 100-150 is slightly hard; 150-200 is moderately hard, 200-300 is hard and >300 is very hard. The maximum value of 98.07 mg/L is below the range for hard water (100-300 mg $CaCO_3$/L). The mean value of 26.85 ± 25.74 mg/L for all the sites is within the soft water range (0-100 mg $CaCO_3$/L). Most fish species will grow adequately over a range of 30-100 mg/L. Aquaculture species exposed to $CaCO_3$ concentrations that do not meet their species-specific requirements, could indicate reduced growth, disruption of osmotic balance, decreased hatchability and survival of fry, as well as reduced resistance to disease (DWAF, 1996 B). The more important aspect is the secondary effect water hardness can have on the other parameters, such as an increase in the toxicity of heavy metals (DWAF, 1996 B).

The LSM value for non-fish farmed sites was 26.80 mg/L with a standard error of 1.15. The value for the farmed sites was 26.63 mg/L with a standard error of 1.80. This resulted is that there is no significant difference between the hardness concentration for fish farmed and non-fish farmed sites ($p<0.05$). The results also indicated that there was no statistically significant difference in hardness ($p>0.05$) between the surface and bottom of sites. The statistically significant difference between sites ($p<0.05$) can be ascribed to the surrounding geological formations. Hardness of water is influenced by the geology of the catchment, in particular the presence of soluble calcium and magnesium inorganic constituents (DWAF, 1996 B).

The concentration of physico-chemical parameters most likely not to be influenced by fish farming (depth, temperature, pH, TDS, Na, K, Ca, Mg, Fe, Cl, CO_3, HCO_3, Mn, B, Cu, Zn, Al, SO_4, alkalinity and hardness) indicated a strong affinity to regional site specific patterns. The process is mainly influenced by geology and the prevailing climate in terms of temperature and rainfall. Soils in the WCP are mainly from weathered Table Mountain Sandstones and shales from the Malmesbury Group. The Mediterranean climate of the WCP means that there is winter rainfall and subsequently diluted waters, whereas in summer higher temperatures cause increased evaporation and concentrated waters. Thus, major ions in the water fluctuate according to the changing weather patterns.

Overall, the water quality parameter ratios for fish farmed dams to non-fish farmed dams were ranging between 0.17 (SO_4) and 2.07 (Mn) (see Table 2.4). Most of the parameters have a ratio close to one indicating that the physical environment and site location have a much larger influence than the presence of fish on the concentration levels of these parameters. The ratio of carbonate was relatively high (71.24) and this can be explained by the presence of weakly buffered waters or it could be an outlier value. Furthermore, the influence of leaf litter from surrounding natural vegetation and soils accumulating through erosion and lateral transfers should also be considered as potential agents affecting water quality.

2.5.2 Parameters most likely to be influenced by the presence of aquaculture

a. Secchi disk

A Secchi disk is used to determine the transparency level in the water. The disc is lowered into the water and the depth at which the darker and lighter colours cannot be differentiated, is read (Bartram & Balance, 1996). The recorded minimum reading of 10 cm is not good enough for optimal trout production. Trout requires a water transparency of >50 cm to feed optimally (Salie et al., 2008). Some researchers found that there are different levels of feeding at fluctuating turbidity levels (Hanson & Larsson, 2009). Such a low transparency reading could lead to a decline in FCR at fish farms (Salie et al., 2008). The maximum value of 510 cm is very good for trout production. It is accepted that the deeper the transparency, the deeper the depth of photosynthesis. A high level of photosynthesis with abundant plant life can lead to sustained fish production in the morning. The mean value of 139 ± 94 cm indicated that the dams involved in this research have sufficient transparency to support good feeding practices.

The LSM value for non-fish farmed sites was 116 cm with a standard error of 5. The value for the farmed sites was 147 cm with a standard error of 4. The non-fish farmed sites had a lower value for transparency over the research period. The Secchi disk reading is influenced by an increase in TSS which will result in an increase in the turbidity of the water as well (Yi et al., 2003). TSS can be inorganic (sand, clay, silt) or organic (waste products, uneaten feed, phytoplankton). The inorganic TSS can be influenced by the transporting of soil from the adjacent landscape through erosion and runoff. Considerable quantities of suspended material are derived from weathering and erosion (DWAF, 1996 B). The organic TSS is primarily influenced by the feed, faeces and organic effluent in suspension and secondarily through increase in phytoplankton biomass as a result of available nutrients. Available nutrients could be linked to fish farming operations as well as agricultural runoff and industrial effluent entering the water resource. Beveridge (1984) explains that most studies on species culture have recorded increases in the levels of suspended solids and nutrients (alkalinity, total P, PO_4, NH_4-N, organic N & C) and decreases in O_2 in and around the enclosures and net cage systems. Overall, both farmed and non-fish farmed sites were found to be appropriate for aquaculture, based on the Secchi disk reading. The maintenance of good visibility for the cultured species is crucial for optimum performance in the production system.

There is no statistically significant difference between surface and bottom Secchi disk reading ($p>0.05$). There is a statistically significant difference in Secchi disk readings ($p<0.05$) at different sites and this can be related to the factors contributing to the Secchi disk reading namely fish metabolic waste and uneaten feeds, silt and sand due to erosion and plant debris from surrounding vegetation. There is a statistically significant difference between Secchi disk readings ($p<0.05$) at fish farmed and non-fish farmed. This difference can largely be attributed to the fish activity. Firstly, during fish farming operations water movement increases during feeding, creating turbulence that can dislodge settled solids from the cages and dam bottom and reduce the transparency of the water column. Secondly, with intensive farming, daily feeding is administered and the fish biomass produces metabolic waste that disperses and partially dissolves. The other contributing aspect is feed waste through uneaten feed and excess feed through insufficient management. Turbulent conditions also lead to the mixing of bottom and top layers resulting in an increase in total suspended solids. In holomictic dams the turnover phase can be associated with extreme fluctuations in the concentrations of the water quality parameters.

In non-fish farmed dams, transparency can be influenced by the presence of phytoplankton and other organic and inorganic debris brought to the dam by agricultural runoff and surrounding storm water outlets. Furthermore, the nutrient level in the water of specifically monomictic dams can also decrease the water visibility. Soil particles contribute most to suspended matter in natural waters and subsequently to turbidity (DWAF, 1996 B). Higher concentrations of phytosynthetic biomass usually lead to a decrease in transparency. Naselli-Flores & Barone (2000) found in their study that under the same climatic conditions, autogenic (increase of biomass, decrease in light penetration and euphotic depth) and allogenic (use of the stored waters, anticipated breaking of the thermocline, increase of the mixing depth) processes may shift the structure of phytoplankton assemblage in the same direction even though the quantity of biomass remains linked to nutrient availability.

b. Dissolved oxygen (DO)

The DO in natural water bodies depends on the physical, chemical and biochemical activities in the water body. Measurements of DO provide a good indication of water quality. Changes in DO concentrations can be an early indication of changing conditions in the water body (Bartram & Balance, 1996). The DO concentration in dams is generally the limiting environmental parameter to stocking density (Colt, 1986; DWAF, 1996 B). Many stocking densities are determined through calculating the oxygen budgets of dams. Every fish species has its oxygen requirement. In order to facilitate sustainable fish production, the dam has to deliver sufficient concentrations for optimal growth. It is advisable that there should be at least 5 mg/L of DO throughout the night and at dawn to support trout production (Salie et al., 2008). The biological oxygen demand will increase with fish farming and the dam has to be evaluated to make sure it can support additional demand for DO. The target water quality range for optimal growth and production is 6-9 mg/L (DWAF, 1996 B).The minimum reading of 0.3 mg/L was way below the requirements and would not be supportive of fish farming (Klontz, 1991). Such a dam would have a weak biological balance and the ratio between producers and consumers of DO is disproportionate. Such low DO concentration is also indicative of eutrophication and biological overload (DWAF, 1996 B). Fish would not be able to survive under such low concentrations and this value was probably taken during summer when there were no fish in the dam. In any event, such a dam is not a good site for fish farming for the fluctuation in DO is too great. The maximum value of 16.40 mg/L is excellent and borders on super-saturation of the dam. This can lead to gas bubble disease if not monitored carefully. The mean of 8.07 ± 2.49 mg/L for the dams involved in the research indicated that most of these dams have sufficient DO concentrations to support fish farming. The challenge is to maintain such levels and avoid any extreme fluctuations that can adversely affect the fish population.

The LSM value for non-fish farmed sites was 8.21 mg/L with a standard error of 0.1478. The value for the farmed sites was 8.09 mg/L with a standard error of 0.12. Although the concentration of DO is slightly higher for non-fish farmed sites, the difference of 1.2 mg/L indicates that the biological oxygen demand is almost similar in both. Thus, there is not a statistically significant difference between fish farmed and non-fish farmed dams with regard to dissolved oxygen ($p>0.05$). Mirrasooli et al. (2012) found that the there was little difference between the upstream DO and the downstream DO from the discharge point of trout farms indicating minimum influence on DO levels by the fish.

There is a statistically significant difference between the concentration of dissolved oxygen ($p<0.05$) at the surface and the bottom of dams. Farm dams generally have lower DO concentrations in the hypolymnion or bottom layers. Maleri (2011) found in her studies that the duration of anoxia in the hypolymnia can be between 2.3-4.6 months. The bottom parts of the water column are characterized by the accumulation of organic and inorganic material which is brought about by alluvial processes in riverine ecosystems, agricultural runoff, housing developments and storm water conditions. The thermocline and the relationship between temperature/oxygen and depth in lakes are shown in Figure 2.7. External organic nutrient loading can be caused by fish farming and other agricultural and anthropogenic activities such as industry effluent, grazing cattle, spraying programmes with pesticides and fertilizers and household sewage (treated or untreated) discharge. Aquaculture operations usually attract bird populations, and bird excreta also add to the organic loading. The BOD of the dam increases as bacteria and fungi uses DO to decompose organic debris.

There is a statistically significant difference in dissolved oxygen ($p<0.05$) between sites. It is expected that the DO profiling for sites differ from one another. Each site has its own agents/vectors influencing the DO concentration. The DO levels can fluctuate in short periods of time within a single day or over longer periods of time due to sporadic weather pattern changes. The prevailing DO could be influenced by photosynthetic aquatic plant biomass, zooplankton, presence of pollution, organic loading and other sources of nutrient enrichment.

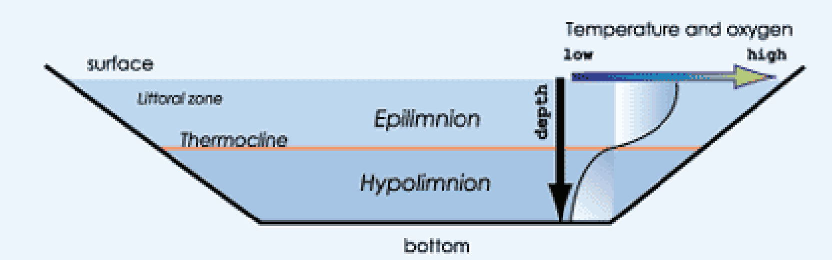

Figure 2.7. Thermocline and the relationship between temperature/oxygen and depth in lakes (Williams, 2001).

All these factors contribute to producing and using oxygen. A good site for fish farming should have a stable minimum requirement concentration with fluctuating concentrations that do not fall below the minimum requirement for the species under production. Therefore, farmers are advised to calculate an oxygen budget and firstly determine the carrying capacity of a water body under prevailing stocking densities, then secondly, implement measures that ensure sustainability of fish biomass. The effect of low DO on fish is a factor of exposed time, fish health and the water temperature (DWAF, 1996 B).

c. Phosphorous (P)

Groundwaters rarely contain more than 0.1 mg/L phosphorus unless they have passed through soil containing phosphate or have been polluted by organic matter ((Bartram & Balance, 1996).The global target range, at which concentrations cause algal blooms, is ≤ 0.005 to 0.01 mg/L (C.E Boyd, personal communication, 10 August 2012). The minimum reading of 0.001 mg/L is below the global target range. Optimum growth of fish species is achieved at concentrations < 0.6 mg/L (DWAF, 1996 B). The maximum value of 0.735 mg/L is slightly outside the range for optimal growth, and can lead to changes in the trophic status of the water body. No trophic changes occur at levels ≤ 0.1 mg/L (DWAF, 1996 B). The mean value of 0.065 ± 0.233 mg/L is below the levels found by Heath (1990). Phosphorus compounds are present in fertilizers and pesticides as well as in human and animal excreta, and consequently in both ground and surface waters with sewage, industrial wastes, storm water, agricultural runoff and fish farming effluent (DWAF, 1996 B). Large quantities are also found where decomposition of organic material occurs (DWAF, 1996 B). High concentrations of phosphorus compounds may produce a secondary problem in water bodies. In such situations the presence of additional phosphorus compounds can stimulate algal productivity and enhance eutrophication processes (Bartram & Balance, 1996).

Increases in total surface phosphorous were indicated in dams with a trout production of approximately 5 tons per year (Maleri, 2011). Heath (1990) found phosphorous concentrations of 0.100 mg/L to 0.120 mg/L and a maximum concentration 0.420 mg/L in freshwater bodies with a stocking density of 1600 kg/ha of fish. Approximately 5-15 g of phosphate is produced for each kilogram of dry pelleted feed fed to trout; moist and trash fish-based diets produce higher levels of waste products (DWAF, 1996 B). The following calculation is relevant to the rainbow trout producers in the WCP:

Box 1. Example of the amount of P released from feed into the environment for small-scale trout culture.

In a dam approximately seven metres deep, with surface area of three hectares thus, (7 x 30000 m^2 = 210000 m^3), the following calculation applies: The trout farms visited during the research period indicated an average FCR of 1.3 feed to 1.0 kg fish weight. The extruded artificial diets used for fattening/on-growth of the trout included 7 g of P per kg of feed, or 0.007. Thus, the result is 1.3 x 0.007 = 9.1 g P in feed. Further, one kilogram of fish x 0.0025 (2.5 g P in fish ÷ 6.6 g P in water (65% to sediment), thus 6.6 g P x 0.35 = 2.31 g P in water per kg trout produced (C.E Boyd, personal communication, 10 August 2012).

The LSM value for farmed sites was 0.101 mg/L with a standard error of 0.021. The value for the non-fish farmed sites was 0.049 mg/L with a standard error of 0.011. There is a statistically significant difference in phosphorous ($p<0.05$) concentration between fish farmed and non-fish farmed sites. Readings at farmed sites were almost double the P concentration compared with non-fish farmed sites. Maleri (2011) found in her studies that 84% of the dams investigated showed an increase of > 50% addition to the P concentration.

However, the LSM for orthophosphate for farmed sites was 0.185 mg/L with a standard error of 0.042. The value for the non-fish farmed sites was 0.168 mg/L with a standard error of 0.034.There was little difference in orthophosphate between farmed and non-fish farmed sites. Orthophosphate is the reactive phosphorous and the most stable kind of phosphates in the water column of freshwater bodies. It is the limiting compound for micro-and macro plant growth. Phosphorus is essential for metabolism, and therefore present in animal waste (General information on phosphorous, [s.a.]). Phosphate concentrations should be interpreted in conjunction with the concentrations of nitrate, total suspended solids (turbidity) and dissolved oxygen. Site-specific conditions should also be taken into account (DWAF, 1996 B).

The statistically significant difference in P ($p<0.05$) between surface and bottom is due to the DO status of the hypolymnion. Sediments in dams can have high concentrations of Fe, Mn and P. These chemical compounds can be released to the water column in large quantities from the bottom of the lake when oxygen levels are very low. Therefore, the P concentration at the bottom and surface of dams will always differ due the P dynamics as in the P nutrient budget (DWAF, 1996 B, Maleri, 2011, C.E Boyd, personal communication, 10 August 2012). The statistically significant difference of P ($p<0.05$) between sites is a result of different external and internal factors influencing the P concentration of sites. At all the research sites, farm dams are used for irrigation during the summer months. The farms were all located in the agricultural belt of the WCP. These sandy soils derived primarily from Cape Granite and Table Mountain Sandstone are low in nutrients, specifically low in phosphorous and are characteristic of the Cape Fynbos Biome (Mitchell et al., 1984; Cramer, 2010). Therefore, farmers use frequent dosages of fertilizers, such as double superphosphate and uream to enrich the soils for the farming of high-value plant crops such as grapes, deciduous fruit, olives, etc. However, the P concentration is low indicating that the perennial plants utilise the P effectively and the residual P has no negative impact on water quality. Therefore the major external point source of P to dams is from agricultural runoff. Other sources include effluent from industrial and housing developments. Phosphorous has been described as an important limiting factor for plant growth in dams (Temporetti & Pedrozo, 2000; Maleri, 2011; C.E Boyd, personal communication, 10 August 2012). Thus it is important to consider loading through other potential sources when investigating the impact of trout farming on the ecological balance of dams. The major sources of nutrients in lakes are indicated in Figure 2.8.

