D - 5.3-5.4 DESIGN SPECIFICATIONS OF FARM AND OPERATIONAL PLAN

Design specifications of farm and operational plan

Promoting Community-Based Climate Resilience
in the Fisheries Sector Project

Submitted to:
THE NATIONAL FISHERIES AUTHORITY

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Date and version:
03-12-2020 report V4 FINAL D5

Content

1 PART I. SUMMARY

A. Overview

This report on resilient fish farm design describes the preliminary design and several engineering considerations for the development of a technically and economically feasible aquaculture system (RAS) for the tilapia culture in Jamaica. The aim is to formulate a sustainable farm concept that can be technically and financially verified against actual farm conditions in Jamaica.

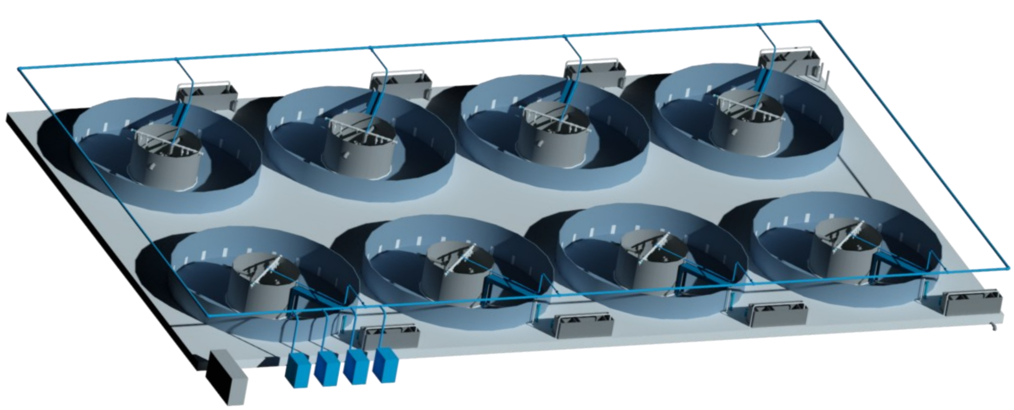
The farming principle which has been selected is intensive recirculation in order to minimise the interaction with the environment (footprint < 5%, and water saving > 90%) and to reduce the potential impact of changing climate factors (droughts, rains, winds, predators).

The total farm system contains 8 circular tanks to secure year round supply (weekly harvest). It has been designed to handle a daily amount of 200 kg of feed per day. The farm has been estimated to have an annual production capacity of ± 50 ton of fresh red tilapia or ± 70 ton of silver tilapia.

Its design covers the biological and technical aspects of the intensive tilapia culture and has specific characteristics which make the set-up unique. The biofilter is placed in the centre of the fish tank which prevents a lot of pumping energy and investments in piping. The system is self-supporting in terms of heat. The structure generates and captures enough heat to maintain a 25-26°C temperature. Oxygenation of water is purely done by aeration which creates a secure environment for up to 60 kg of tilapia per m^3.

Specifications of the preliminary design of the fish farm are:

Type of farm	: 8 tank Recirculation Aquaculture System (RAS)
Type of superstructure	: Framework with coated steel plate cover, or canvas liner
Type of tank	: 8 x corrugated steel frame with aqua liner
Oxygenation	: Fine bubble aeration, low energy roots blowers supporting > 12 kg O_2/h
Biofiltration	: Moving bed bio reactor (MBBR) for ammonia removal
Solid removal	: Packed sedimentation reactor
Water consumption	: 500-750 litre per kg feed
Type of fish	: Tilapia red, Oreochromis niloticus (50 - 350 grams in 22 weeks)
Feed	: Daily 8 –36 kg, average 24 kg per tank and 200 kg of feed per day
Output	: Tilapia red of 350 grams, net production 50000 kg, sales volume annual 58000 kg



The operation expenses to produce tilapia from 50 g to market size (350 g) in Jamaica are estimated to be around JMD 562/kg in the RAS system in accordance with the proposed plans, recommendations and technology described in this report.

The farm hardware would require 41.3 million JMD and the required working capital 9.6 million JMD. Based on the business plan with a sales price of 770 JMD/kg or 350 JMD/Lb a profit margin of 17 % can be seen and a Return on Investment would be in the range of 2 years.

Cost price overview: details can be found in chapter 4.3

Annual production costs	**JMD / kg fish**	**JMD/Lb**	**%**
Fingerlings	140	64	19%
Feed	205	93	28%
Electricity and water	100	45	14%
Labour	84	38	12%
Others	32	15	4%
operational costs	**562**	**255**	**78%**
Depreciation	61	28	8%
Interest costs	34	15	5%
Corporate taxes	65	30	9%
finance costs	**160**	**72**	**22%**
Cost price of production	**722**	**328**	**100%**

The results show that a climate resilient design, intensification and sustainability can go hand in hand with a RAS system. This can be a valuable opportunity for developing the aquaculture sector in Jamaica. This report shall be used as a base study and framework for a detailed design phase. Knowledge exchange (farmer courses) for the operational management can be provided during the implementation phase. Results and recommendations have been presented to the board of the Fisheries Division. The conclusions in the underlying study have been drawn based on actual information and cannot partly or completely be copied or linearly converted to other locations, farms or aquaculture facilities without recalculation.

B. Disclaimer

This report is prepared for the sole purpose of providing The National Fisheries Authority with information regarding the development of a modern, bio-secure and well-equipped hatchery of appropriate capacity. In addition, it provides information regarding climate-resilient demonstration fish farming.
The drawn conclusions are based on the gathered information and although reasonable care was taken to ensure the reliability of this report, no warranty is made by Til-Aqua International and/or Holland Aqua BV as to its accuracy or completeness. The mentioned organisations accept no liability for any damage resulting from the use of the results of this study, or for the application of the advice it contains.