Most intensive fish farms are characterised by high stocking densities of candidate species and high volumes of artificial feeds. As previously explained, the potentially polluting sources can originate from the uneaten feeds, fish metabolic waste and non-removal of dead fish. Thus, P enters the water body via commercial fish feeds. The diets used for trout farming contain 0.7 g per kg of feed (L.F. De Wet, personal communication, 5 August 2012). It is estimated that 11% of the total amount of P contained in fish feed dissolves in the water and that about 66% of P in fish feed accumulates on the bottom sediments. The other 23% is removed with the harvest (Temporetti & Pedrozo, 2000; C.E Boyd, personal communication, 10 August 2012). Farm dams serve as phosphorous sinks (C.E Boyd, personal communication, 10 August 2012). Dr Boyd also explained that when P is adsorbed to particles and settles in the substrate, it is gradually covered by sediment and remains there. This causes P to be removed from any further bio-circulation. Maleri’s (2011) results indicate a concentration of 0.068 mg/L for non-production sites and 0.144 mg/L for fish production sites. Pulatsu et al., (2004) also found an increase in P values for fish farmed sites, but postulated that P in fish farming effluent can be much reduced if farmers comply with feed management guidelines. Therefore a holistic strategy is supported whereby the supply chain in fish feed manufacturing work together to follow guidelines which will provide future sustainability to the industry. This approach will also encourage environmental awareness and accentuate the potential negative effect it can cause.

d. Total Ammonia Nitrogen (TAN)

In chemical analysis the TAN is measured and it includes two forms of ammonia: unionized form (NH_3) and the ammonium ion (NH_4^+) form. The unionized form is considered to be toxic to fish (Moogouei et al., 2010). In open-water aquaculture such as the cage culture of trout, there is a likelihood of the organic load from the metabolic waste of cultured organisms and unused feeds accumulating, sometimes giving rise to a high biological oxygen demand, the accumulation of toxic gases and the creation of anoxic areas under the cages (Tomasso, 2002; Beveridge, 2004; Pillay & Kutty, 2005). When nitrogenous organic matter is destroyed by microbiological activity, ammonia is produced and it is therefore found in many surface and groundwaters. Higher concentrations occur in water polluted by sewage, fertilizers, and agricultural wastes or industrial wastes containing organic nitrogen, free ammonia or ammonium salts. Certain mesophyllic aerobic bacteria such as *Nitrosomonas* and *Nitrobacter* spp convert ammonia into nitrites and then into nitrates. Nitrogen compounds, as nutrients for aquatic micro-organisms, may be partially responsible for the eutrophication of lakes and rivers (Bartram & Balance, 1996). Ammonia can result from natural reduction processes under anaerobic conditions. The proportions of the two forms of ammonia nitrogen, i.e. free ammonia and ammonium ions, depend on the pH. The relationship between pH, ammonia and ammonium is illustrated in Table 2.6.

The target water quality range 0.000 to 0.025 mg/L is prescribed as the levels where no harm is expected to occur in fish (DWAF, 1996 B). Concentrations of > 0.3 mg/L can lead to adverse conditions for cold water fish such as rainbow trout, whereas concentrations > 1.0 mg/L are reported to cause mortalities to warm water fish such as the African catfish (DWAF, 1996 B). The maximum value of 6.480 mg/L can be detrimental to trout when maintained at low oxygen levels with a higher pH and temperature. The minimum reading of 0.015 mg/L is within the target water quality range. The mean value of 0.475 ± 0.682 mg/L is indicative across the sites that farm dams generally maintain higher than desirable levels. Fish farmers have to be aware of high TAN levels that might influence optimal production performance.

Table 2.6. Relationship between pH, ammonia and ammonium (Bartram & Balance, 1996).

pH	6	7	8	9	10	11
% NH_3	0	1	4	25	78	96
% NH_4	100	99	96	75	22	

The LSM value for non-fish farmed sites was 0.593 mg/L with a standard error of 0.088. The value for the farmed sites was 0.476 mg/L with a standard error of 0.050. These values indicate that there is no statistically significant difference in TAN ($p>0.05$) between fish farmed and non-fish farmed sites. However, when comparing farmed and non-fish farmed sites Maleri (2011) reports an increase from 0.118 to 0.474 mg/L from non-productive to productive sites.

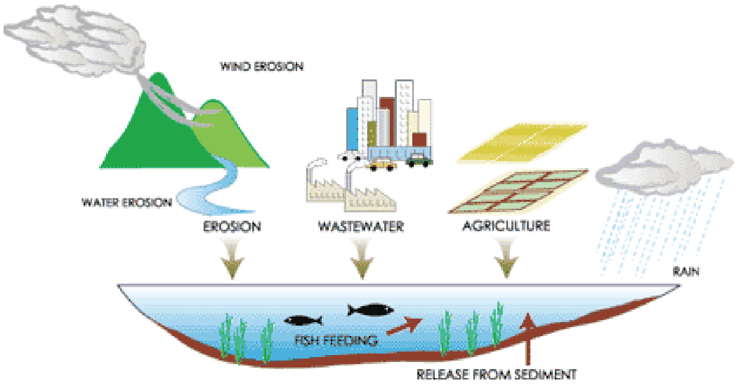

Figure 2.8. Major sources of nutrients in lakes (Williams, 2001).

TAN concentrations in dams are usually caused by enriched effluent from agricultural runoff, storm water and surrounding housing settlements. Commercial agriculture contributes enrichment to water ecosystems through fertilization and pesticides application regimes. The pathways of major sources of nutrients into lakes are shown in Figure 2.8. Through these regimes much N, P, K, etc. eventually reach surface and bottom waters (Maharaj, 2005; Dabrowski et al., 2009).There is a statistically significant difference in TAN ($p<0.05$) between surface and bottom waters. In open-water aquaculture such as cage culture of trout, there is a likelihood of the organic load from metabolic waste of cultured organisms and unused feeds accumulating, sometimes giving rise to a high biological oxygen demand and accumulation of toxic gases and creating anoxic areas under the cages (Tomasso, 2002; Beveridge, 2004; Pillay & Kutty, 2005). Thus, the higher TAN concentration in fish farmed sites can be ascribed to the addition of feeds and the presence of high density fish biomass. Maleri (2011) states that more ammonia accumulates in the hypolimnion of production sites and that this can be directly linked to different processes in the sediment water interface of the dams and the consequent decomposition of organic material and corresponding deoxygenation. Thus, higher TAN concentrations in the bottom waters of dams are associated with organic loading of dams, irrespective of whether the point source was fish farming or natural eutrophication. Ammonium concentrations also tend to be elevated in waters where organic decomposition takes place under anaerobic conditions. According to the South African Water Quality Guidelines for Agricultural Use for Aquaculture (DWAF, 1996 B), it is explained that natural waters may also contain high concentrations of ammonium due to sewage effluent, effluents from industries and agricultural effluents (manure and fertilizers containing ammonium salts). The results further indicate that there is no statistically significant difference in TAN ($p>0.05$) between sites.

e. Nitrate-Nitrogen (NO_3-N)

Nitrate accumulates in aquaculture production systems as the final product in the nitrification of ammonia and enters the water in fish excretory products (DWAF, 1996 B). Therefore it is commonly present in surface and ground waters as the end product of the aerobic decomposition of organic nitrogenous matter. Other sources of nitrate are chemical fertilizers and pesticides from agricultural cultivated land as well as drainage from livestock housing and domestic and some industrial waters (Bartram & Balance, 1996). Unpolluted natural waters usually contain only minute amounts of nitrate and it was found that fresh water with low or no pollution sources has < 5 mg/L nitrate (DWAF, 1996 B). The minimum reading of 0.009 mg/L is indicative of unpolluted water. The maximum value of 7.360 mg/L is indicative of some form of impact having occurred that enriched the water. The mean of 0.535 ± 0.851 mg/L was taken across the 29 sites involved in the research and shows that most farms (fish farmed or non-fish farmed) are within the range of impacted fresh water resources (< 5 mg/L). DWAF (1996 B) indicates that target water quality levels < 300 mg/L have no adverse effect on aquatic species. Therefore, although the maximum value reads high when compared to the mean, the concentration is considerably low for water quality requirements of both agriculture and aquaculture.

The LSM mean value for non-fish farmed sites was 0.493 mg/L with a standard error of 0.0726. The value for the fish farmed sites was 0.503 mg/L with a standard error of 0.0574. Thus, there is no statistically significant difference in Nitrate-Nitrogen ($p>0.05$) between fish farmed and non-fish farmed sites. Further analysis also indicated that there is no statistically significant difference in Nitrate-Nitrogen concentration between surface and bottom waters and no statistically significant difference between sites for Nitrate-Nitrogen ($p>0.05$).

Nitrate is the least toxic to fish of the inorganic nitrogen compounds (DWAF, 1996 B). In surface water, nitrate is a nutrient taken up by plants and assimilated into cell protein. Nitrate and ammonium are the most important nitrogen sources for phytoplankton growth and nitrate seems to become limiting at concentrations lower than 20 µM, especially when it is considered that N-limitation is significant in summer (Domingues et al., 2011). Stimulation of plant growth through increased nitrate concentrations, especially of algae, may cause water quality problems associated with eutrophication. The subsequent die-off and decay of algae and other aquatic plants produces secondary effects on water quality, which may also be undesirable (Bartram & Balance, 1996). In such events the DO concentrations of the water will decrease and the production of CO^2 and NH_3 will increase.

f. Nitrite-Nitrogen (NO_2-N)

Nitrite is an unstable, intermediate stage in the nitrogen cycle and is formed in water either by the oxidation of ammonia or by the reduction of nitrate. During nitrification, two groups of highly aerobic, autotrophic bacteria, mainly *Nitrosomonas* spp. and *Nitrobacter* spp., oxidise ammonia to nitrite, and nitrite to nitrate (DWAF, 1996 B). Thus, biochemical processes can cause a rapid change in the nitrite concentration in a water sample. In natural waters nitrite is normally present only in low concentrations (a few tenths of a milligram per litre). Higher concentrations may be present in sewage and industrial wastes, and in treated sewage effluent (Bartram & Balance, 1996). The target water quality range of 0 to 0.05 mg/L is the level preferred where no adverse effect on salmonid species is expected to occur (DWAF, 1996 B). The minimum reading of 0.001 mg/L and the recorded mean of 0.024 ± 0.024 mg/L found at the sites involved in the research were both within the prescribed target range. However, it should be noted that the maximum reading of 0.200 mg/L is close to the value of 0.250 mg/L, which can be toxic to salmonids.

The LSM value for non-fish farmed sites was 0.017 mg/L with a standard error of 0.002. The value for the fish farmed sites was 0.023 mg/L with a standard error of 0.001 and it was found that there is a statistically significant difference in Nitrite-Nitrogen ($p<0.05$) between fish farmed and non-fish farmed sites. Although there is a statistically significance difference in Nitrite-Nitrogen concentrations between fish farmed and non-fish farmed sites, the difference in values can have a limited effect on the chemical composition of the water column. Maleri et al., (2008) also found the difference between Nitrite-Nitrogen concentrations to be negligible between fish production and non-fish production sites.

There is a statistically significant difference between surface and bottom concentrations of Nitrite-Nitrogen ($p<0.05$). Nitrite-Nitrogen is a product of nitrification by oxidative micro-organisms. Therefore with higher TAN concentrations in the bottom layers of dams, the Nitrite-Nitrogen should be higher as well if sufficient DO is available for nitrification. The results for DO have indicated a mean of 8.06 mg/L for all samples which could explain adequate DO availability for nitrification. There is a statistically significant difference between sites with regard to Nitrite-Nitrogen ($p<0.05$). This could be explained by the different periods of time during which the sites were exposed to agricultural activities, and different sources of effluent and discharge finding pathways to the dam.

g. Total suspended solids (TSS)

It is recommended that the TSS levels should be > 120 mg/L for trout production (Elsenberg, 2010). TSS can be of an organic or inorganic nature. Inorganic suspended solids can derive from sand and clay silting material from erosion and runoff while organic suspended solids derive from animal faeces and uneaten feed and dead fish. Higher levels can lead to physical irritation of the gills as well as providing a nutrient substrate for microbial growth. In open water dams the TSS has a direct effect on the penetration depth of sunlight, thus in cases where it is high, it can limit the photosynthesis depth. TSS is also indicative of the presence of the phytoplankton biomass. The maximum reading of 1396mg/L is in excessive of the recommended concentration and is unlikely to support trout farming. Such high values were recorded in a study by McLaughlin et al., (2009) who investigated discharges from construction sites and found values of 4130 up to 11 800 mg/L. Therefore, the maximum reading could be from a site with turbid water caused by erosion and runoff containing high concentrations of sand and clay particles. It could also indicate the presence of carp populations which can lead to an increase in turbidity as a result of their feeding behaviour. Du Plessis (2007) and Bruton (1985) both explain that the level of turbidity of inland waters is strongly affected by the amount of suspended material in the water column. During the selection of fish farmed sites, transparency is very important for optimal feeding and feed management. The mean value of 53.28 ± 114.4 mg/L is more acceptable for fish farming. Salmonid species indicate no adverse effects at concentrations of <86 mg/L (DWAF, 1996 B). It is indicated in Figure 2.9 that trout requires relatively clear vision to allow for efficient feeding.

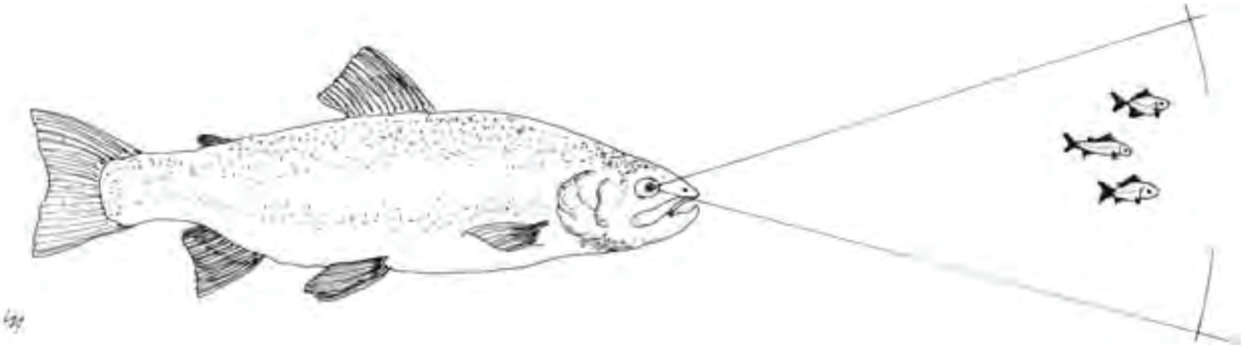

Figure 2.9. Clear vision will allow trout to feed efficiently (Woynarovich et al., 2011).

The LSM value for non-fish farmed sites was 23.76 mg/L with a standard error of 7.86. The value for the fish farmed sites was 55.94 mg/L with a standard error of 6.75. This indicated that there is a statistically significant difference in TSS ($p<0.05$) between fish farmed and non-fish farmed sites. The farmed sites have been shown to have a value almost twice as high as the non-fish farmed sites. Fish farming can increase TSS concentrations through waste, uneaten feeds, dead fish and increased fish movement during feeding and mating, and therefore farmed sites are expected to have higher TSS. However, Pulatsu et al. (2004) found the upstream TSS to be lower than the TSS downstream of the trout farm, but indicated that the difference was not statistically significant. Maleri (2011) indicated not much difference between the mean for fish production sites (15.3 mg/L) and non-fish production sites (14.2 mg/L). There is no statistically significant difference in TSS ($p>0.05$) between surface and bottom sites, but definitely a statistically significant difference in TSS ($p<0.05$) between sites. The TSS of individual sites can contain both organic and inorganic material. It is a function of the soil stability of the damwall and surrounding contours, the establishment of vegetation or the lack thereof, effluent discharges, agricultural runoff, and industry through development and construction.

The concentrations of the following parameters (Secchi disk, DO, P, TAN, NO_3-N, NO_2-N, and TSS) are most likely to be influenced by fish farming. There can be a primary influence where organic particles emanating from excess feeds and faeces are suspended in the water column, changing the TSS concentration and consequently the water transparency observed in the Secchi disk reading. Secondarily, nitrogenous compounds are released into the water environment through nitrification by aerobic micro-organisms (*Nitrosomonas* and *Nitrobacter* spp, as well as through denitrification. Dissolved oxygen levels are influenced by the rate of photosynthesis and decomposition of organic material. Phosphorous is mainly released from the feed. The ratio of water quality parameters of fish farmed to non-fish farmed sites ranges from 0.8 for TAN and 2.06 for P. These ratios are relatively low and are indicative of good water resource management by both fish- and crop farmers.

The above-mentioned water quality parameters are directly associated with organic loading; either via fish farming practices or surrounding vegetation and agricultural activities. The total nutrient loading is relatively low and does not pose any significant threat to the sustainability of fish farming and irrigated crops. However, enriched waters can lead to algal blooms when the critical environmental cues (temperature, oxygen, air, pH, nutrients) are present. In such cases the quality of trout production can be compromised through off-flavours in the fish as well as the irrigation systems as a result of excessive clogging and consequent mechanical damages.

2.5.3 Phytoplankton

a. Group Bacillariophyta (diatoms)

Twenty genera were identified in this group. Of the 2600 samples collected, it had a presence of 130 for the 29 sites over the five season research period (spring 2010 to spring 2011) and an absence of 2470. The frequency of occurrence for the six groups across the 29 sites (in descending order) is shown in Table 2.7.