THIS REPORT HAS A CONFIDENTIAL STATUS

2 PART II. Technical Approach and Methodology

2.1 Objective and Scope of work

Subject of the underlying report is the specification of a climate resilient fish farm. It is part of a larger assignment, which includes (1) a situation analysis and plan for seed production in Jamaica, (2) an upgrade of the existing hatchery owned by the Fisheries Division and (3) the development of a climate resilient fish farm.

The implementation of the outcome of this assignment aims to promote community-based climate resilience in the fisheries sector, of which the objective is to strengthen fisheries and aquaculture policy and regulations, strengthen the livelihoods of fishers and fish farmers and reduce vulnerability of fish farming communities to climate shocks.

The research scope is limited to red tilapia as this is the dominant cultured fish species in Jamaica. This study does not discuss measures for existing ponds, but elaborates an aquaculture vision for the longer term. The general, not site specific, design is based on a business process from which fish can be routinely supplied to customers.

2.2 Technical approach and research methodology

This study contains a technical design, an operational plan and a business plan. Research methods include expert interviews, desk research, field research and farm visits.

For the technical design of the climate resilient aquaculture farm, the consultant has evaluated several farm sites, their restrictions and climate risks as well as their environmental and social requirements. Based on this assessment, the consultant has drawn up technical design specifications for the farm facility.

The adjoining operational plan includes information regarding production capacity, biosecurity and climate control measures, an electricity and water management plan, waste treatment, growth and efficiency.
The financial business plan is defined based on calculations for investments, cost price and turnover. Calculations are based on a 3-5 years scope.

2.3 Relation to subprojects

The development of a climate resilient fish farm is related to two other projects: (1) A situation analysis and plan for seed production in Jamaica and (2) The upgrade of the existing hatchery owned by the Fisheries Division. Both the development of the fish farm and the upgrade of the hatchery include design specifications and preparation of a business, management and operational plan.

3 PART III D-5.3 DESIGN SPECIFICATIONS OF FARM (LAY-OUT, FUNCTIONAL & TECHNICAL)

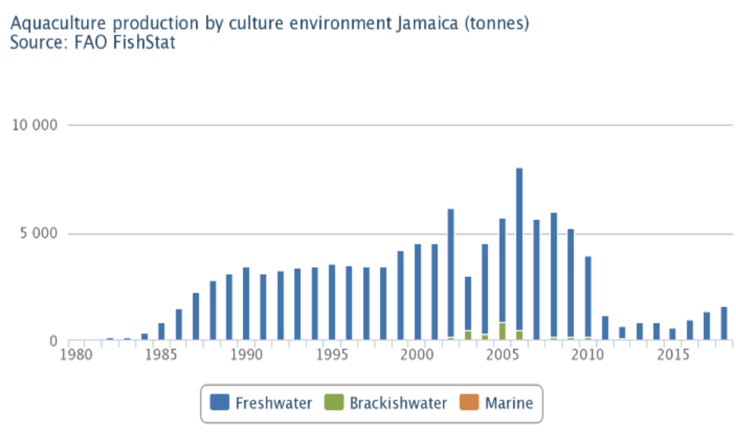
3.1 Site evaluation

According to earlier Jamaican publications, three groups of farm types are used to define the aquaculture production sector. The three types of farming (small, medium sized, and large), are divided based on total amount of acres of farm site and tend to illustrate a progression from semi-intensive and intensive to highly intensive culture practices.
Only a small fraction of the available land in Jamaica has been used for fish farming. During the ACPfish2 project 2013, GIS maps have been composed of the island. Available inland areas suited for aquaculture counted in total 75,631 ha, based on suitability ratings for five predefined land characteristics (texture, slope, erosion, land pH, root zone), on land use and access to water and roads. The parishes with substantial, suitable aquaculture areas are St. Catherine, Clarendon, St. Mary and St. Thomas.

A lot of fish farms and potential farming sites are dormant. The farmers have listed a number of challenges that restrain the potential:

- High production costs.
- No recordkeeping on inputs and harvest. Difficult to get production figures complete.
- Losses due to burglary on farm sites and losses by birds foraging on the stocks.
- Difficult access to market, technical and business knowledge.
- Difficult market access due to requirements and standards for quality assurance.
- Difficult access to financial resources to invest in maintenance, change and improvements.
- Ineffective extension support (commercial and institutional) for small scale farmers.

A clear trend appears from the production data over the last 20 years. The total farm output from 2011 until 2020 has been reduced to 25% of the peak output of average 6500 tons / year during the period 2005-2009. (Watanabe, O 2002).



Clear addressable causes are:
1) the stop of major fish export by Jamaican Broilers and their connected contract farmers, 2) droughts, 3) high production costs, 4) competitive position.
After 2010 the remaining farmers have a combined output level close to 600 tons. In the more recent years a growth of around 300 ton per year can be seen. This is partly generated by the start of Pangasius culture by Algix.

In 2011 the large farms covered 70% of the area (350 Ha) under production. These larger farmers also tend to have a higher efficiency. The small farms cover 14% of the area under production (approx. 70 ha), cover 12-18% of the production volume (150-175 tons) and have a lower efficiency of 0.25 kg/m^2/year.

In 2020 around 76% of the area (170 Ha) is under production by the large farms. The small (20 Ha) and medium (34 Ha) farms cover an area of respectively 9% and 15%. These two groups of farms will produce in the range of 135 tons per year, accounting for around 10% of the total production. The remaining 90% of the total fish is farmed by 8 large scale farmers, who produce at a higher efficiency of 0.75-2.0 kg/m^2/year.

Table: Number of farms in Jamaica in 2001, 2011,2020 with a forecast by the project team.

	2001	2011	2020	Forecast 2030
Total number of farmers	**400 (100%)**	**179 (100%)**	**48 (100%)**	**45 (100%)**
Small farms (1-4 acres)	300 (75%)	115 (62%)	29 (60%)	15 (33%)
Medium farms (5-20 acres)	76 (19%)	38 (21%)	11 (23%)	10 (22%)
Large farms (>20 acres)	24 (6%)	26 (14%)	8 (17%)	10 (22%) +20

Globally, there is a trend that for primary production, the number of smaller farms is reducing and a stable number of larger farmers show increasing farm areal and output volumes per farm.

Table: Indication of the total production, divided over the 3 classes of farms in Jamaica, with a forecast by the project team based on trend over 2001, 2011, 2020.

- indicative estimates -	2001	2011	2020	Forecast 2030
Total output tons/ year	**4450 (100%)**	**1152 (100%)**	**1600 (100%)**	**5000 (100%)**
Small farms (1-4 acres)	500 (11%)	150 (14%)	100 (7%)	100 (3%)
Medium farms (5-20 acres)	950 (22%)	150 (14%)	200 (13%)	400 (9%)
Large farms (>20 acres)	3000 (67%)	800 (72%)	1250 (80%)	4400 (88%)

Assumed that the existing capacity of small and medium farms was for 20% allocated in 2011.

The average production capacity of the different farm types is as follows: small 2 tons/y, medium 15 tons/y and large 150 tons/year. With the existing number of farms (40-50) in operation, 2000 tons per year would be a moderate production plateau in 2020.
A total annual production of 5000 tons/year can be achieved with an equal number of fish farmers if the existing large farmers can triple their production efficiency, or start farming with increased water consumption rates. The water exchange is a limiting factor to productivity.
An alternative could be to have 20 additional large scale farms opening new sites or 200 medium farmers starting a new farm. Also, a new route to a more intensive form of aquaculture in order to add 3000 tons can for example be done by adding 3 large intensive industrial 1000 tons farms.
From older Jamaican literature references, high output per hectare can be found (43 ton/Ha) in comparison to standard operational practises of open pond farming (7-15 ton/Ha). This almost always relates to high water exchange rates and is based every time on flowthrough ponds. Of course by the nature of this type of farming, the productivity is extremely sensitive to droughts caused by climate changes and cannot be ranked as sustainable.

In this report the conceptual design of the resilient farm will be based on a production capacity range of the medium type of farm (5 - 50 tons/year). This will allow small farmers to make a step forward, medium farmers to secure their production and large farmers to explore new technology that may be useful.

3.1.1 Biological assessment of the site

Tilapia can be cultivated in different ways such as ponds, cages, raceways (also known as continuous flowthrough system), tanks, recirculation systems (RAS), cages in lagoons, reservoirs or dams and irrigation channels, with ponds being the most common medium currently used.
The culture of tilapia in ponds is a technique that allows to consider factors such as size, location, drainage, water source, and dike construction. Small ponds are easier and faster to harvest in comparison to other techniques, which allows for a better control of the culturing process. It is worth mentioning that in small ponds there is less susceptibility to erosion by wind, and large ponds are less susceptible to oxygen problems due to the waves and mixing effect of the wind.

The fish production can be done in an extensive way. The production technique is usually developed with very low investments. In this system densities of 0.5 to 3.0 fish/m3 are used, depending on the target market size of the fish. The small farmer usually owns the land and the fishponds are not the only source of income. Normally, ponds of 1 to 4 hectares are used with little water replacement, and agricultural by-products are used as complementary feed. The production of tilapia with this technique usually ranges from 4,000 to 10,000 kg/ha/year.

In a semi-intensive way of farming of tilapia, tanks or ponds of 0.5 to 3 hectares are used with water replacements of 15 to 30% of the pond volume on a daily base. Aerators are used for the oxygenation of the tanks in order to compensate for an oxygen dip in the early morning or to increase the overall output of the system. For this system it is very important to monitor ammonium levels, pH, temperature and the level of dissolved oxygen. A farmer can achieve a production within 10,000 to 25,000 kg/ha/year. Fish can be sold pond side, but can also be sold to distributors or to a contract fish processor.

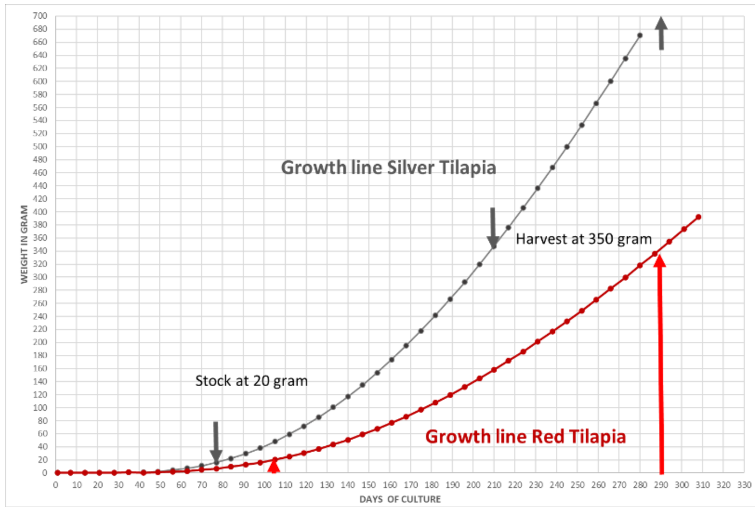
When applying an intensive tilapia farming technique, the production system is made in small tanks of 50 to 1000m^3 or in ponds with a constant water exchange and densities of between 80-150 fish/m^3. The production of fish will depend on the amount of water available and the oxygen level for optimal development of the fish. Large farms are typically partnerships or subsidiaries of larger firms engaged in other businesses. These types of farms stock at higher densities, use greater water exchange and aeration, and manage integrated systems for maintaining broodstock, producing fingerlings, processing, and marketing. Input costs are higher (better feeds) and feed efficiencies slightly lower, in order to produce larger size fish, and yields of 25,000 to 45,000 kg/ha/y can be achieved.
The highest level of intensification of pond culture in Jamaica was illustrated by Aquaculture Jamaica Ltd., a 42 ha farm in the Parish of St. Elizabeth that produced 1800 mt of marketable fish/year (4,3 kg/m^2) (Watanabe, O 2002).