Table 2.8 described that the type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence of Bacillariophyta ($p>0.05$). Both genus and season has a statistical significance for frequency of occurrence for Bacillariophyta ($p<0.05$). The occurrence of phytoplankton is directly linked to the nutrient availability in the water. The nutrient concentration fluctuates according to season. In monomictic dams the nutrient levels are at their highest during the low water levels in summer and during mixing of the water in the turnover phase in winter. During winter nutrients are recycled from the enriched sediment of the dams and provides high concentrations of nitrogen and phosphorous to the water column. Elevated phosphorous concentrations have been found to directly influence algal biomass (Maleri, 2011). The findings of Van Ginkel et al., (2007) were similar. Du Plessis (2007) states that in terms of biomass, the highest occurrence was found during the winter months. With the increase nutrient availability the diversity in genera also increases. Phytoplankton size distribution and community structure are considerably changed with rising eutrophication (Du Plessis, 2007, Maleri et al., 2008, Maleri, 2011). Trout farming is seasonal and the additional organic input from the farms can alter the trophic state of the water environment. In this study the fish farming season (April-October coincided with winter when the dams have turnover phases. Therefore, if care is not taken to optimise feed management, farmers can experience secondary problems of oxygen shortages due to an increase in algal populations.

In Figure 2.10 the phenomenon of seasonal development of phytoplankton occurrence is schematically presented. In summer production usually decreases and the production that does occur during summer is the result of regenerated nutrients. During autumn with the onset of winter weather conditions and increased turbulence and mixing, mainly by north-westerly winds, small blooms are generated. By June there are higher concentrations of nutrients due to turbulence and the mixing of water layers. The declining light levels limit production, which gradually falls off towards the winter rates.

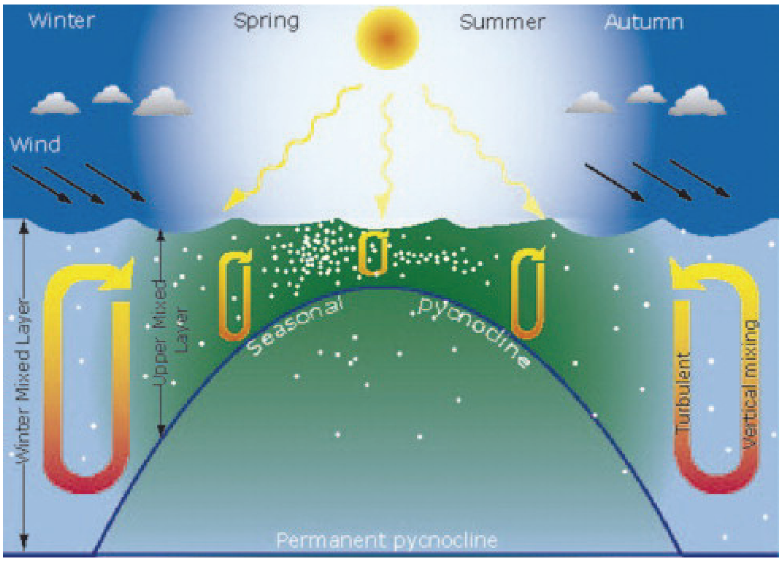

Figure 2.10. Schematic representation of the seasonal development of phytoplankton and the main physical factors affecting it. White dots represent phytoplankton biomass (Rey, 2004).

b. Group Chlorophyta (green algae)

Twenty-three genera were identified in this group. Of the 2985 samples collected, it had a presence of 371 and absence of 2614. The type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence of Chlorophyta ($p>0.05$). The results are presented in Table 2.8.

Both genus and season had a statistical significance for frequency of occurrence of Chlorophyta ($p<0.05$). The statistical significance for genus and season has been explained.

c. Group Chrysophyta (golden-brown algae)

Two genera were identified in this group. They were found to be present in 34 samples and absent in 226. The type 3 analysis of effect indicated that geographical location as well as season had no statistical significance for the frequency of occurrence of Chrysophyta ($p>0.05$). This can be seen in Table 2.8. Only genus had a statistical significance for frequency of occurrence of Chrysophyta ($p<0.05$). The statistical significance for genus has been explained.

d. Group Cyanophyta (blue-green algae)

Five genera were identified in this group. They were found to be present in 66 samples and absent in 584. The type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence for Cyanophyta ($p>0.05$). This can be seen in Table 2.8. Both genus and season had a statistical significance for frequency of occurrence of Cyanophyta ($p<0.05$). The statistical significance for genus and season has been explained

e. Group Dinophyta (dinoflegellates)

Three genera were identified in this group. They were found to be present in 320 samples and absent in 70. The type 3 analysis of effect indicated that geographical location has no statistical significance for the frequency of occurrence for Dinophyta ($p>0.05$). This can be seen in Table 2.8. Both genus and season had a statistical significance for frequency of occurrence of Dinophyta ($p<0.05$). The statistical significance for genus and season has been explained.

f. Group Euglenophyta (euglenoids)

Three genera were identified in this group. They were found to be present in 9 samples and absent in 381.The type 3 analysis of effect indicated that geographical location, genus and season had no statistical significance for the frequency of occurrence for Euglenophyta ($p>0.05$). This can be seen in Table 2.8.

Table 2.7. Frequency of occurrence of the six groups across the 29 sites (in descending order).

Group	Total observations	Occurrence	Non-occurrence
Chlorophyta	2985	371	2614
Bacillariophyta	2600	130	2470
Cyanophyta	650	66	584
Dinophyta	390	70	320
Euglenophyta	390	9	381
Chrysophyta	260	34	226

The Group Cryptophyta was omitted from the research for there was only one genus found in this group. The group is also known as the cryptomonads (Van Vuuren et al., 2006). The genera in the seven major groups of phytoplankton are listed in Appendix 6.

2.5.4 Production data

There is a statistically significant difference between source of juveniles and amount (kg) of fish harvested (p<0.05). The juveniles were obtained from four different locations, namely from the hatcheries of Lourensford Trout Farm (Somerset West), Remhoogte Trout Project (Ceres), De Hoek Trout Farm (Gouda) and Jonkershoek Trout (Stellenbosch). The trout farms in the WCP area make use of more or less the same genetic stock of rainbow trout (*Oncorhynchus mykiss*) as well as the same formulated diet. The one aspect that could be considered is the specific growth rate of the fish in each hatchery. Trout ova are hatched in winter (June/July) and placed in on-growth systems during summer (Dec-Feb) until the juveniles are of a stocking size of 150-250 g (April). The hatcheries which perform the best are the ones with the largest and healthiest stocking size juveniles (Salie, 2011). The prevailing water quality (specifically during summer) is the differentiating factors between hatcheries with regard to temperature, quantity and DO.

The 15 trout producing projects all operate grow out facilities for juvenile fish to fish with a market size of approximately 1.2 kg. The performance of the projects in terms of total kg harvested is dependent on the quality of juveniles supplied for stocking. The overall performance of fish in a system is affected by a number of factors including the environment and the condition of the fish itself (Priestleyet al., 2006).

There is a statistically significant difference between FCR and amount (kg) of fish harvested (p<0.05). Apart from fish physiology and environmental conditions, the FCR of a fish production project is mainly a function of the feed management on the farm (Goddard, 1996).

Table 2.8. The effect of variables genus, geographical location and season on the occurrence of the phytoplankton groups. The effects were considered statistically significant at a 95% confidence level (p<0.05). The highlighted (light grey) rows indicate variables which had a significant effect on the occurrence of the different groups.

Group: Bacillariophyta		**Chi-square value**	**p-value**
	Genus	57.893	<.0001
	Geographical	48.722	<.0001
	Season	4.514	0.3409
Group Chlorophyta			
	Genus	194.375	<.0001
	Geographical	39.092	<.0001
	Season	9.776	0.044
Group: Chrysophyta			
	Genus	13.674	0.0002
	Geographical	0.303	0.860

	Season	1.555	0.817
Group: Cyanophyta			
	Genus	27.929	<.0001
	Geographical	11.439	0.0033
	Season	10.152	0.0379
Group: Dinophyta			
	Genus	8.296	0.016
	Geographical	0.586	0.746
	Season	5.413	0.248
Group: Euglenophyta			
	Genus	0.446	0.8
	Geographical	11.606	0.003
	Season	2.135	0.711

Good feed management ensures less wastage and optimal utilisation of feed. Nutrient loading has been directly associated with insufficient feed management (Pulatsu et al., 2004). The trout in the floating net cages are completely dependent on the quantity feed fed to them on a daily basis. The FCRs are calculated by determining how much average weight the fish has gained compared to the amount of feed used during that period. The farm average is approximately 1.3:1, thus for every 1.3 kg of feed used, the fish grows1 kg (Salie et al., 2008). Sub-sampling of the fish population is conducted every month and the FCR calculated determines the adjustment of the daily required feed quantities. Projects with excellent FCRs are indicative of good management, thus resulting in increased final total kg of fish harvested. The operational strategy of producing trout in net cages on irrigation dams in the WCP is limited to the few colder months of the year (Maleri et al., 2008). Therefore it is important that each project endeavors to reach the highest weight in the available months for optimum profitability of the operation. There is no statistical significance between physico-chemical parameters and kg fish harvested ($p>0.05$), thus it can be extrapolated that the other external factors affecting production such as feed and fingerling are more prominent than the water quality parameters of DO, pH, TAN, PO_4 and Secchi disk. This can be seen in Appendix 3.

2.6 Conclusion

In this chapter the focus was on evaluating the impact of rainbow trout aquaculture on the water quality of irrigation dams. It was determined that these dams were fit for the farming of high value trout destined for the higher income retail market. Similar findings have been expressed for the WCP and underline the importance of the region for the trout industry (Maleri et al., 2008, Salie et al., 2008; Maleri, 2011; Salie, 2011; Stander et al., 2011). In order to provide sustainability to the aquaculture-agriculture integrated farming system, it is important that the wider understanding of the dynamics of such a system be explored. Whilst fish farming is dependent on the water quality, the commercial land-based crop farmer has to recognize the value aquaculture adds to the productivity of the water resource. Although irrigation systems using stored or diverted water have increased in number exponentially during the past 50 years, fish farming within these irrigated systems has not expanded equally (Fernando & Halwart, 2000). Therefore this situation, together with the agro-climatic conditions of the WCP, necessitates investigating opportunities in the field of aquaculture. Escalating pressure on access to clean and safe freshwater necessitates exploring ways to optimise existing use. The general populace have to experience the tangible benefit and therefore aiming for sustainability requires not only the achievement of environmental goals, but also the provision of clear economic benefits for fish farmers in the long term (SustainAqua, 2009).

Water resource management endeavours to maintain water quality parameters within the *no adverse effect range*. This is the target water quality range of concentrations or levels at which the presence of that parameter would have no known or anticipated adverse effect on the fitness of water for a particular use (i.e. aquaculture) or on the protection of aquatic ecosystems. These ranges were determined by assuming long-term continuous use (life-long exposure) and accommodating an additional margin of safety to the required concentration (DWAF, 1996 B). The rationale is that any form of intensive agriculture, including aquaculture, is expected to have some level of environmental impact. For fish farming the challenge is always to grow fish as fast as possible within the shortest period of time, notwithstanding taking cognisance of the farming in balance with nature (Cho & Bureau, 2001; Dinar et al., 2008). In intensive aquaculture animals are farmed under high stocking densities and fed volumes of high energy artificial diets rich in oils and proteins (Sørensen, 2012). Therefore, waste production will always be a byproduct of fish farming. It cannot be eliminated because fish cannot retain all the feed they consume and part of the feed will remain uneaten. Waste output amounts to an equivalent of at least one-third of the feed input (Amirkolaie, 2011). This is the nature of most aquaculture enterprises which are driven to maximise profits and optimise feasibility. However, the future success of the operation is threatened if farmers cannot foresee long term environmental sustainability and neglect managing water ecology within target water quality parameters.

The results indicated that DO, TAN and Nitrate-Nitrogen did not differ significantly between fish farmed and non-fish farmed sites. They further indicated that total suspended solids, Secchi disk reading, Nitrite-Nitrogen and phosphorus associated with fish farming, have been impacted through an increase in concentrations. Mirrasooli et al. (2012) state that Nitrate-Nitrogen and TAN have been affected, but the changes in DO and pH are considered to be negligible. Azevedo et al. (2011) found in their estimation of waste output from rainbow trout that concentrations of ammonia and of dissolved and particulate phosphorus are not reflective of waste loading of cage origin, suggesting efficient removal through uptake by biota and/or in the case of ammonia by nitrification. This indicated the importance of aeration and mixing in dams to facilitate an ecological balanced system by providing uniform concentrations of DO in the water column.

Agriculture has been recognized, both locally and internationally, as an important non-point source contributor to NPS pollution of water resources (Correll, 1998; Rossouw & Görgens, 2005; Matthews et al., 2012). The role and function of aquaculture in a nutrient budget of farm dams were emphasized. Enrichment via the application of fertilizers and pesticides to the crops and soils could lead to eutrophication (Van der Laan et al., 2012), but temporal patterns of nutrient concentrations in both soils and waters were mainly the result of fertilizer application (Jovanovic et al., 2012). However, different land uses surrounding the dams produce different volumes of runoff and consequently different amounts of mobilised sediment (Jovanovic et al., 2012).

All the irrigation dams in this research were surrounded by natural vegetation or perennial commercial plant crops such as vineyards, olives, deciduous fruit and citrus and therefore these planted soils are expected to produce less runoff. Jovanovic et al. (2012) further postulated that uncultivated (bare) soils produced more runoff and subsequently the NO_3 and PO_4 concentrations resulting from fertilizer application varied according to time of application and rains/runoff distribution. The WCP has a Mediterranean climate with wet winters and dry summers. The first continuous rains are usually observed in May/June with the onset of winter. Agricultural non-point source load was greatest during the wet season, especially with the “first flush” associated with the start of the wet season (Cullis et al., 2005). It is within this context that the impact of fish farming should be evaluated, and collaboration between the fish farmer and the land-based crop farmer is important to ensure both follow better management guidelines. Van der Laan et al. (2012) suggest that farmers can reduce N leaching from deeper soil profiles by not applying subsequent N fertilizer and forcing the crop to remove N from deeper in the soil profile. Complementary fish farmers can reduce organic pollution via wasted (unutilized) fish feeds by observing fish response to feed and adjusting feeding volume and frequency to fish behaviour. These practices could both lead to lower pollution levels of receiving waters.

The analysis of variance between groups indicated that the difference in bottom and surface samples and the site location is more important than whether there was fish farmed or not. Burford et al. (2012) also found that total nitrogen and phosphorous were higher in bottom- than the surface layers. The difference in bottom and surface layers is directly linked to the ecological status of the sediment, which serves as a nutrient sink. In monomictic dams in Mediterranean areas, mixing occurs during the winter turnover phase (Maleri, 2011). Nutrients are released due to surface and bottom water mixing, brought about by torrential rains and wind turbulence. Thus, it was found that the organic state of the sediment and bottom waters is a function of the nutrient loading over time, irrespective of whether the point source was fish farming or past agricultural activity. Therefore, it can be postulated that the initial selection of site is very important to sustain trout farming. Initiating fish farming on a site with good physical and chemical water characteristics will increase the level of performance success (Maleri, 2008, Salie et al., 2008; Rosa et al., 2012). Many dams in the WCP are bordering eutrophic status due to a history of collecting nutrient-rich effluent and runoff from different sources. When sites of this nature are used for fish farming, the nutrient status is directly influenced for fish farming will add to the nutrient budget. It is on the onus of the fish farmer to limit the nutrient addition through appropriate management.

Phytoplankton abundance was directly associated with the availability of nutrients, specifically P and N. The occurrence and biomass distribution fluctuated with dam water levels and nutrient concentrations (Oberholster & Ashton, 2008; Van Ginkel, 2012). The dynamics of prevailing phytoplankton communities are important to fish farmers for two reasons. Firstly it can cause fluctuation in the dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis), and secondly it can cause algal taint of trout flesh due to geosmin producing species. Bremner (2012) explains that in freshwater, blooms of blue-green algae may cause toxins which can be passed along the food chain and affect the texture and taste of cooked fish flesh. Fluctuating oxygen levels as well as tainted flesh are detrimental to successful trout farming. It is crucial for farmers to be able to anticipate when algal blooms are likely to occur in order to implement measures to avoid crisis management. One way of achieving this is to monitor the nutrient levels regularly and employ the required procedures when it is anticipated that the environmental conditions favour potential outbreaks. Such conditions could be high temperatures and DO, rich organic matter and also high concentrations of CO_2 and NH_3.

The analysis of the production data indicated that there was not a direct linked between water quality and fish yield at a number of fish farms. The yields of farms were associated with the quality of juveniles supplied by hatcheries and the FCR obtained. Through this analysis the importance of management to secure sustainable production was highlighted. Irrigation dams can play a role in providing water bodies for floating net cage farming systems. There is a case to promote integrated aquaculture-agriculture farming through robust site selection, supported by hands-on farm management. This approach will ensure that commercial plant crop farmers' irrigation regime and yield quality will not be negatively affected.

The general water quality indicated that irrigation dam water quality is relatively well-managed by the commercial crop farmers in the WCP. However, other researchers elsewhere in South Africa, i.e. KwaZulu-Natal and Mpumalanga classified the dams in those areas as eutrophic and in certain cases hypertrophic. Thus, the concern remains that our water resources as a whole in South Africa lack appropriate management and compliance to better management practices. Aquaculture has proven to provide real benefits to rural and urban communities and co-existence between fish farmers and crop farmers as an integrated aquaculture-agriculture system will only prosper when both primary and secondary users of irrigation dams apply practices to sustain good water quality.