For a good technical design, all the climate-resilient design factors should be taken into account, such as weather conditions, market size of fish, design of the tanks or ponds, functional and economical points of view, culture density, feeding and feed levels, dissolved oxygen levels, ammonium levels, temperature and exchanges in water, all to ensure a good potential tilapia production.

From a biological design perspective, the design should target an intensive way of production in order to secure a stable growth and should incorporate a reduced water consumption by implementing water recirculation technology (RAS).

As part of the biological engineering process a growth curve for the local strain of tilapia has been established based on farmers information obtained during the site visits. This allows the engineers to calculate biological needs and loads, a pollution factor, and the demand for i.e. oxygen.

The dominant species of farmed tilapia is an Oreochromis hybrid. The graph shows that silver tilapia grows faster than red tilapia; respectively 130 days and 180 days (20 - 350 grams).
The difference in growth rate becomes visible in other technical production characteristics and culture densities.
The final weight of the fish, which is determined by the end user (350 g for a whole fish and > 700g for fish fillet), is also an important parameter to base the system design on.



The farm will be designed for the existing red tilapia species. They will be grown to a market size of 350 grams (as plate size fish) and used for the regional wholesale.
For the tilapia the growth is considered to be from 5 to 25 grams in 7 weeks and from 25-350 in 26 weeks.
The final density of the design is related to the intensity of the aeration capacity and the potential water exchange. In regular green water ponds this does not exceed the 1 kg/m^3 (3 fish/m^3). In a green water aerated pond this can be increased to 5 kg/m^3 (15 fish/m^3), assuming a high water exchange rate or biological filtration. In the intensive farming systems, density can be increased to 60 kg/m^3 (150 fish/m^3).
In the resilient design a fully aerated RAS tank will be proposed. This can be either outdoor in a concrete pond structure or in a tank with biofiltration.

The proposed biological parameters used for the resilient design are listed below.

Topic	Unit	Actual production level 2020, according to field reports Jamaica	Proposed production schedule for the resilient farm
Pond size	Ha	0.5 – 1.0 (5000-10000 m^2)	0.05 – 0.01 (tanks of 50 m^2)
Growth	grams	20 - 350	20 - 350
Days of cycle	days	180 -210	150
Density	#/m^2	2 - 3 (max 0.6 - 1 kg/m^3)	170 (max 60 kg/m^3)
Survival	%	50 - 70%	85 - 95%
FCR	-	1.4 - 2.5	1.2 - 1.4
Yield	kg/m^2/y	0.75 - 2.5	120
Cycles	#/year	1-2	2.4
Water usage	m^3/kg fish	20	0.4 - 1

The major changes are the proposed higher densities and faster growth which, if combined, will result in a much higher productivity. The resilient design is more compact and thus less exposed to environmental factors. With better control over the production, it is also possible to improve on the feed conversion rate and to reduce water consumption by 90%.

3.1.2 Technical assessment of the site

The developments over the last 20 year show that under the given conditions Jamaican small farmers have had to stop production and the large farmers have struggled to survive. This fall-off was attributed to, among other things, the continued scarcity of red tilapia seed stock which negatively impacted production, as well as the drought conditions which affected pond operations according the PIOJ in 2016. The tilapia sector is slowly recovering from its lowest production point. However, several major technical issues holding back growth can still be seen during farm visits or interpreted from information given by farmers.

The lack of working capital results in a situation where the farmer decides to buy cheaper fish feed, which often results in a poor feed conversion rate; up to 3 kg feed per kg of fish. Farm and pond maintenance and replacement of technical parts and equipment is postponed to the latest moment. All the visited farm sites have earthen ponds for the grow-out. The production level is generally low, 0.5 - 1.0 kg/m^2/y , and fish densities in the green water pond do not exceed 1 kg/m^3.

Only a few farmers keep clear farm records and are able to show technical production results. The lack of accurate production management could mean a 30% lower production. Technical production results are heavily impacted by the type of feed the farmer is using. In the market low (28%) protein feed is available, which results in very poor feed conversion rates. Smaller farmers are forced to buy either locally produced feed or high quality import feed for a premium price.

Due to the open nature of the pond farming a lot of praedial larceny is expected and seen. Farmers sometimes have accountable losses up to 25%. Some farmers are also competing for the resources of influent water. Restrictions on usage of water will lower the production as well.

3.1.3 Design criteria and farm capacity specifications

For sustainable aquaculture practise a certain critical output production volume is required to cover the basic operational costs and to generate income and make a profit. In order to design and set up a business case around it, a 'scope for the production' should be defined.