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CHAPTER 3: Mitigation measures to reduce organic pollution emanating from excess feeds and fish metabolic wastes

3.1 Introduction

Fish farmers are continually faced with challenges regarding environmental sustainability and the safety of their products (Buzby, 2001; Jahncke, 2007). The term sustainable development simply implies that current demands on resources will not affect the ability of future generations to meet their demands and any food production system need to be efficient and as far as possible cause minimal impact on the environment (Colt et al., 2008; Snow & Ghaly, 2008; World Commission on Environment and Development, [s.a.]). Aquaculture is no different from any other form of agriculture and both sectors have to consider the ecological, social, and economic aspects of development (White et al., 2004). Therefore, to fully understand the concept, farmers' reactions to these challenges are based on their understanding and comprehension. They need to understand in which way the farmers' strategies/activities impact on the environment and to what extent the envisaged impact will infringe on the profitability of their operations. The economies of scale and physical size of their fish farms have no bearing on the compliance of farmers to reducing waste output (Gumbo 2011). Traditionally aquaculture was a component of a mixed farming system in association with other land-based animals such as cattle and ducks. These systems were operated extensively or semi-intensively and were geared to meet subsistence and local market needs (Beveridge & Little, 2002). In this type of farming, generally pond based, the fish were fed on products of the natural food web as well as by-products from agriculture (Azim & Little, 2006). Farmers did not need to rely on aquafeed to feed the fish, making traditional aquaculture more sustainable. However, today there is an international market for aquaculture products making extensive farming practices an impracticable and unprofitable means of farming to meet market demands (Lansdell, 2010). Intensive fish farms rely on aquafeed as their primary source of fish nutrition. In intensive aquaculture commercial feeds can contribute 30-60% to operational costs (Sugiura et al., 2005; Gurung et al., 2006). Waste from fish farms collects on the bottom of the dam. Containment and collection of wastes, both solid and dissolved, is very difficult and costly (Cho & Bureau, 2002). Therefore, it is imperative that sufficient attention should be paid to reducing waste output to the environmental (Cho & Bureau, 2002; Boyd et al., 2005; Webb, 2012; FTAD, [s.a]; SASSI, [s.a.]).

According to the National Water Resource Strategy (DWAF, 2004), South Africa depends mainly on surface water resources for most of its urban, industrial and irrigation requirements. Modern agricultural practices have a significantly effect on South Africa's water resources and the distribution of natural vegetation (Moran & Hoffman, 2012; Struyf et al., 2012). With the wide spread use of pesticides and fertilizers there is an increase in the amount that washes and leaches into the groundwater. Freshwater pollution, in the form of chemical oxygen demand, is estimated to be 4.74 tons/km^{-3} while the average phosphorous concentration in the natural water resources of South Africa (as orthophosphate) has been estimated at 0.73 mg/L. These values are indicative of moderate to highly eutrophic conditions in South Africa's freshwater resources (Oberholster & Ashton, 2008). While water enrichment in pond aquaculture systems can be partially attributed to agricultural runoff and the decomposition of organic materials in the pond and surrounding catchment, the main source of nutrient enrichment is often via unutilised feed and fish excrement. Aquaculture effluent contains significant amounts of dissolved organic matter and nutrients that could contribute to eutrophication (Axler et al., 1997;

Deksissa et al., 2003; Snow & Ghaly, 2008). The largest components of these wastes are phosphorus- and nitrogen-based metabolites that are not effectively used by the fish. Milne (2012) found in a sensitivity analysis of a lake with trout cage culture that non-point sources are the most significant parameter for total phosphorous loading, followed by the lake sedimentation, then the contribution by aquaculture. Phosphorus is the limiting nutrient in freshwater primary production, and excessive levels can cause premature eutrophication and the deterioration of water quality (Coloso et al., 2003; Schultz et al., 2003; McDaniel et al., 2005). Thus, it is important to treat the water before it is released back into the environment as it can have a detrimental effect on the ecology of the water body.

The introduction of plant-based filtration systems is a simple solution to reduce nutrient build-up and eutrophication (Shutes, 2001; De Stefani et al., 2011). The integrated aquaculture-plant systems are also referred to as floating gardens or aquaponics (Blidariu & Grozea, 2011). Fish manure is similar in its chemical composition to other livestock manures, and should be suitable for use as a plant crop fertilizer (Naylor et al., 1999). By using the plant’s ability to transform dissolved nutrients into growth an easy filtration system can be constructed that has the ability to produce a useful product. It has been reported by Li & Li (2009) that planting aquatic vegetables on a one-sixth covered area of the fishponds could efficiently remove nutrients and improve water quality. Thus, the floating garden concept in conjunction with fish farming cages, entails growing plants where the roots are suspended in enriched water (Fedunak & Tyson, 1997; Sikawa & Yakupitiyage, 2010). In this type of system the dam water is slow moving and almost stationary and no aeration takes place (Kratky et al., 2008). Slow moving waters provide excellent retention periods for nutrient extraction by aquatic plants. However farmers should be mindful of potential blockages in the recirculation systems caused by accumulation of suspended material in the water.

Water stability of feed is of paramount importance in the manufacture of aquaculture diets (Paolucci et al., 2012; Sørensen, 2012). Water stability is greatly influenced by the properties of binders in diets, and the ingredients themselves have a direct influence on the characteristics of the binders (Dominy & Lim, 1991). Therefore, feed and faecal integrity have a significant influence on water stability and hence capacity to withstand the leaching of polluting nutrients into effluent water (FAO, 2012). Any means of improving feed and faecal integrity will improve effective sedimentation or screening in through-flow and recirculation aquaculture systems, and hence on the water quality management in such systems. The results of recent research on the use of non-starch polysaccharides (NSPs) such as guar gum in aquafeeds to enhance the stability of rainbow trout faeces, showed improved removal efficiencies of suspended solids and total phosphorous of about 40%, and of total organic nitrogen,18% (Brinker, 2008). The ability of omnivorous fish such as tilapia to digest NSPs may however limit its value as dietary faecal binding additive and needs to be evaluated.

The strategy followed to deliver feed to fish can have a significant effect on the efficiency of feed utilisation by fish and the amount of feed wastage. Therefore feeding strategies are highly relevant to the control of pollution levels in the water (Midlen & Redding, 1998). The nature of the feeding regime can be regarded as a critical control point for adverse effects on water quality in aquaculture systems. Small-scale trout farmers in the WCP use a combination of *“ad libitum”* and feeding programmes as primary feeding methods. This entails the administration of pre-determined quantities of artificial diets by hand to their fish stocks at regular intervals (mostly two to three times a day). Although it remains a less expensive option than technologically advanced automated feeders, the method has several disadvantages with regard to feed management and, consequently, the influence that aquaculture feeds have on water quality. Some small-scale farmers do not interpret the feeding behaviour of the fish correctly. They are inclined to feed fish too much in order to attain market size earlier in the season. The benefits of this approach, however, are less important than the adverse effects, namely the impact that the greater amount of wasted aqua feed has on the water quality in the pond. Also, the fish feeding routines of the small-scale farmers are often dictated by the availability of transport and the routines of their primary obligations and duties on the commercial crop farms. Disparities therefore exist between the fish's optimal physiological readiness for accepting feed and the actual availability of feed. As a result, fish are often fed under biologically sub-optimal conditions. The ideal feeding method may therefore be a demand feeding system (self-feeders), which allows the fish to control feed supply (Yue et al., 2008). Self-feeders rely on fish to activate a trigger that results in a release of food from a dispenser (Anders 1992; Alanärä, 1992; Alanärä et al., 2001). Such feeders will reduce the amount of feed wasted and in return will have less of an adverse effect on water quality. During this study four mitigation measures were investigated, *inter alia*, improved feed management, improved feed ingredients, demand feeders and floating gardens. When applied correctly, each of these measures has the potential to reduce organic pollution.

3.2 Materials and methods

3.2.1 Feed management

Where possible the FCR data were collected from the farms and evaluated for accuracy. The minimum, maximum and mean FCRs were calculated. These were compared with the general FCR for small-scale trout farming systems with a carrying capacity of approximately six tons of final harvested weight. Finally it was calculated what the saving on feed cost would be with every kg of feed saved, and what the associated reduction on environmental impact would be. The results were presented to the farmer as a simple visual indicator which can be applied to calculate operational cost savings and provide an incentive to labourers and management to explore as motivation.

3.2.2 Feed ingredients

Mozambique tilapia (*Oreochromis mossambicus)* has been identified as a warm water candidate species for net cage culture in irrigation dams. The researchers evaluated the effect of increasing levels of a guar gum based pellet binder on the feed and faeces of tilapia. Treatment consisted of a control diet with increasing levels (0, 9, 17.5, 35.0 and 70.5 g kg^{-1}) of a commercial animal feed binder Duracube® (Bitek, Midrand) containing 170 g kg^{-1} guar gum. Binders were added to the diet ingredients in their powdery form and mixed and then hot water was poured onto the mixture. The mixture was then stirred thoroughly to obtain dough (Orire et al., 2010). All treatment was cold-extruded and dried at 60°C for 12 hours to decrease the moisture content and then stored (Ruscoe et al., 2005). Each tank containing a different level of binder was replicated four times and each treatment was evaluated for water stability as well as for effect on faecal stability. The amount of reduced leaching was calculated where faecal matter and uneaten feeds remained intact. The reduced impact on the environment where minimum wastage occurred was evaluated (Brinker & Friedrich, 2012). Data were analysed using one-way ANOVA and Turkey's multiple comparison test with the level of statistical significance taken as $p<0.05$ (SPSS v. 17 SPSS Inc, Chicago, IL, USA). The results for tilapia were also compared with those for trout as discussed by Brinker (2007).

Feed water stability: The test was done in a system consisting of 100 stainless-steel test-containers with wire mesh tops and bottoms placed on an elevated chamber-grid (96cm circumference) in twenty 25 litre chambers (5 test-containers per chamber) with a central airlift pipe which encourages turbulent water flow over the containers (see Figure 3.6). The chamber-grid was positioned to sustain the test-containers in top-water to ensure good water flow over feed samples. Feed samples were placed and weighed in the test-containers (approximately 20 gram feed sample per container). Following the water stability test, dietary treatments were dried at 60ºC for 16 hours in the test-containers after which final weight was recorded (Crous et al., 2010).

Faecal quality: Twenty-four metabolic chambers were stocked with three fish weighing approximately 40 g each. Each chamber was fitted with a faecal collecting canister at its bottom. A 14-day digestibility trial was performed during which faecal quality was scored for visual appearance in terms of colour and length, as well as for its ability to limit leaching of nitrogen and phosphorous – as quantified by the water quality parameters of dissolved nitrogen and phosphorous. In order to limit mixing of feed and faecal matter, faecal matter was collected before feeding, with un-consumed feed collected directly afterwards (Crous et al., 2010).

3.2.3 Mechanical feeders

The results of the mechanical feeding method (demand feeders) were compared with the results of hand-feeding according to a feeding programme and also feeding fish *ad libitum* on demand (Hinshaw, 1999; Attia et al., 2012). The amount of feed saved through minimum wastage and the consequent influence on the FCR and SGR was evaluated. A pendulum-operated demand feeder was built according to available literature and following the construction of unused commercial units.

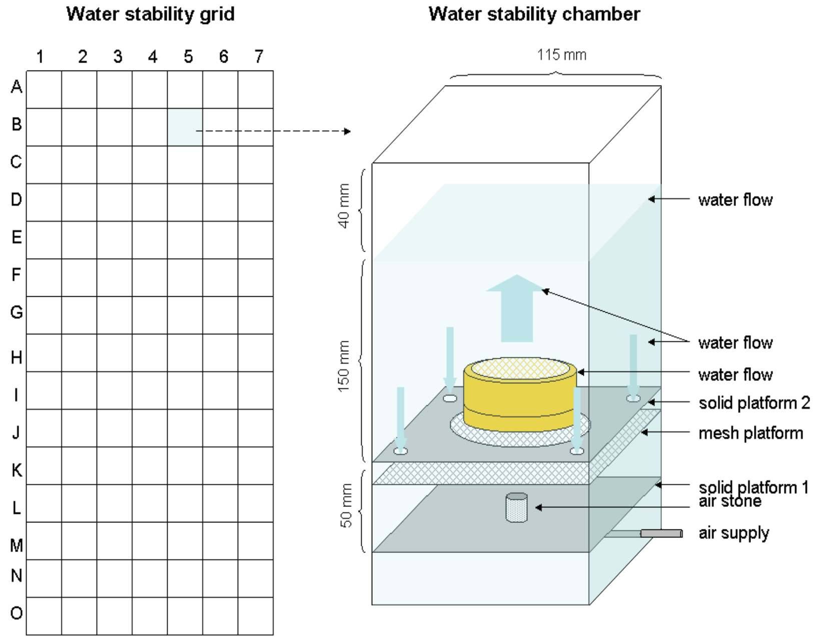

Figure 3.1. Water stability test chamber (Courtesy of Feedtech Group, Stellenbosch University, 2011).

The goal was to build a pendulum-operated demand feeder that was easy to construct, inexpensive, required no power or batteries and could withstand the elements associated with net floating cage system. Two pendulum demand feeders were implemented on opposite sides of a floating net cage system at a commercial trout farm. The feeders were monitored for two months. Unfortunately the farmer did not allow fish to be fed only by the demand feeder for fear of affecting the FCR. Therefore fish were fed using a combination of providing feed with a demand feeder and feeding by hand *ad libitum*. The practical implementation, performance and management of the device were evaluated on the fish farm through daily reports from the farm manager. Findings were compared with those found in the literature.

3.2.4 Floating gardens

Floating gardens were incorporated in floating net cages without fish. Figure 3.2 and Figure 3.3 provide illustrations of ancient floating gardens as incorporated by the Aztec civilisation (The Aztec floating garden, [s.a.]). Polystyrene flotation was used and holes were drilled to accommodate pots holding selected crops including a variety of lettuces, rocket and basil plants (Building a floating garden, [s.a]). Leafy plants were used of which the edible parts did not generally include the roots. Felizeter et al., (2012) explains that when plants are exposed to contaminated nutrient solutions that might enter water bodies via industrial and household wastes, the roots are likely to contain higher concentrations hazardous to humans, i.e. perfluorinated alkyl acids as the roots are suspended in the water. The floating gardens were monitored for nine weeks. Site visits were conducted weekly during which the performance of the system under prevailing climatic conditions was evaluated. During each visit, the plants were weighed and notes were taken on the general appearance and condition of plants, presence of pests and root formation. The extraction rate of parameters such as N and P were calculated. The samples were taken before the plants showed any signs of going into the seeding phase. The whole plant, including roots, stems and leaves was collected to determine the chemical composition of the plant according to the standards of Ako & Baker (2009). Water samples were taken every four weeks during the trial period to determine if there was any change in the concentrations. BEMLAB conducted the analyses.

Figure 3.2. Illustration of a floating garden in a fish pond.

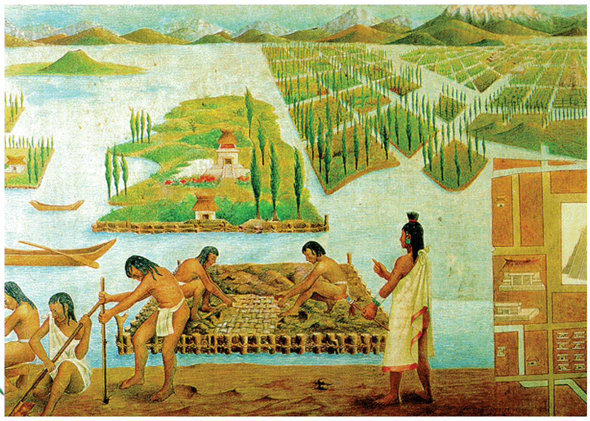

Figure 3.3. Illustration of earlier Aztec floating gardens. (Pictures from www.pondplantgirl.com).

3.3 Results and discussion

3.3.1 Feed management

The FCRs and SGRs of the 14 production sites for 2009 are presented in Figure 3.4. The mean FCR is 1.96 ± 1.15 and the mean SGR is 1.00 ± 0.37. The lowest FCR recorded was 1.17 and the highest 4.81. Pradhan et al. (2012) describe FCRs of 1.66-2.63 for trout farms in Nepal, while Danish farms have to follow regulations where they are encouraged not to exceed FCRs of 1. Theoretically FCRs of 0.8-1.0 are possible with high oil diets (Jokumsen & Svendsen, 2010). The trout farms in Denmark are also regulated with maximum allowable annual feed quotas, thus encouraging farmers to achieve optimal feed utilisation. Lansdell (2010) has written feed management procedures and guidelines, proposing a management system for responsible aquaculture. Both documents are presented in Appendices 4 and 5.

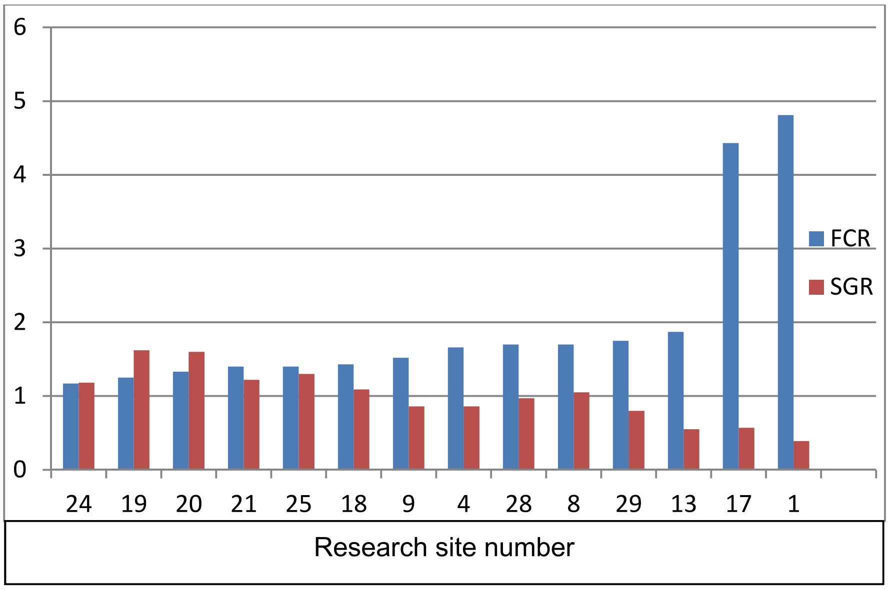

Figure 3.4. The average FCR and SGR of the 14 fish farmed sites as used in Chapter 2.

3.3.2 Feed ingredients

Feed water stability: There were no significant changes in the feed water stability with an increasing level of binder (p>0.05). This could possibly be explained by the binder's effect on extrusion dynamics. During manufacturing of the test diets it was observed that high levels of binder addition increased extrusion temperature, probably due to the high-hydration character of guar gum – thereby retaining water from the gelatinisation process as water addition was kept constant over all treatments. Visual assessment of faecal length showed no significant differences (p>0.05) in either length or colour. However faecal matter tended to become lighter at high levels of binder inclusion, which can possibly be explained by increasing digesta viscosity (Amirlolaie et al., 2005; Crous et al., 2010).

Faecal quality: Water analysis and visual assessment of faecal length and colour showed no significant difference (p>0.05) between treatments. The tendency of faecal matter to become lighter (see Figure 3.6) with increasing levels of binder inclusion may possibly be explained by an increased gut emptying rate due to the viscous nature of the soluble fibre component of the binder. In addition the level of binder did not influence the digestibility of the experimental diets. Unlike carnivorous fish such as rainbow trout, tilapias have a better ability to digest NSPs. Therefore, inert faecal binding solutions should be investigated for use in tilapia feeds (Crous et al., 2010).

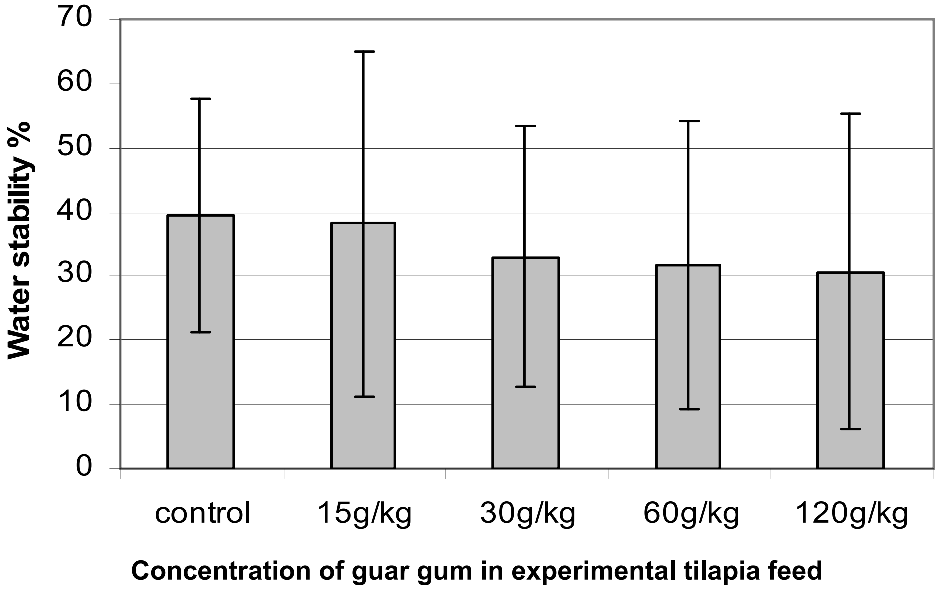

Figure 3.5. The 16-hour water stability treatments

Figure 3.6. Influence of guar gum concentration on length and colour scoring of faecal matter (Courtesy of Feedtech Group, Stellenbosch University, 2011).

3.3.3 Mechanical feeders

The pendulum-operated demand feeder constructed by the research team is shown in Figure 3.7. Initial results indicated that fish responded to the self-feeder within three days after installation. However, it was also observed that the feeder was activated unnecessarily through wind and wave action. This resulted in overfeeding and feed wastage for fish accustomed to be fed only when hungry. Wurtsbaugh & Davis (1977) described when unlimited feed was released, the bite frequency reached a level at which the trout were unable to eat all the released pellets. Also, innate behavioral responses triggered by, for example, the presence of feed or other fish feeding, rather than by actual hunger, could be the reason for some feeding activity in fish with access to unrestricted demand feeders. This can lead to feed being released unnecessarily, resulting in feed waste and poor FCR. (Alanärä, 1992)

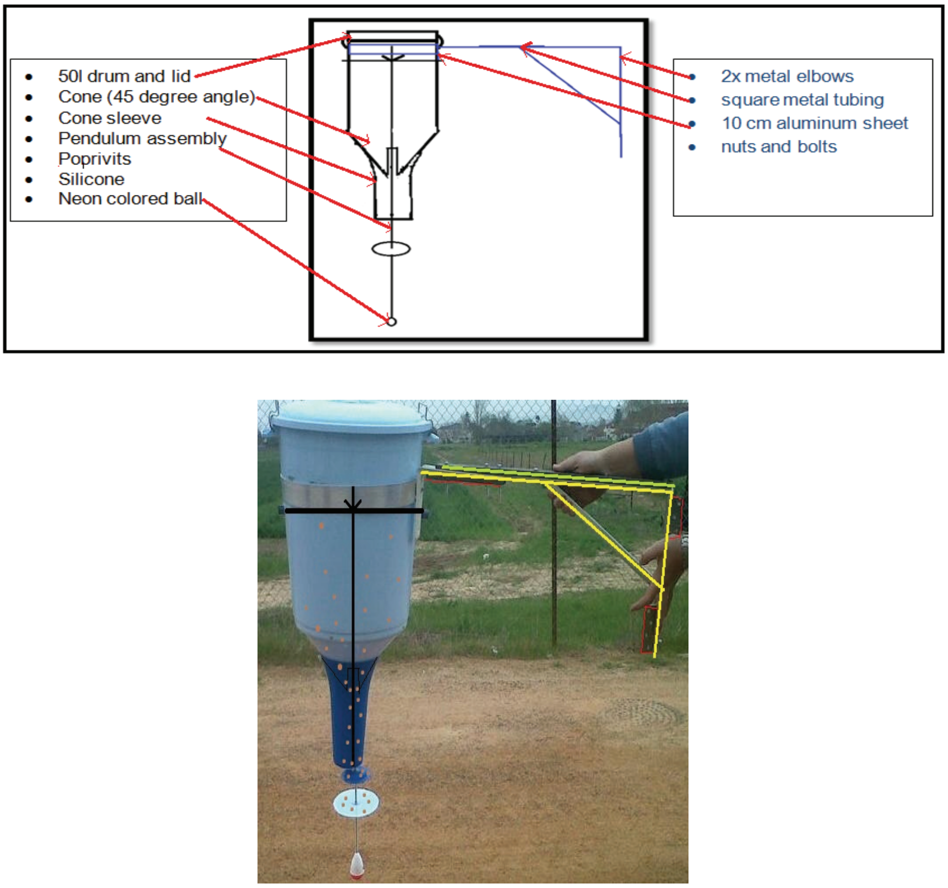

Figure 3.7. Illustration and picture of the demand feeder built by the research team.

Mohapatra et al., (2009) stated that Indian major carp, *Labeo rohita*, reared in outdoor culture systems where the pendulum demand feeder was not affected by wind and wave action, had growth rates 12.61% higher when fed with demand feeding systems compared to fish fed by hand. Furthermore, the efficiency of demand feeding with regard to the FCR was found to be better for rainbow trout than when feeding by hand (Alanärä, 1992). Table 3.1 indicates the SGR and FCR for different methods of feeding. The FCR of 1.08 for the restricted demand feeder was the best.

Table 3.1. SGR of rainbow trout (weighing 1.0-1.2 kg) expressed as % per day, and FCR within feeding regimes (modified from Alanärä, 1992).

Feeding regime	**SGR**	**FCR**
Timer-restricted	0.72	1.36
Demand feeding – restricted	0.87	1.08
Demand feeding – unrestricted	0.93	1.49

3.3.4 Floating gardens

The polystyrene-based floating garden provided a stable platform for the pots housing the plants. Of all the plants used the lettuces performed the best. Plant mortalities were minimal. Plants died when they were dislodged by the force of the wave action beneath the rafts pushing the plants upwards through the holes. Plants that were replanted did not recover completely and their growth was stunted. The plants that survived grew well and there was significant growth in leaf number and size. Most of the growth was observed in the root section of the plants (see Figure 3.8).

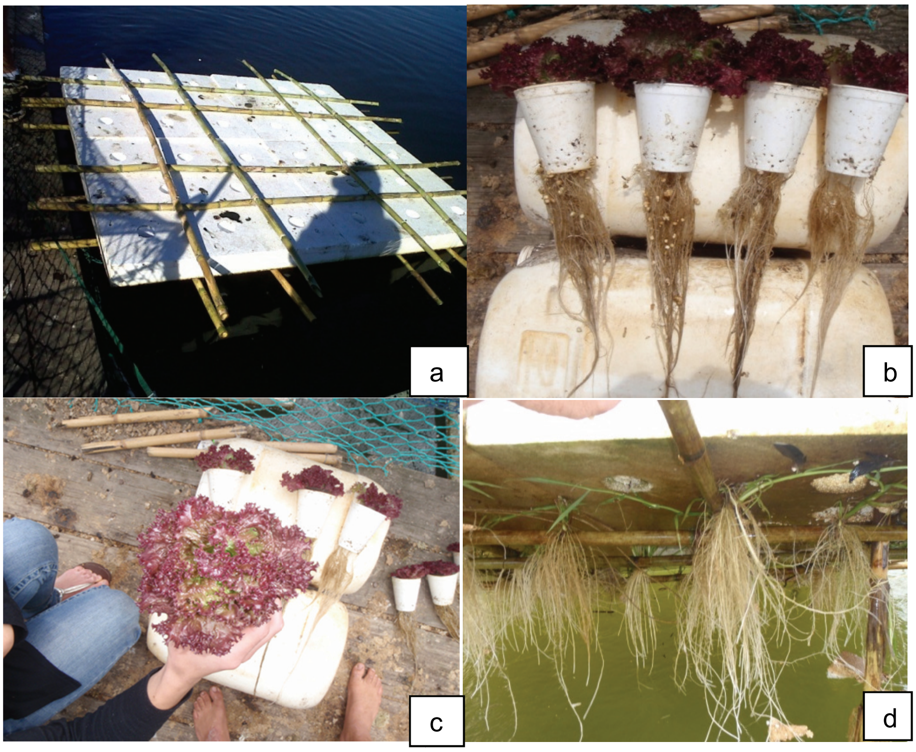

Figure 3.8. Polystyrene raft (a), root formation in lettuce (b), leaf foliage of the lettuce (c) and roots on bamboo shoots (d).

In Table 3.2 it is shown that the plants grew well. The mean weight increase is 95.10 g ± 43.50. In Table 3.3 the chemical analysis of the plants is shown. It indicates that there was an uptake in the primary macronutrients (N, P, K) and secondary macronutrients (Ca, and Mg). Other micronutrients such as B, Cu, Fe, Mn and Zn were present. Dediu et al., (2012) found that lettuce registered a greater amount of both biomass and yield in low flow treatments. They found the average weight gain to be 75.49 g. However, this was recorded over a three-week period. TAN removal rate should be in the range of 0.24 to 0.64 $g/m^2/d$ (Eding et al., 2006; Lyssenko & Wheaton, 2006). The removal rate of TAN for lettuce was 0.27 $g/m^2/d$. For the production of 3.5 kg/m^2 lettuce, a ratio of 1.09 plants/fish (1.84 g feed/day/plant) is required to limit the accumulation of residual nutrients in a fish farming system (Dediu et al., 2012). The P concentration decreased from 0.157 mg/L to 0.071 mg/L over a nine week period, which amounts to 0.001 mg/L/day. In their study Trang and Brix (2012) reported values of 0.002 g/day by lettuces. The available nutrients as recorded concentrations of the water quality parameters during the study are indicated in Table 3.7. For the plants to survive on the raft it is crucial that the nutrients in the water must be in the correct molecular form and concentration. Through the action of bacteria around the roots of the plants these nutrients can be transformed into usable molecules. All the parameters, except pH and TAN showed a decline in concentration as indicated in Table 3.4. However, due to the scale of the trial, it was difficult to qualify the decline due to the presence of the floating garden. Furthermore, nitrification and oxidation of ammonia to nitrite and then to nitrate is essential for the development of plant biomass (Cockx & Simonne, 2003).

Table 3.2. Weight of the individual plants at planting and at harvesting. The initial weight is measured with seeding soil and the initial clean weight after the soil has been washed off. Harvested weight includes the weight of all the plant parts.

Sample no	Initial weight (g)	Initial clean weight (g)	Harvested weight (g)	Weight increase (g)
1	12.00	3.00	90.00	87.00
2	14.50	5.50	149.00	143.50
3	14.00	5.00	136.00	131.00
4	10.00	1.00	36.00	35.00
5	10.00	1.00	80.00	79.00

Table 3.3. Chemical analysis of harvested plants.

Sample no	N%	P%	K%	Ca%	Mg%	Na (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
1	1.70	0.14	2.17	0.97	0.39	3774.00	978.00	6782.00	24.00	42.00	24.00
2	1.94	0.24	2.60	1.01	0.41	2726.00	779.00	10268.00	54.00	57.00	25.00
3	2.01	0.14	2.11	0.96	0.36	2915.00	785.00	8863.00	60.00	47.00	23.00
4	1.82	0.12	1.98	1.18	0.45	2463.00	927.00	11074.00	39.00	51.00	25.00
5	1.62	0.12	1.63	1.30	0.52	2202.00	561.00	9256.00	36.00	40.00	19.00

Table 3.4. Water quality results for the physico-chemical parameters of the dam.

Parameter	Sample 1	Sample 2
pH	7.9	8.3
EC mS/m	52.1	50.5
Na mg/L	68.6	67.1
K mg/L	8.05	6.53
Ca mg/L	25.99	19.19
Mg mg/L	15	12

Parameter	Sample 1	Sample 2
Fe mg/L	0.56	0.69
Cl mg/L	123	96.2
CO_3 mg/L	12.1	18.1
HCO_3 mg/L	79.62	73.43
SO_4 mg/L	24.28	19.41
B mg/L	0	0.02
Mn mg/L	0.221	0.018
Cu mg/L	0	0
Zn mg/L	0.1	0.01
P mg/L	0.157	0.071
PO_4 mg/L	0.48	0.22
TAN mg/L	0.42	0.54
NH_3-N mg/L	0.008	0.001
NO_3-N mg/L	0.29	0.25
NO_2-N mg/L	0.019	0.01

3.4 Conclusion

Aquaculture can have a negative effect on the environment and can influence freshwater ecosystem functioning. However, if optimal volume and flow rates in production systems are maintained the impact can be drastically reduced (Soofiani et al., 2012). Fish farming of rainbow trout has the advantage that the production season coincides with the winter rainfall when dams are filled to capacity. In addition, farm management has to take responsibility to plan and implement mitigation measures to reduce organic pollution and achieve sustainable aquaculture practices. Employing appropriate mitigation has reduced aquaculture's impact on the ecosystem (O'Beirn & O'Brien, 2011). The rationale is that any cost-effective measure that reduces pollution improves the overall ecologic status of the water body.

In order to facilitate sustainable aquaculture practices for small-scale community-based fish farming, procedures have been written to guide farmers (Landsdell, 2010). The challenge is to make these accessible and comprehendible at farming level. Bhujel (2012) argues that education and training systems are important to ensure success in aquaculture livelihood enterprises and therefore proposes that aquaculture curricula should be incorporated at secondary and tertiary learning institutions. As feed is responsible for most of the environmental impacts, a sensitivity analysis was done and it was confirmed that FCR improvement had a positive impact on all the environmental indicators (d'Orbcastel et al., 2009). The mean FCR for fish farmers was 1.96 ± 1.15. Farmers were using juvenile trout of about 0.2 kg, and sold fish to the market at approximately 1. 2 kg. Thus the weight gain was 1 kg. Farmer were stocking 6000 fish and using on average 11760 kg of feed for the production season (Salie et al., 2008; Stander at al., 2011). If farmers could reduce/improve their FCR by 0.1 (i.e. from 1.96:1 to 1.86:1) it would translate into a saving of 600 kg of feed (5%) or 100 kg per ton of fish produced. The estimated waste output from rainbow trout cage farms per ton of fish produced as given as total solids of faecal and feed origin (236.0 kg), solid nitrogen (12.8 kg), solid phosphorous (5.3 kg), dissolved nitrogen (41.3 kg) and dissolved phosphorous (3.4 kg) respectively (Azevedo et al., 2011). Thus a 0.1 decrease in the FCR would result in 5% reduction in nutrient loading. The management system for responsible aquaculture nutrition is indicated in Appendix 3. Good management practices for sustainable aquaculture were also supported by the Freshwater Trout Aquaculture Dialogue initiative (FTAD, [s.a.]).