For this exercise a medium sized farm capacity of 12 ton is assumed. Technical efficiencies are based on general aquaculture practices, which are corrected for more Jamaican practices in accordance with available data.
The table below shows the different farm design specifications for 5 different farming methods for a similar annual production of 12 tons tilapia. The figure shows a footprint comparison for the same production level.

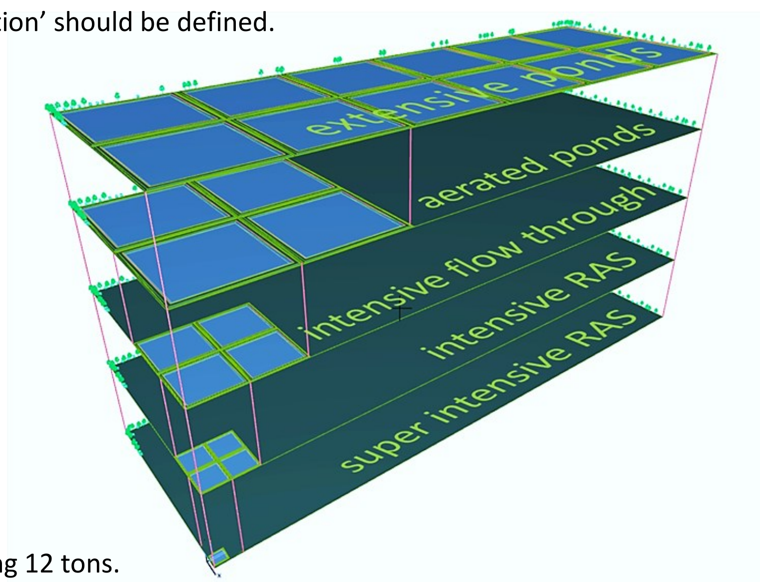


Figure: footprint of extensive to intensive farming 12 tons.

Table: Specification of 5 farming methods for a similar annual production of 12 tons tilapia (the first 2 blue columns are the most regular choices in Jamaica).

Footprint of farming technology	**Extensive ponds (no aeration)**	**Aerated ponds (part of the time)**	**Flowthrough or aerated tanks**	**Intensive RAS aerated ponds**	**Super intensive RAS tank system aerated**
Production annual kg fish	**12000**	**12000**	**12000**	**12000**	**12000**
Number of ponds or tanks	12	4	4	4	1
Ponds or tanks size m2	4000	4000	1000	250	100
Total area m2	48000	16000	4000	1000	100
Hectare in total	4.8	1.6	0.4	0.1	0.01
Productivity kg/m2 /year	**0.25**	**0.75**	**3**	**12**	**120**
Water consumption m3/day	**720**	**800**	**1600**	**48**	**13**
Water consumption % of volume	1,5%	5%	40%	20%	13%
Water consumption m3/h	30	33	67	2	1
Water consumption rate m3/kg vis	**22**	**24**	**49**	**1.2**	**0.4**
Investment in land USD 2 /m²	**96,000**	**32,000**	**8,000**	**2,000**	**200**
Investment in pond construction USD /m² 1,25	60,000	20,000	5,000	1,250	125
Investment in pond liner USD 3 /m²			30,000		
Investment in concrete tanks USD 30 /m²				7,500	
Invest RAS tank USD 100/m²					10,000
Investment culture volume	156,000	52,000	43,000	10,750	10,325
Capex farm volume/kg production	**13.0**	**4.3**	**3.6**	**0.9**	**0.9**

In Jamaica the regular production takes place in extensive or aerated ponds with large volumes of water consumed (first 3 columns of the table above). The proposed resilient farm is in line with the last column.

The location of the farm in relation to the footprint, environment and climate impact can only be considered if a basic comparison for intensifying production is made. The footprint also gives a first indication of the sensitivity of the farm layout system to climate factors such as droughts, winds, flooding, predation and water consumption.

Positioning the climate resilient farm design in the medium size farm segment would be beneficial for small farmers, as they could grow to this stage, and for the medium farmers, as they may convert their farms. When a 'new' business set-up needs to be defined, scalability and uniformity would have the preference. Definition of the resilient farm design will be of the type 'super intensive RAS'.

3.2 Risk through climate changes

Climate change is currently of major concern to the growing aquaculture production centres in Asia (China, Bangladesh, India, Vietnam etc.), and Africa (esp. Egypt). Climate change has altered the wet and dry seasons. For many Southeast Asian nations (Vietnam, for example), the dry season has come earlier and lingered longer during the past decade. Upstream dams have caused a loss of freshwaters, salinization and subsidence in southern Bangladesh, altering valuable aquaculture farming systems in this region. As the Intergovernmental Panel on Climate Change (IPCC) predicts major shifts in rainfall patterns and storm intensities, pro-active and adaptive approaches will be required to preserve these important food production centres from accelerated climate change (Costa-Pierce et al., 2010).

Also Climate change is point of attention for Jamaica. Detailed climate modelling projections (by Caribsave 2012) for Jamaica predict:

- an increase in average atmospheric temperature by 1^{o}C
- reduced average annual rainfall by -20% till -40%
- increased Sea Surface Temperatures (SST)
- the potential for an increase in the intensity of tropical storms

For the aquaculture, tilapia production sector the reduced rainfall and the increase storms can be highlighted from the list above. ECA (European Climate Assessment and Dataset) studies conducted by the Caribbean Catastrophe Risk Insurance Facility (CCRIF, Selvaraju 2013) in 2010 outline two main groups of interventions: risk mitigation measures and risk transfer solutions.
Risk mitigation measures are adaptation measures aimed at reducing damage, and include asset-based structural measures (e.g. dikes) and behavioural measures (e.g. enforcing construction codes).
Risk transfer solutions include risk insurance and adaptation measures aimed at limiting the financial impact for people affected by distributing the risk to other players in the market.