The guar-gum based binders did not make a significant improvement in the water stability of the feed and the faecal quality for tilapia. The reason could be that tilapia has the capacity to digest non-starch polysaccharides, and therefore guar-gum based binders did not present a good solution for stabilising faecal matter. However, the guar-gum binders did improve the water stability and faecal quality of rainbow trout diets. Improved feed quality can reduce nutrient leaching in the water and allow the removal of it via mechanical methods such as waste suction and hydroclonic filtering systems.

Demand feeders were used to give fish access to feed when triggered on demand. This ensures that fish will feed according to appetite and that minimum quantities will go to waste. The construction of a pendulum-based demand feeder indicated a feasible option in terms of cost and level of ease of building. However, usage on cages in open water systems was not practical because external factors, such as wind and wave actions, triggered the feeder unnecessarily and released feed not utilised by fish. Farmers did not benefit from such mechanical feeders. To best evaluate alternative mechanical feeding, devices need to be investigated that are not influenced by external factors, but are only triggered by fish. The pendulum demand would work well in enclosed aquaculture systems.

Heavy wind storms and wave actions made it difficult to implement and monitor the floating garden system. For the lettuce to survive in water-based agriculture, the dam has to provide growth conditions and nutrient quality similar to that found in land-based agriculture and hydroponics. The first goal was achieved in that a practical and economical floating garden was constructed. The second goal namely to determine whether or not plants could survive and grow was also achieved, but due to the nature of the project not enough data on plant growth were collected. However it was possible to collect data and practical knowledge on the design and construction of viable floating rafts.

The growth of lettuce was slow due to harsh weather conditions. During the study period growth was achieved in nine weeks, very similar to what Dediu et al. (2012) achieved in three weeks. However, the floating garden presented good plant biomass for a system in an irrigation dam. Dediu et al., (2012) found that lettuce can achieve higher biomass and yield in low water velocity production systems. TAN removal rate should be in the range of 0.24 to 0.64 g/m^2/d (Eding et al., 2006; Lyssenko & Wheaton, 2006). The removal rate of TAN for lettuce is usually 0.27 g/m^2/d. For the production of 3.5 kg/m^2 lettuce, a ratio of 1.09 plants/fish (1.84 g feed/day/plant) is required to limit the accumulation of residual nutrients in a fish farming system (Dediu et al., 2012). Thus for typical small-scale trout producing system housing 6000 fish, 6540 lettuces would be required. This explains why there was not any decline in the concentration of TAN at the stocking rate of plants. The scale of the trial did not allow sufficient analysis to be done to ascribe decreases in concentration of parameters to the presence of the floating garden. Furthermore, the role of oxidative biological processes also needs to considered for the nitrification and oxidation of ammonia to nitrite and then to nitrate, which is essential for the development of plant biomass (Cockx & Simonne, 2003).

There is a good case to further investigate the potential of herbs (parsley, basil, celery, coriander) and cut flowers as floating garden crops. An increase in the size and stability of the floating garden would also make higher stocking densities possible (32 plants per m^2 were used). Due to the improvements made to the rafts during the study, there was an unexpected result. River reeds (*Phragmites* sp) were used to improve raft stability. Root growth was observed from the nodes. Roots tripled in biomass within three weeks. Stem and leaf growth was minimal but after three weeks stems of up to 30cm were observed. The fact that the reeds indicated growth might have had a negative effect on the growth of the lettuce due to competition for nutrients. The growth of both lettuces and reeds confirmed that plant growth can be sustained on floating platforms. The preliminary findings remain that when floating gardens are implemented it can reduce evaporation and nutrient concentration and simultaneously produce viable crops as a byproduct.

It was shown in the study that mitigation measures can be incorporated to reduce organic pollution and improve water quality. However, this was an investigative research project and only provided the basis for further investigation. Therefore, an investigation of the extent to which water purification takes place through different mitigation measures should be considered for future research.

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CHAPTER 4 Summary, conclusions

4.1. Background

Water resources are a precondition for the existence of human populations, and one of the most important raw materials for our economic activity and welfare. Water is increasingly being seen as a limited resource and greater attention is being focused on priorities with regard to its allocation and management. Increasing drought affecting Africa, the problems of flood control and water quality in south-east Asia, and the impacts of development on coastal and inland waters in Latin America, all point to the particular and vital importance of water resource management in developing countries. The growth of the South African population and the pressing demand from a myriad of users intensify the challenge associated with providing sufficient water for rural-, urban- and industrial-, as well as agricultural needs and to meet future food production requirements. However available water resources are increasingly being threatened by pollution from point and non-point sources which could reduce the quality and threaten the overall efficient usage. Due to the increasing demands made on existing water resources, productivity needs to be optimized by means of controlled and limited eutrophication. Integrating aquaculture into irrigation dams is promoted as a non-irrigation benefit. Farming systems have been successful in incorporating multiple water use for irrigation and aquaculture into the wider context of planning, development and management of water bodies. Particular attention has been focused on integrating fish production in engineered water systems designed for water storage. Opportunities to extend the potential for these forms of integration have been explored. In order to consider the derived benefits from South Africa's existing water resources, it is important that the relevant ecosystems be thoroughly investigated and consulted in order to present an environmentally sustainable, socially acceptable and commercially viable partnership. Not only will this prevent conflict between potential water users, but it will also allow insight into where and in which manner diversified farming options can be expanded in the future. Aquaculture is a user and not a consumer of water and should not infringe on water quantity requirements for agriculture and other anthropogenic users. However, there might be potential conflict in the demand for water space in a catchment. The overarching benefit of aquaculture to rural and peri-urban livelihoods accentuates the motivation to exploit aquaculture in the water storage networks of South Africa.

Aquaculture can improve the efficiency of water use within the farm and even improve its economic value for integrated land- and water-based crop production. Most forms of waste are regarded as a resource out of place. This can have deteriorating effects on the water ecology when mismanaged. However, wastes from fish culture, especially the nutrient rich water and sediments, can also be conveniently used for the irrigation of land-based crop production and in aquaponic systems. They can further enhance wetland- and riparian regeneration and ecological functioning, thus providing a habitat for plant- and animal recruitment. The research project is a continuation of other research that monitored and evaluated the impact of aquaculture on the water quality of irrigation dams.

4.2. Description and analysis of water quality and production parameters

The focus of the study was on evaluating the impact of rainbow trout (*Oncorhynchus mykiss*) aquaculture on the water quality of irrigation dams. It had been determined that these dams were fit for farming high value trout destined for the higher income retail market. In order to provide sustainability to the aquaculture-agriculture integrated farming system, it was important to explore the dynamics of such a system. Whilst fish farming is dependent on the water quality, the commercial land-based crop farmer has to recognize the value aquaculture adds to the productivity of the water resource. The number of irrigation dams has increased significantly over the last couple of decades, but aquaculture in these systems has not achieved parallel growth. Thus, this situation, together with the moderate agro-climatic conditions of the WCP, necessitates the investigation of the opportunity.

The rationale is that any form of intensive agriculture, including aquaculture, will have some level of environmental impact. In aquaculture, animals are farmed under high stocking densities and fed high volumes of artificial rations. Waste production is a byproduct of fish farming. It cannot be totally eliminated because fish cannot assimilate all the feed they consume, and part of the feed will remain uneaten. The wasted part can be as high as one-third of the feed input. This is the nature of most aquaculture enterprises which are driven to maximize profits and optimize feasibility. However, the future success of the operation is threatened if farmers cannot foresee long term environmental sustainability and neglect managing water ecology within target water quality parameters.

The results of research indicated that DO, TAN and Nitrate-Nitrogen did not differ significantly between fish farmed and non-fish farmed sites. It further indicated that total suspended solids, Secchi disk reading, Nitrite-Nitrogen and phosphorus associated with fish farming, have been impacted through an increase in concentrations. The estimation of waste output based on fish feed for rainbow trout suggested that concentrations of ammonia and of dissolved and particulate phosphorus were not completely reflective of waste loading from cage culture. The most important non-point sources of nutrient export to receiving waters were agricultural activities. The role and function of aquaculture in the nutrient budget of farm dams were emphasized. Enrichment via the application of fertilizers and pesticides to the crops and soils could lead to eutrophication of dams, irrespective of whether aquaculture was present or not.

The analysis of variance among the group of water quality parameters indicated that differences in bottom and surface samples and between site locations is more important than whether there was fish farmed or not. The difference in bottom and surface samples is directly linked to the ecological status of the sediment, which serves as a nutrient sink. In monomictic dams in Mediterranean areas, mixing occurs during the winter turnover phase. Nutrients are released due to surface and bottom water mixing brought about by torrential rains and wind turbulence. Thus, the organic state of the sediment and bottom waters is a function of the nutrient loading over time, irrespective of whether the point source was fish farming or past agricultural activity. Therefore, it can be postulated that the initial selection of site is very important in order to sustain trout farming.

Phytoplankton abundance was directly associated to the availability of nutrients, specifically phosphorous and nitrogen. The occurrence and biomass distribution fluctuated with dam water levels and nutrient concentrations. The dynamics of prevailing phytoplankton communities are important to fish farmers for two reasons, firstly it can cause fluctuation in the dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis) and secondly, it can cause algal taint of trout flesh due to geosmin producing species. Fluctuating oxygen levels as well as tainted flesh are detrimental to successful trout farming. It is crucial for farmers to be able to anticipate when algal blooms are likely to occur in order to implement measures to avoid crisis management. One way of achieving this is to monitor the nutrient levels regularly.

The analysis of the production data indicated that there was not a direct link between water quality and yield. The fish yields of farms were associated with the quality of juveniles stocked in the net cages and the FCR obtained. Through this analysis the importance of management to secure sustainable production was accentuated. Irrigation dams can play a role in providing water bodies for floating net cage farming systems. There is a case to promote integrated aquaculture-agriculture farming through robust site selection, supported by hands-on farm management. This approach will ensure that commercial plant crop farmers' irrigation regime and yield quality will not be negatively affected.

4.3. Mitigation measures to reduce organic pollution

Aquaculture can have a negative effect on the environment and can influence the functioning of freshwater ecosystems. In addition, farm management has to take responsibility for the planning and implementing of mitigation measures to reduce organic pollution and achieve sustainable aquaculture practices. Employing appropriate mitigation can reduce aquaculture's impact on the ecosystem and therefore the rationale is that any measure that reduces pollution improves the overall ecologic status of the water body.

In order to facilitate sustainable aquaculture practices for small-scale community-based fish farming, procedures have been written to guide farmers. The challenge is to make these accessible and comprehendible at farming level. Education and training systems are important to ensure success in aquaculture livelihood enterprises and it is therefore proposed that aquaculture curricula should be incorporated at secondary and tertiary learning institutions. As feed is responsible for most of the environmental impacts, it was confirmed that FCR improvement had a positive impact on all the environmental indicators. The mean FCR for fish farmers was 1.96 ± 1.15. Farmers were using juvenile trout of approximately 0.2 kg and sold fish to the market at around 1. 2 kg. Thus the weight gain was 1 kg. Farmers were stocking 6000 fish and using on average 11760 kg of feed for the production season. If farmers could reduce/improve their FCR by 0.1 (i.e. from 1.96:1 to 1.86:1) this would translate into a saving of 600 kg of feed (5%) or 100 kg per ton of fish produced. The estimated waste output from rainbow trout cage farms per ton of fish produced was given as total solids of faecal and feed origin (236.0 kg), solid nitrogen (12.8 kg), solid phosphorous (5.3 kg), dissolved nitrogen (41.3 kg) and dissolved phosphorous (3.4 kg) respectively. Thus a 0.1 decrease in the FCR will result in 5% reduction in nutrient loading.

The guar-gum based binders did not make a significant improvement in the water stability of the feed and the faecal quality for tilapia (*Oreochromis mossambicus*). The reason could be that tilapia has the capacity to digest non-starch polysaccharides and therefore guar-gum based binders did not present a good solution for stabilizing faecal matter. However the guar-gum binders did improve the water stability and faecal quality in the case of rainbow trout diets. Demand feeders (self-feeders) were used to give fish access to feed when triggered on demand. This ensured that fish ate only when hungry and that minimum quantities were wasted.

Farmers did not benefit from such mechanical feeders as they were activated by wave and wind action to deliver feed at times when fish appetite was low. This resulted in feed waste.

Heavy wind storms and wave actions made it difficult to implement and monitor the floating garden system. For the lettuce to survive in water-based agriculture, the dam had to provide growth conditions and nutrient quality similar to that found in land-based agriculture. The first goal was achieved in that a practical and economical floating garden was constructed. The second goal namely proving whether or not plants could survive and grow was also achieved. The growth for lettuce was slow due to harsh weather conditions. The study achieved growth in nine weeks, very similar to what commercial farmers would achieve in three weeks in conventional hydroponic systems. For a floating garden, in association with small-scale cage culture, to be successful requires 6540 lettuces to 6000 fish to limit the accumulation of residual nutrients in a fish farming system.

4.4. Research questions which were structured around the research, and answers.

a. *What was the longer term (over four years) water quality dynamics of smaller irrigation dams associated with periods of fish farming and non-fish farming?*

Small water bodies are dynamic structures with erratic changes according to seasonal patterns and climatic conditions. Repeated measurements and assessments provided sufficient sample size to explore the dynamics and the fitness-for-use of irrigation water for both fish- and land-based crops.

b. *What was the effect thereof on parameters most likely to be influenced by aquaculture (i.e. dissolved oxygen, total ammonia nitrogen, phosphorous, total suspended solids) and parameters most likely not to be influenced by aquaculture (i.e. temperature, total dissolved solids, alkalinity, hardness)?*

The concentration of the parameters most likely not to be influenced by fish farming (depth, temperature, pH, TDS, Na, K, Ca, Mg, Fe, Cl, CO_3, HCO_3, Mn, B, Cu, Zn, Al, SO_4, alkalinity and hardness) indicated a strong affinity to regional patterns. The process is mainly influenced by geology and the prevailing climate in terms of temperature and rainfall. Soils in the WCP are mainly from weathered Table Mountain Sandstones and shales from the Malmesbury Group. The Mediterranean climate of the WCP provides winter rainfall and subsequently diluted waters, whereas in summer higher temperatures lead to increased evaporation and concentrated waters. Thus, major ions in the water fluctuate according to the changing weather patterns.

The concentrations of the parameters most likely to be influenced by fish farming (Secchi disk, DO, P, TAN, NO_3-N, NO_2-N, and TSS) can be influenced by fish farming activities. There can be a primary influence where organic particles emanating from excess feeds and faeces are suspended in the water column, changing the TSS concentration and consequently the water transparency observed in the Secchi disk reading. Secondarily, nitrogenous compounds are released into the water environment through nitrification by aerobic micro-organisms (*Nitrosomonas* and *Nitrobacter* spp), as well as through denitrification. Dissolved oxygen levels are influenced by the rate of photosynthesis and the decomposition of organic material. Phosphorous is mainly released from the feed. The ratio of fish farming to non-fish farming ranges from 0.8 (TAN) to 2.06 (P). These ratios are relatively low and are indicative of good water resource management by both fish- and crop farmers.

c. *To what extent do surface and bottom water differ?*

Irrigation dams generally indicated no levels of stratification, thus showing adequate mixing of surface and bottom waters. This can be ascribed to relatively shallow dams with an average depth of 7 m. Dams with low Secchi disk readings (transparency) also indicated lower oxygen levels in bottom strata. The following parameters, DO, pH, Fe, P, PO_4, TAN, NO_2, TSS, TDS and alkalinity, indicated statistical significance between surface and bottom. The following parameters Na, K, Ca, Cl, SO_4, B, Mn, Cu, Zn, NO_3, AL and hardness, did not indicate statistical significance between surface and bottom.

d. *What was the occurrence of phytoplankton occurrence and diversity in irrigation dams?*

The occurrence and phytoplankton biomass distribution fluctuated with dam water levels and nutrient concentrations. The prevailing phytoplankton communities are important to fish farmers for two reasons*, inter alia*, namely: 1. They have an influence on dissolved oxygen concentrations via users (respiration and decomposition) and producers (photosynthesis), and 2. There may be an algal taint of trout flesh due to geosmin producing species. The anticipation of the impact of existing phytoplankton on the quality of trout production requires attention. It was evident that phytoplankton biomass and diversity can be controlled by ensuring sub-optimal conditions through reducing nutrient input. The frequency of occurrence indicated that the Group Chlorophyta (including genera, *Chlamydomonas, Closterium, Oocystis, Scenedesmus, Staurastrum, Tetraedron*, etc.) occurred most often (371) with Chrysophyta (including genera, *Dinobryon, Mallomonas, Synura*, etc.) occurring least often (34). The type of genus as well as the prevailing season had a significant influence on the occurrence of phytoplankton ($p<0.05$). However, the geographical location of the research site had no significant influence on the occurrence of phytoplankton ($p>0.05$).

e. *What is the role and function of historical commercial agriculture in farm dam dynamics?*

The general water quality indicated that irrigation dam water quality is relatively well-managed by the commercial crop farmers in the WCP. However, in studies elsewhere in South Africa, e.g. KwaZulu-Natal and Mpumalanga, dams in the area were classified as eutrophic and in certain cases hypertrophic. Thus, the concern remains that our water resources as a whole lack appropriate management and compliance with better management practices. Aquaculture has been proven to provide real benefits to rural and urban communities and co-existence and integrated aquaculture-agriculture will only prosper when both primary and secondary users of irrigation dams apply practices to sustain good water.

f. *Can negative as well as positive impacts be identified?*

It was found that aquaculture in irrigation dams has a negative impact on the water quality due to organic enrichment via excess feeds and faeces. Some farmers also reported clogging of irrigation systems. Positive impacts were identified as an increase in diversity in aquatic plant and animal occurrence. The post-fish farm zone showed the establishment of additional wetland plant species. An increase in birdlife, rodents and small mammals was also observed in and around dams where fish farming activities took place.

g. *How does fish production data compare with water quality parameters?*

Fish production output (total kg fish yield) from farms was closely associated with the quality of juveniles for stocking. The other important parameter determining harvest quality was the farm's FCR. Thus, management of the operation is considered to be more important than the prevailing water quality. The water quality parameters, including, DO, pH, TAN, PO_4 and Secchi disk did not influence the yield of farms.

h. What are the land-use changes and interactions associated with catchments in fish farming projects?

Aquaculture is conducted in irrigation dams. The land-use is primarily affected by the volume of water released below the dam. The below-dam ecology has adapted to these flow patterns. Light industry and agriculture around the dam area are more aware of potential pollution from their operations and are generally more cognisant of harming the aquaculture operations.

i. Does freshwater aquaculture add value to the livelihood strategies of rural and peri-urban farming communities?

Peri-urban and rural communities are in dire need of economic activity to present income and livelihood opportunities. These communities support aquaculture in their areas for it has been found to lead to job creation.

j. Are there feasible mitigation measures to reduce point and non-point sources of pollution in farm dams?

Mechanical mitigation measures were found to be impractical or too costly. Extraction of nutrient from dams via floating gardens has been found to have potential to reduce organic pollution arising from feed, faeces and surrounding land.

k. Can eutrophied water bodies be used for plant production?

Nutrient rich water bodies can be considered as hydroponic systems e.g. floating gardens on farm dams. In our investigation it was found that certain vegetables can be successfully grown on floats incorporated next to net cages for fish.

l. What are the challenges associated with technology and knowledge transfers?

To achieve technology transfer, we need to understand the following elements:

i. What information is available?
j. In which manner is the information accessed?
k. How is the obtained information used?
l. What constraints do fish farmers experience when accessing information?
m. What processes influence priority in information selection for implementation?
n. How much of farmer knowledge is based on existing or new information?
o. What is the cost-benefit of information access and dissemination?
p. How are our farmers managing the mass influx of information?

Thorough understandings of these elements will provide a measure to the success of technology transfer.

m. What is the public's understanding of aquaculture?

The broader public's understanding of aquaculture in South Africa is limited and mainly associated with large-scale operations with shrimp and salmon. The public needs to be made aware of the potential of aquaculture to contribute to food security and socio-economic development. Aquaculture can provide individuals and communities the opportunity to run a sustainable enterprise and to participate in the aquaculture sector.

n. What are the key issues for regulators and decision makers?

Integrated aquaculture-agriculture systems provide an alternative strategy to optimise utilisation of South Africa's water resources. Our existing resources are continuously under pressure from the increasing demand from the public and industrial sectors. National government should be encouraged to:

g. Promote integrated farming systems in irrigation dams through incentives to farm owners
h. Develop strategies to optimise associated water resource management requirements
i. Regulate effluent discharge to reduce ecosystem pollution and ecological integrity
j. Facilitate captive markets for fish and crops
k. Encourage secondary and tertiary learning institutions to include aquaculture in their curricula
l. Support directed research programmes on farm dams.

One of the objectives of developing aquaculture is to encourage sector participation and contribute to food security and poverty alleviation amongst a growing low-income populace. Fisheries and aquaculture provide a crucial investment in the world's well-being and prosperity and contribute to the livelihoods of millions of men and women. In order for aquaculture to make a major impact on prosperity in South Africa, there needs to be a conscious move to develop species that can be mass produced and still be affordable at the end of marketing chain. Species with this potential are tilapia, catfish and common carp. The National Aquaculture Strategic Framework indicates that aquaculture in South Africa and its development thinking is not oriented towards this objective. The second crucial issue is that of access and ownership of land and water. Farming communities residing on farms appear to have a better chance of leasing or being allowed to use land (and water) owned by their employers. In some cases, municipalities own land that is not being used and have made such land available to communities for aquaculture activities. For most communities access to water resources remains a contentious issue. South Africa is generally a water short country, and is in the process of making serious plans to import water from neighbouring countries. In the Western Cape, water saving measures are common especially in seasons of poor rainfall resulting in dams not filling to capacity. Shortage of water could therefore have a negative impact on the development of aquaculture, both nationally and in the Western Cape in particular.

There was large scale scepticism and negativity about aquaculture among the general public driven by ignorance or misinformation about its products and its potential. This was clearly echoed by the producers with whom the research team worked throughout the study. Aquaculture remains an area in need of investigation. Promotion and awareness-raising are important building blocks when developing a sector. What is clear though is that the trout seems to be thriving as a candidate species farmed in cages in irrigation dams. Aquaculture farmers are optimistic about the future of the sector in South Africa and they acknowledge that the sector is still in its infancy but that the sector has the potential to sustain a diversity of markets.

The emphasis on the preservation of biodiversity should be in balance with unlocking opportunities in aquaculture for socio-economic welfare in South Africa. This can be achieved where development strategies include conservation objectives. It is only when tangible livelihood initiatives are presented to the community at large, that they will appreciate the natural resources of the country.

Education forms the foundation of all good plans and therefore it is required to improve the knowledge base of aquaculture. The WCP in South Africa is one of the leading provinces in the country in terms of promoting aquaculture through applied research and project implementation. It is home to Stellenbosch University where under- and postgraduate curricula in aquaculture are presented. Further education and training could go a long way towards promoting the understanding and dynamics of aquaculture. Although the sector exists within a free market economy, the lack of co-operative strategies among producers is seen as being negative and hampering the growth of the sector. Efforts to promote coherent production and marketing strategies for the benefit of all within the sector should be encouraged.

4.5. Recommendations and future research

The study concluded that irrigation dams in the WCP could be enriched via nutrient loading from a number of potential sources including agricultural runoff and effluent discharges from industry, housing and informal settlements. The incorporation of aquaculture into such dams will add quantifiable nutrients to the water column and sediment. Therefore future research needs to focus on:

- The prevention and minimisation of pollution deriving from aquaculture through improved management. This can be achieved by optimising technology transfer.
- Monitoring catchment as a continuum with all the external factors affecting the ecology of farm dams. This can be achieved through qualifying the point source and presenting guidelines to minimise it.
- The sediment processes and dynamics need to be understood. This can be achieved through incorporating monitoring programmes on the ecological status of the bottom waters of the dams.

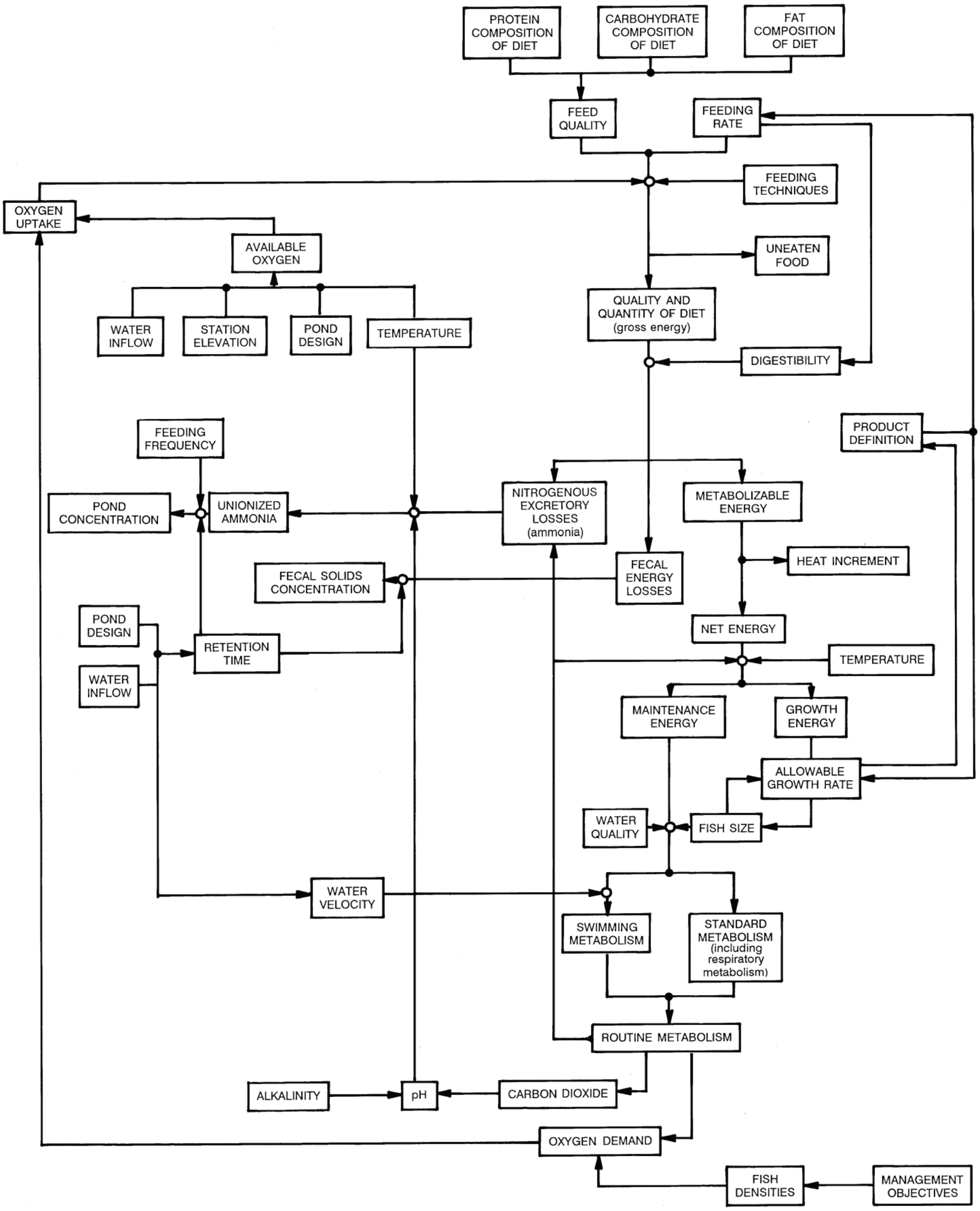
Furthermore, this research project is one of a series of research studies with the aim of investigating the interaction of floating net cage fish farming and irrigation farm dams over the last decade. It is proposed to consolidate the research protocol and monitor and evaluate the impact of gained knowledge and technology advancements at farmer level. Of particular interest are:

- Accessibility to knowledge,
- Level of comprehension and practicality,
- Cost-effectiveness of adapting and implementation,
- Indication of cost-benefit to the farmer,
- Effectiveness of knowledge and technology application on production performance.

The outcome of such a project will provide an agenda and new evidence in order to set the benchmarks for forthcoming research and development.

APPENDICES

Appendix 1: Interaction of biotic and abiotic factors in an aquaculture system (Klontz, 1991)



<u>Appendix 2:</u> Research site information, including production years (2008-2011), geography, hydrology and land-use.

Site no	Site name	‘08	‘09	‘10	‘11	Coordinates	Mean depth (m)	Elevation (m)	Water supply	Underlying geology	Surrounding land-use	Resource utilisation
1	Nietvoorbij	X	X			S33º55’4.02’’S 18º51’47.46’’E	5.0	148	Plankenbrugriver, runoff	granite, shale	vineyards	aquaculture, irrigation
2	Damn Dam					33º53’52.55’’S 19º1’8.77’’E	12.0				vineyards, orchards	aquaculture, irrigation
3	Ginaskloof	X				33º53’42.17’’S 19º0’57.32’’E	6.6				vineyards, orchards	aquaculture, irrigation
4	Plaisir de Merle	X	X			33º51’6.21’’S 18º57’4.95’’E	6.5				vineyards, orchards	aquaculture, irrigation
5	Kleinplaasdam	X	X			33º58’31.68’’S 18º56’38.36’’E	6.7			granite, sandstone	vegetation, plantation	aquaculture, drinking
6	Rondawel	X				S33º54’27.0’’S E18º53’2.58’’E	4.4	198	upper dam, runoff	granite, shale	vineyards, fruit orchards	aquaculture, irrigation
7	Buzzardkloof					33º53’19.22’’S 18º53’40.35’’E	9.7			granite, shale	vineyards, orchards	irrigation
8	Rachelsfontein		X	X		33º52’18.14’’S 18º57’29.97’’E	8.4				vineyards, orchards	aquaculture, irrigation

9	Mountainvineyards		X	X		33º52’20.07’’S 18º57’20.09’’E	10.5				vineyards, orchards	aquaculture, irrigation
10	Ezelfontein	X	X			33º24’14.70’’S 19º26’33.57’’E	7.1			sandstone	orchards	aquaculture, irrigation
11	Rocklands		X			55.42’’S 19º17’53.68’’E3 3 04 55 42	9.5	1000m	3 mountain streams	sandstone	orchards, vegetables	aquaculture, irrigation
12	Soetfontein	X	X			17’53.68’’E	5m7.8	1000 m	mountain stream	sandstone	orchards, vegetables	aquaculture, irrigation
13	Boplaas		X			32º58’43.95’’S 19º21’42.98’’E	7.5	1000 m	mountain stream	Bokkeveld shale	orchards	aquaculture, irrigation
14	Môrester		X			32º57’02.16’’S 19º23’42.42’’E	9.0	1100m	mountain stream	sandstone	orchards, vegetables	aquaculture, irrigation
15	Weltevrede/Tweefontein		X			32º56’17.86’’S 19º23’07.99’’E	6.7	1100m	mountain stream	sandstone	orchards, vegetables	aquaculture, irrigation
16	Toeka		X			32º59’53.21’’S 19º25’10.49’’E	9.4	1000m	mountain stream	Bokkeveld shale	orchards, vegetables	aquaculture, irrigation
17	Westland/Kolk		X			33º00’49.66’’S 19º23’15.21’’E	3.4			sandstone	orchards	aquaculture, irrigation

18	Worcester	X	X			33º35’53.69’’S 19º26’25.25’’E	8.9				golf course	aquaculture, irrigation
19	Goedgeloof – old	X	X	X		33º30’24.91’’S 19º11’45.84’’E	7.8				vineyards, orchards	aquaculture, irrigation
20	Goedgeloof – new	X	X	X		33º30’13.15’’S 19º12’9.05’’E	6.7				vineyards, orchards	aquaculture, irrigation
21	Cape Olive		X	X		S33º42’22.8’’S 19º1’59.34’’E	11.5	189	River, runoff	granite, alluvial, shale	vineyards, olive orchards	aquaculture, irrigation
22	Theewaterskloof	X				34º2’35.03’’S 19º19’37.98’’E	6.6				orchards	aquaculture, irrigation
23	Voorhoede	X	X			34º13’14.38’’S 19º29’37.72’’E	6.6				orchards	aquaculture, irrigation
24	Barton	X	X			33º15’40.01’’S 19º10’8.17’’E	5.8				orchards	aquaculture, irrigation
25	Nuwejaarsrivier	X	X	X	X	34º17’34.76’’S 19º4’43.00’’E	5.9				orchards	aquaculture, irrigation
26	Boomerang	X				34º11’15.95’’S 19º1’59.34’’E	8.4			granite, sandstone	orchards	aquaculture, irrigation

27	Duiwelskloof	X				34º11’26.13’’S 19º1’36.26’’E	13.0			granite, sandstone	orchards	aquaculture, irrigation
28	Remhoogte 1	X	X			34º11’26.13’’S 19º1’36.26’’E	8.9			granite, sandstone	orchards	aquaculture, irrigation
29	Remhoogte 2	X	X			34º11’26.13’’S 19º1’36.26’’E	6.9			granite, sandstone	orchards	aquaculture, irrigation

Appendix 3: Production data of trout farms for 2009 with associated physico-chemical water quality parameters