For a climate resilient fish farm design the focus will be on the mitigation measures. The effect of droughts and storms can be avoided by reduction of the farm footprint and by implementing back-up measures.
The transfer risks can be avoided by cooperation in the sector. If one hatchery fails to deliver can the others upscale their production to supply the farmers. Or if one farmer fails to deliver consumption size fish, a corporation could fill in the market demand though another member.

Table: Estimated risks associated with aquaculture production systems considering climate changes

		Tilapia production in :	Open ponds	Flow through tank	RAS -tank
1.	Technological	- during pre-grow-out phase	Low	Low	Average
		- during grow-out phase	Low	Average	Average
2.	Environmental	- wind damage	Average	Low	Average
		- wave damage	High	Low	Low
		- flooding	Low	Low	Low
		- polluted water	Average	High	Low
		- shortage in water supply	High	High	Average
3.	Disease	Disease	High	Average	Low
4.	Predators	Predators	High	Average	Low
5.	Economic	- sensitivity to market demand	Average	Average	High
		- sensitivity to import prices	High	High	High

3.2.1 Evaluation of interaction due to local climate

Fish farming depends upon resource inputs (water, energy, land, seed and feed) that are connected to, amongst others, the food, processing, transportation, retail and catering sector. The negative impacts of climate change on these inputs will have a number of implications on the aquaculture productivity, on the value chain and on the livelihood of communities dependent on aquaculture activities. Outputs from aquaculture systems such as uncontaminated waste waters and fish waste, can in their turn be valuable inputs to ecologically designed farming systems.

Implications of climate changes on the tilapia value chain in Jamaica are studied by Luzardo (2019). Within the aquaculture value chain, droughts (50%), hurricanes (42%) and heavy rainfall (23%) were found to be the most severe effects of climate change. The same survey also revealed that market volatility (50%) and cost of production are factors heavily affecting the fish farming value chain.

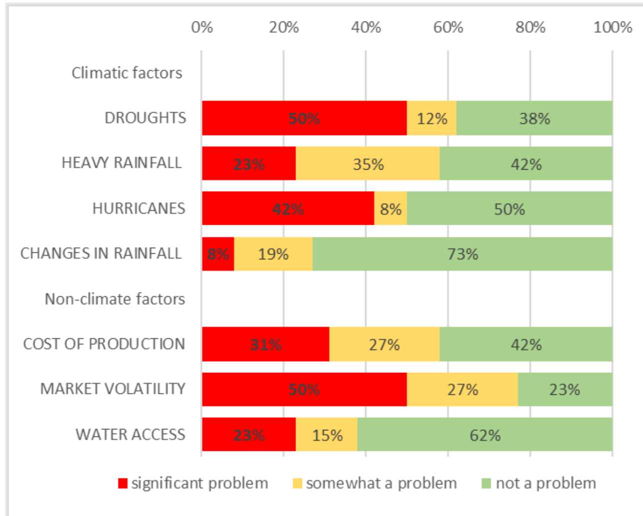
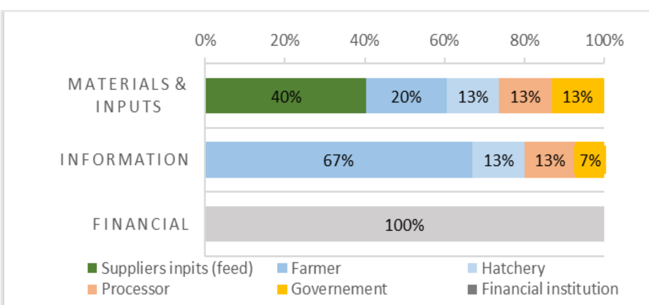


Figure: Perception of climate factors from stakeholders within the tilapia value chain of Jamaica.



A side survey on 15 actors for material, financial and information networks was conducted, which revealed that with regard to the materials in the tilapia value chain, the input supplier (feed) plays a major role. The information exchange basically takes place between all chain players (producer, trader, processor) but mainly between the farmers. On the financial side, solely financial institutions are actors.

Figure: Analyses on actors for the material, financial and information networks of the tilapia value chain.

For a resilient aquaculture technology to be implemented successfully, the primary production sector needs to be informed in a 'farmer to farmer' approach. To get access to finance, the financial institutions need to be informed, which can be secured with a complete business plan. The fish farming hardware should be made available through a third party supplier who can assemble hardware, do civil and plumbing works and can install electrical installations.

It would be beneficial to exchange production knowledge between farmers who implement resilient aquaculture technology. This should be accomplished with an initial training program and a long term support structure. If smaller resilient farms can combine planning and marketing efforts for the stakeholders this would be beneficial to the feasibility of the projects. In this case a production cooperation would be desirable for support and sales activities.

3.2.2 Technical considerations and measures

The list of potential hazards due to climate change is a long one. In the table at the end of this chapter a list of climate factors and non-climate factors is shown. It includes the mitigation route and technical solutions for the direct hazards specified for fish farming.

More directly related to the farm operations are the following 5 critical fields, considerations and possible measures:

Topic	Consideration	Measures
1) WATER	Water saving > 90%	Water recirculation with physical & biological filtration
	Reduce evaporation	Smaller footprint / more intensive farming
	Secure intake water quality	Use of borehole water
	Minimise consumption rate	Target for <1 m^3 / kg fish
2) WIND	Wind breaking	Wind shielding, dikes and trees
	Wind proofing	Superstructure indoor construction or cover
3) RAIN	Erosion	Use pond liner, wall protection or concrete
	Flooding	Overflow, secure enough drains
	Escaping fish	Fenced overflow
4) ELECTRICITY	Secure supply	Generator to backup grid power
	Price and usage	Use low energy consumption equipment
	Alternative	Solar
5) LOSSES	Praedial Larceny	Reduce area to secure (prevents 5-10% losses)
	Predation	Reduce bird foraging (prevents 20% loss)

In conclusion, in order to reduce the external factors, the resilient farm design should exclude large interactions with the surrounding environment and should include preventative measures.

Water is a primary resource to a fish farm. In the actual open ponds or flowthrough ponds, 10-50 m^3 of water is used to produce 1 kg of fish. Any form of drought will have a direct effect on the productivity. The impact can be enormous, production volumes need to be reduced down to a point that the farming activity needs to be ceased. Competition around the source of the water, or a higher concentration of pollutants in the water source or in the pond water are commonly seen.

The current and proposed adaptive and mitigative options to cope with the consequences of climate change:

Climate factors	Direct effect / hazard	Mitigation / measure	Examples of technical alternative
Temperature variations	Reduced growth, low oxygen	Controlled conditions	Water temperature control
Droughts	Less production, no replacement	Water saving Reduce evaporation	Recirculation with biofiltration or crops Smaller fish farm surface (intensify)
Heavy rainfall	Overflowing, turbidity	Farm protection	Cover
Flooding	Loss of fish stock	Farm location	Relocate farm
Tropical storms	Damage to infrastructure / repairs	Wind proof	Design of farm
Hurricanes	Damage to site / equipment / repairs	Hurricane proof	Compact technology
Sea level rise	Loss of infrastructure	Farm location	Selection of farm sites

Non-Climate factors	Direct effect / hazard	Mitigation / measure	Examples of technical alternative
Predation-air	Loss of fish stock	Bird nets	Compact with shelter / cover
Predation-land	Loss of fish stock	Fencing, guards	Closed area
Pest	Spreading disease	Pest control	Safe storages
Diseases	Loss of stock, Introduction of pathogens	Biosecurity	No free interaction with surrounding environment
Cost of production	Loss of margin	Cost reduction	Increased efficiency
Market volatility	Loss of market	Planning and contracts	Data records and forecasting
Water access	Reduced production	Water storage	Well
Electricity supply	Loss of stock	Backup alternative	Generator
Electricity dependence	Loss of production capacity	Renewable resources	Solar
Soil erosion	Loss of site / stock	Renovation	
Siltation	Loss of farming land	Reduce water use	Small units with controlled effluent
Turbidity, pollution	Loss of production / loss of stock	Secure safe inlet water	Use of well water
Lack of funding	No growth of production	Bankable concept	Total farm concept / not location based
Poverty	Increased theft		

3.3 Concept design, functional and technical specifications

3.3.1 Concept design and functional description

A proper analysis prior to the design process increases the chances of success. The scope of the farm design is limited by the type of fish, the climate, the clients demands, technical requirements and voluntary preferences. These conditions, needs and requirements are listed before the start of the design phase. The use and the quality of the juvenile fish, feed and management also have a huge influence on the production results and are therefore an integrated part of the success of the farm design.

In order to launch the proposed concept design, a local, medium to large range farm can be used. The previous chapters have shown that the design must comply in general terms with **"technology for higher culture densities combined with less environmental impact and less sensitivity for droughts and winds".** The resilient farm for Jamaica has been designed to stock at a moderate fish density and Recirculation Aquaculture System (RAS) technology is proposed. Due to the fact that less water is consumed in RAS, the waste nutrients are more concentrated and can thus be used as fertilizer or as inflow for hydroponic crop production.

Definition of production, investment (capex, opex) aspects of resilient farm design

In essence, the choice for a specific farming technology and for a type of building, is a way to optimise the overall productivity and operational production costs (OPEX) of the fish under the given conditions. In general, higher productivity systems require a higher investment (CAPEX). Within the aquaculture sector, the RAS technology offers a near-optimal water quality for growth and a controlled environment as its major advantages.

For this design stage, the following operational cost (OPEX) factors have been used as preliminary values:

Juveniles	2.5 pieces per kg at harvest of 400 grams, plus 10% mortality (20 JMD for 20 grams fish)
Feed	1.3 kg of feed needed to produce 1 kg of fish at a feed cost of around JMD 88 per kg
Electricity	<3.0 kW consumed per kg of fish at a cost price of JMD 33 per kWh
Labour	125 hours per 1000 kg production at a cost price of JMD 150 per hour
Other	Service, maintenance, material at JMD 20 per kg

Main system components:

Fish holding:	Fish tank
Oxygenation:	Aeration
Water treatment:	Water purification recirculation (RAS)
	Waste collection
Superstructure:	Rain cover
	Sun protection
Infrastructure:	Electricity grid and generator
	Water well and buffer
	Storage
	Fences & roads

System functionality

The basic principle of RAS is to re-use water through the application of suitable treatment processes. There are different degrees of water re-use depending on the system design. A flow-through fish farm layout, where the water supply is diverted through ponds or tanks and then discharged, has no water re-use. If aeration or oxygenation is added to the pond or tank, a somewhat longer usage of the water is possible, and more fish can be produced using the same water flow. However, recirculation implies treatment of some or all of the discharged water and the return of this water to the fish rearing system.

Considering the above, a key design parameter is the ratio of recycled water to waste water. Recycling 90% of the water in the main oxygen rich (aerobic) water flow, using basic solids removal and re-aeration technology as primary treatment will increase productivity. Many experts in this area consider the term RAS to only apply to systems with more than 90% recycling (less than 10% water replacement per day).