Project	Hatchery	Stocking	Harvesting	Product. days	Kg in	Kg out	Avg kg in	Avg kg out	Nr fish in	Nr fish out	Mortality	FCR	SGR	DO mg/L	pH	TAN mg/L	PO_4	Secchi
Barton	Lourensford	2009/05/25	2009/10/22	150	1206	6355	201	1155	6000	5500	500	1.17	1.18	8.9	6.5	0.518	0.244	113
Bo-Plaas	Remhoogte	2009/06/12	2009/10/16	126	3430	6068	570	1130	6018	5369	649	1.87	0.55	9.4	7.1	0.183	0.018	135
Cape Olive	Remhoogte	2009/05/22	2009/10/19	150	1086	6100	181	1109	6000	5500	500	1.40	1.22	8.7	7.2	0.214	0.061	90
Dennegeur 1	De Hoek	2009/06/29	2009/11/26	150	1604	4854	210	883	7638	5500	2138	1.70	0.97	10.3	7.0	0.309	0.092	163
Dennegeur 2	De Hoek	2009/06/30	2009/11/27	150	1180	4340	241	789	4896	5500	-604	1.75	0.80	10.6	7.2	0.293	0.080	158
Ezelfontein	Remhoogte	2009/05/20	2009/09/29	132	1200	1482	198	355	6061	4178	1883		0.45	9.7	7.5	0.307		126
Goedgeloof (new)	Jonkershoek	2009/05/13	2009/10/07	147	708	7027	118	1197	6000	5870	130	1.33	1.60	8.8	7.2	0.183	0.024	123
Goedgeloof (old)	Jonkershoek	2009/05/13	2009/10/06	146	708	7422	118	1212	6000	6126	-126	1.25	1.62	8.5	6.7	0.174	0.009	130
Mountainvineyard	Remhoogte	2009/06/22	2009/11/23	154	1760	6583	325	1197	5415	5500	-85	1.52	0.86	8.4	6.9	0.353		140
Nietvoorbij	Lourensford	2009/06/05	2009/10/22	139	2591	3740	400	680	6478	5500	978	4.81	0.39	9.8	7.5	0.470	0.144	76
Nuwejaarsrivier	Jonkershoek	2009/05/12	2009/11/16	188	708	6769	118	1327	6000	5101	899	1.40	1.30	8.8	6.9	0.481	0.065	80
Plaisir de Merle	Lourensford	2009/06/04	2009/10/30	148	2298	6662	345	1211	6661	5500	1161	1.66	0.86	9.4	7.1	0.185	0.042	98
Rachelsfontein	Remhoogte	2009/06/24	2009/11/27	156	1256	5568	200	1012	6280	5500	780	1.70	1.05	8.9	6.9	0.404		130
Westland	Remhoogte	2009/06/15	2009/10/13	120	2593	3616	570	1115	4549	3243	1306	4.43	0.57	9.3	7.1	0.109	0.069	133
Worcester	Remhoogte	2009/05/19	2009/10/20	154	1188	6067	198	1045	6000	5805	195	1.43	1.09	8.2	6.8	0.155	0.087	121

Appendix 4: Management system for responsible aquaculture nutrition

SUBJECT:	Policy framework for responsible and sustainable aquaculture nutrition	FILENAME:	Framework for responsible and sustainable aquaculture nutrition.doc
REFERENCE:	Management system for Responsible Aquaculture Nutrition 2011, 1.0	Page 94 of 128	
APPROVED BY:	DATE:	EDITION: 0	

Policy framework for Responsible and Sustainable Aquaculture Nutrition

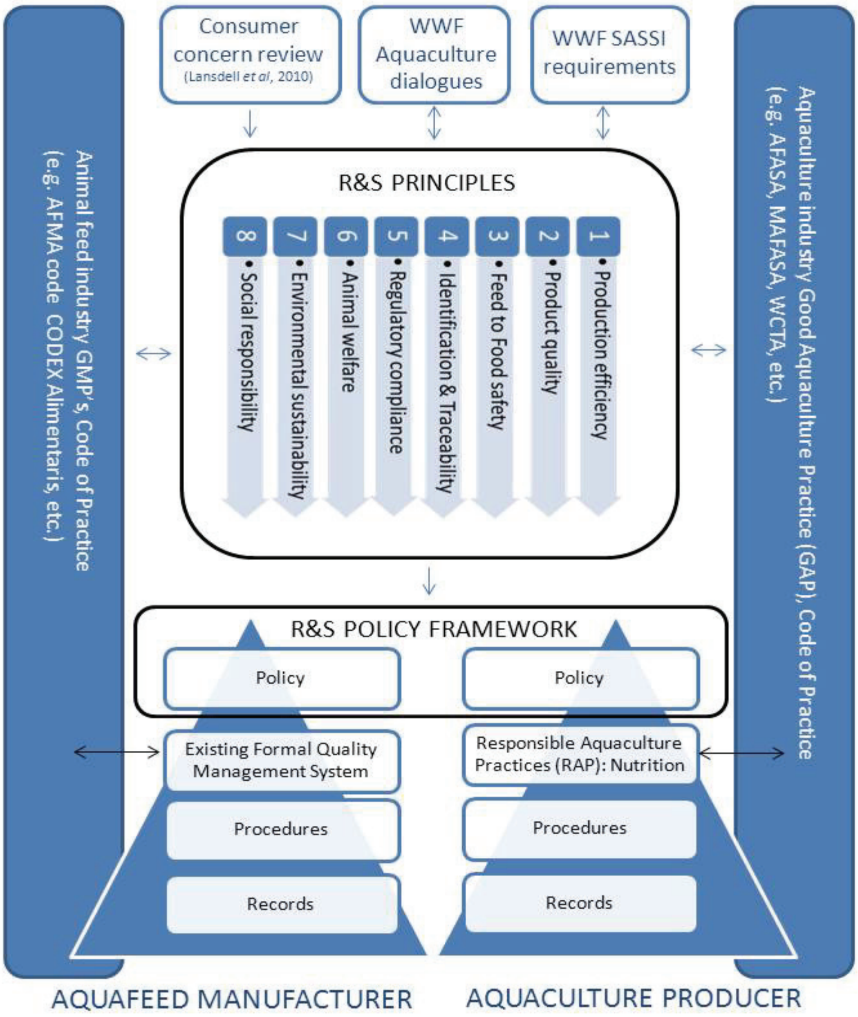


Figure 1. Process model for responsible and sustainable aquafeed management system

To develop, lead and operate a sector and/or organization successfully, it is necessary to manage it in a transparent, systematic and visible manner. The guidance to management offered in this framework is based on eight principles. These principles have been developed for use by role players/stakeholders in order to promote a responsible and sustainable aquaculture sector (Figure 1). These principles are integrated in the contents of the framework and are listed below:

The Organization (feed input supplier, aquaculture producer), in line with the principles set out in the framework, commit to responsible and sustainable aquafeed and feeding management through ideals and practices designed to promote:

- Principle 1 – Production efficiency:
    - Ensuring optimal use of resource,
    - Achieving optimal product output, and
    - Attaining profitable economical returns for sustainable financial input.
- Principle 2 – Product quality
    - Setting, meeting and striving to continuously improve quality objectives of aquafeed and its impact on end-product quality.
- Principle 3 – Feed to food safety :
    - Addressing safety concerns throughout product realisation based on HACCP principles.
- Principle 4 – Identification and Traceability:
    - Where appropriate, the identification of aquaculture produce and aquafeed ingredients by suitable means throughout product realization,
    - Identifying product status with respect to monitoring and measurement requirements,
    - Providing traceability to source when required, and
    - Providing appropriate information for the promotion of transparency,
- Principle 5 – Regulatory compliance:
    - Complying with applicable local, national and/or international laws and regulations
- Principle 6 – Animal welfare:
    - Supporting and contributing to animal welfare in product evaluation, commercial production, and impact on wild populations.
- Principle 7 – Environmental sustainability:
    - Assessing and monitoring the impact of activities on the environment, and
    - Promoting practices that enhance environmental sustainability.
- Principle 8 – Social Responsibility:
    - Acting in a socially responsible manner by
    - Adhering to relevant laws and regulations,

  - Promoting interaction with stakeholders,
  - Respecting the impact on society at large,
  - Promoting fair access to natural resources, and
  - Establishing mutually beneficial relationships.

The organisation believes that excellence is a commitment to consistently procuring and supplying products as well as providing services that meet or exceed our customers' requirements. We are committed to comply with requirements and continually improve effectiveness of our management system and principles. The management system and principles form the basis of our total commitment to meet sector and/or organizational goals, as well as legal and/or regulatory requirements and client and market expectations in a cost effective and acceptable manner. The system outlined in this framework defines the means by which the management and staff of this organisation will constantly strive to meet objectives and to promote principles.

The organization is committed to ensure that:

- The policy is appropriate to the purpose of the organisation, namely to promote a responsible and sustainable sector,
- The necessary resources are available to achieve the objective,
- Staff are familiar with the system and expected to comply with it,
- The policy is supported by measurable objectives,
- The policy is reviewed for continued suitability and effectiveness.

Appendix 5: Examples of procedures written (Lansdell, 2010).

SUBJECT: PROCEDURE FOR CALCULATING PRODUCTION PERFORMANCE OF FISH: FEED CONVERSION RATIO	FILENAME:
REFERENCE: Responsible aquafeeding Practices 2011.1	PAGE NO: Page 97 of 128
APPROVED BY: DATE:	EDITION:

1. PURPOSE:

The purpose of the procedure is to calculate the efficiency of the animal to convert feed mass into body mass and thus to estimate diet efficiency

2. SCOPE:

The procedure is applicable to grow-out managers, farm managers, researchers and general workers.

3. EQUIPMENT NEEDED:

Calculator or Excel sheet.

4. PROCEDURE:

1. Feed conversion ratio (FCR) will be calculated as feed consumption (dry matter) / live weight gain after one month or a certain number of months.

$$FCR = \frac{FI_t\ [g]}{W_t\ [g] - W_0\ [g]}$$

where:

FI = Feed consumption after t days [g]

W_0 = initial weight of the fish [g]

W_t = final weight after t days [g]

I have read and understand the procedure	
SIGNED:	DATE:
SUBJECT: PROCEDURE FOR THE PROCUREMENT OF AQUAFEED	FILENAME:
REFERENCE: Responsible aquafeeding practices 2011.1	PAGE NO: Page 98 of 2
APPROVED BY: DATE:	EDITION:

1. PURPOSE

The Organization is committed to environmentally responsible practices with regard to the sourcing of aquafeed. This procedure complements the existing auditable quality management system to support the drive towards meeting international standards and best practices with regard to Aquaculture. *The Organization* recognises and acknowledges its accountability and commitment to source aquafeed for responsible and sustainable aquaculture

In addition to the principles (principles 1, 2, 3, 4, 5, 6, 7 and 8) set out in the responsible and sustainable aquaculture nutrition policy (RANP), specific objectives of this procedure are to ensure that:

- aquafeed is sourced from responsible aquafeed manufacturers, and
- traceability to source can be verified, without compromising aquafeed quality and performance

2. SCOPE

Where relevant, this procedure applies to the:

- Farm manager
- Farm quality manager
- Aquafeed procurement manager
- Farm technical manager

Specific considerations include:

- All aquafeed processes are audited at least annually. More regular inspections of the farm and products will be carried out where deemed necessary due to risk assessment.
- The scoring of the “Procedure for sourcing aquafeed” statutory requirements and audits are monitored and reviewed regularly.
- There will be cooperation with aquafeed providers to ensure that all aspects of the feed safety management system are adhered to.
- Any issues which it is believed could result in feed borne illness or disease must be reported to the manager
- Appropriate management systems to ensure that all feed is safe will be developed and implemented.

- All risks associated with aquafeed production will be assessed and control measures to reduce those risks to a tolerable level will be introduced.
- It will be ensured that all feed handlers are trained to a level of competence commensurate with their duties.
- All relevant company policies and procedures will be complied with.
- All records will be maintained and be available at each facility for inspection at all times.

3. EQUIPMENT NEEDED

N/A

4. PROCEDURE

The Organization undertakes to source Aquafeeds responsibly by:

- Sourcing aquafeeds from suppliers that take the following principles into consideration (as defined in the responsible and sustainable aquaculture nutrition framework policy)
    1. Production Efficiency
    2. Production Quality
    3. Feed to Food Safety
    4. Identification and Traceability
    5. Regulatory Compliance
    6. Animal Welfare
    7. Environmental Sustainability
    8. Social Responsibility

The Organization also acknowledges the responsibility towards clients for the continuous supply of quality product to ensure sustainable aquaculture. Therefore, if aquafeed is not available from the above-mentioned sources or if it does not comply with internal ingredient quality requirements, it will be procured from alternative sources and clients and/or relevant authorities will be communicated with.

I have read and understand the procedure		
SIGNED:	DATE:	
SUBJECT: PROCEDURE FOR FEEDING RAINBOW TROUT PIGMENT-ENRICHED FEEDS: BROODSTOCK		FILENAME:
REFERENCE: Responsible aquafeeding practices 2011.1		PAGE NO: Page 99 of 1
APPROVED BY:	DATE:	EDITION:

1. PURPOSE:

The aim of dietary pigmentation is to:

- Achieve the most economic pigmentation rate to pigment the whole trout population to a minimum acceptable level,
- With the least variation,
- Without incurring economic loss due to product rejection

This would have unique implications for reproductive performance of brood stock and the hatchability and survival of ova.

2. SCOPE:

The procedure is applicable to the farm manager.

3. EQUIPMENT NEEDED:

4. PROCEDURE:

- Always ensure that the feed containing pigments are stored in a cool and dry environment to protect the integrity of the sensitive pigments.
- Feed older than three months should not be used.
- Feeding rate should be applied according to the recommendations of the feed supplier.
- Feed containing 40 ppm or 80 ppm pigment should be used 8 or 4 months respectively before spawning.
- Always make sure that all fish have equal access to feeding during feeding.
- Do not fast fish during the pigmentation period.
- Do not alternate between different feed sources during the pigmentation period.

5. FURTHER CONSIDERATIONS:

- A 40 ppm trout brood stock feed may typically contain:
  1. A 40 ppm (500 g/ton feed) astaxanthin containing product, which can be either Carophyll Pink® (DSM) or Lucantin® Pink (BASF), typically with 8% astaxanthin activity,

2. A 40 ppm (400 g/ton feed) canthaxanthin containing product, which can be either Carophyll Red® (DSM) or Lucantin® Red (BASF), typically with 10% canthaxanthin activity, or
3. A 40 ppm mixed xanthophyll pigment product may consist of a combination of locally available:

   i. 20 ppm (250 g/ton feed) Astaxanthin containing product, which can be either Carophyll Pink® (DSM) or Lucantin® Pink (BASF), typically with 8% astaxanthin activity, and

   ii. 20 ppm (200 g/ton feed) Canthaxanthin containing product, which can be either Carophyll Red® (DSM) or Lucantin® Red (BASF), typically with 10% canthaxanthin activity.

- On 24 January 2003, the European Commission adopted a directive to reduce the authorized use of cantaxanthin in animal feed. The new Commission Directive (2003/7/EC) sets a maximum of 25 mg/kg for cantaxanthin in feed for salmonids instead of the 80 mg/kg previously allowed. The directive went into effect on 1 December 2003.

I have read and understand the procedure	
SIGNED:	DATE:

Appendix 6: List of genera for seven major groups of phytoplankton. (Number in brackets refers to occurrences).

Group Bacillariophyta with 20 genera; also known as Diatoms	*Amphipleura*Kützing (2) *Asterionella* Hassall (1) *Aulacoseira* Thwaites (16) *Cocconeis* Ehrenberg (1) *Craticula* Grunow (1) *Cyclotella*Kützing*ex*Brébisson (11) *Cymbella* Agardh (8) *Diadesmis*Kützing (2) *Fragilaria* Lyngbye (1) *Gomphonema* Ehrenberg (5) *Gyrosigma* Hassall (1) *Melosira* Agardh (2) *Navicula* Bory (8) *Nitzschia* Hassal (47) *Pinnularia* Ehrenberg (3) *Pleurosigma* W. Smith (2) *Rhopalodia* Müller (3) *Surirella* Turpin (1) *Synedra* Ehrenberg (12) *Tabellaria* Ehrenberg (3)
Group Chlorophyta with 23 genera; also known as Green algae	*Ankistrodesmus* Corda (17) *Ankyra* Fott (2)

	Chlamydomonas Ehrenberg (22) *Chlorella* Beijerinck (3) *Chlorogonium* Ehrenberg (17) *Closterium* Nitzsch *ex* Ralfs (29) *Coelastrum* Nageli (6) *Cosmarium* Corda *ex* Ralfs (3) *Crucigenia* Morren (10) *Crucigeniella* Lemmermann (7) *Dictyosphaerium* Nägeli (47) *Eremosphaera* DeBary (3) *Golenkinia* Chodat (4) *Lagerheimia* Chodat = *Chodatella* Lemmermann (1) *Micrasterias* Agardh *ex*Ralfs (1) *Monoraphidium* Komárková-Legnerová (48) *Oedogonium* Link (1) *Oocystis* Braun (56) *Pandorina* Bory de Saint-Vincent (13) *Pediastrum* Meyen (11) *Scenedesmus* Meyen (16) *Staurastrum* Meyen *ex*Ralfs (49) *Tetraedron* Kützing (5)
Group Chrysophyta with 2 genera; also known as Golden-brown algae	*Dinobryon* Ehrenberg (32) *Mallomonas* Perty (2)

Group Cryptophyta with 1 genus; also known as Cryptomonads	*Cryptomonas* Ehrenberg (45)
Group Cyanophyta with 5 genera; also known as Blue-green algae	*Anabaena* Bory *ex*Bornet *et*Flahault (21) *Arthrospira* Stizenberger *ex* Gomont (1) *Cylindrospermopsis* Seenayya *et*Subba Raju (6) *Lyngbya* Agardh*ex*Gomont (2) *Microcystis* Kützing *ex* Lemmermann (36)
Group Dinophyta with 3 genera; also known as Dinoflagellates	*Ceratium* Schrank (29) *Peridinium* Ehrenberg (31) *Sphaerodinium* Woloszynska (10)
Group Euglenophyta with 3 genera; also known as Euglenoids	*Euglena* Ehrenberg (2) *Phacus* Dujardin (1) *Trachelomonas* Ehrenberg (6)