The essential functions of RAS are:

- To provide a suitable environment for the fish with respect to space, water flow and stock density
- To protect the stock from infection by disease agents and predation
- To provide for the physiological needs of the fish (mainly oxygen and nutrition)
- To remove metabolic wastes from the fish (notably faeces, ammonia and carbon dioxide)
- To remove waste feed and breakdown products (solid and dissolved organic compounds)
- To maintain temperature and water chemistry parameters within acceptable limits

The latter function can be a challenging one, as water quality parameters interact with each other in complex ways. Furthermore, the operating conditions of the system are changing on an almost daily basis as fish grow, diets and feed rates change, and harvesting takes place. The most common processes in RAS are shown in the table below.

Water quality factors	Technology examples
Suspended solids	Sedimentation (for coarse particles)
Ammonia	Nitrification bacteria convert ammonia to nitrite and nitrate
Nitrate	Dilution by lower recycling rate/more fresh water Some denitrification bacteria convert nitrate to nitrogen gas
Dissolved organic compounds (mainly carbon) i.e. colour	Biofiltration Water exchange
Carbon dioxide and nitrogen gas	Degassing e.g. forced air bubble aeration
Oxygen	Aeration at low saturation concentrations Oxygen (emergency situations or peak demand)
Temperature	Heat exchanger with gas fired boilers (water/air) or ventilation (air/air) Chillers or evaporation for cooling, increased ventilation
Pathogens	UV lamps, for small fish
pH	Chemical dosing (e.g. sodium bicarbonate) Denitrification counteract alkalinity consumption

The major design parameters for RAS are shown in the table below.

Parameter	Comments
Production plan	The system is designed around the production plan, which determines the expected length of time the batches of fish will be in specific tanks, when they will be graded and moved to other tanks and when they will be harvested or moved out of the system. The use of multiple batches involving stocking and harvesting schedules is normal in RAS to optimise use of resources and maintain reasonably stable biomass.
Biomass & feeding rate	In general, these are related; the quantity of feed introduced to the system each day is the most important factor for system sizing. Further considerations are the variation in biomass and feed and, in some circumstances, changes to the composition of feed during the culture cycle.
Stock density	This is highly dependent on species, size range and other factors such as water quality, tank dimensions and perhaps water flow dynamics. Higher stocking densities generally imply more efficient utilisation of tank volume and overall facilities.
Water flow rates	These may be calculated in relation to biomass so as to provide a consistent replenishment of water per minute per kg or stock. However, changes in volumetric flow rate need to be avoided as they are related to other parameters such as solids removal and energy expenditure by the fish.
Temperature control and energy efficiency	Maintaining optimum temperatures in RAS can be challenging, particularly where ambient temperatures vary seasonally, or are substantially different to the needs of the stock. The entire facility needs to be designed to minimise energy requirements for heating or cooling. Similarly, the energy required for pumping and gas exchange is probably the second major cost factor after feed. Therefore, careful design is essential to minimise requirements and maximise efficiency (e.g. through minimising the pumping head, selecting wide bore pipes and efficient pumps etc).
Feed system	This will be specified based on volumes and required feed rates, the degree of automation and appropriate methods of (bulk) feed handling and storage.
Monitoring & control	Requirements for system monitoring will be based on the design criteria and set water quality targets, together with a risk assessment of potential points of system failure. Computerised control systems can both help to reduce labour requirements as well as improve response to out-of-range conditions.
Water quality targets	Water quality criteria and targets need to be set at the design stage to help define performance requirements for treatment equipment. Typical parameters include dissolved oxygen and carbon dioxide, ammonia, nitrite and nitrate, pH, alkalinity, salinity and temperature.
Waste treatment and disposal	The major waste stream from RAS is organic solids. This waste stream frequently needs dewatering and other treatment prior to disposal or utilisation elsewhere.
Biosecurity	A risk assessment needs to be carried out considering factors such as species, potential pathogens, disease susceptibility, location and potential infection routes. This will lead to decisions regarding disinfection and other biosecurity measures.
Fish movement and grading	Designs should ensure that basic fish husbandry operations such as stocking tanks, splitting and grading stocks, moving to different tanks, interim and final harvests, vaccination and disease treatments can all be performed as efficiently as possible. Fish pumps are commonly used, but there are implications for tank design and layout & building design. Consideration must be given to the removal of mortalities.

3.3.2 Production plan and process flow

Description of the aquaculture production plan

The aim of a fish farming production plan is to define stepwise the yearly fish production and to determine required culture volumes, filtration technology and floor space to be able to realise this production goal.
There are numerous technical cross relations between i.e. electricity use and investment in a generator but also between daily feed load, aeration and produced waste. For permits, detailed engineering and financial planning, it is essential to have a good predefined culture plan combining technology and fish requirements and containing specifications of farm components.

In this chapter, the fish production in an RAS farm (of approx. 50 ton tilapia) will be explained step by step and overall production plans will be made for the species tilapia. Farm set-up (capacities, volumes etc.) will be calculated from a biological and technical perspective and will be worked out in 5 steps (Growth, Culture plan, Waste, Flow and Treatment).

Design steps RAS system	Farm set-up to produce 50 ton of tilapia
Step 1 Growth	Fish characteristics, growth, feed, conversions
Step 2 Culture plan	Stocking, density, feed load and tank volumes
Step 3 Waste production	Fish & feed composition, digestibility, oxygen
Step 4 Flow rates	Total load, limiting factors, inlet/outlet concentration
Step 5 Treatment systems	Nitrification, solid removal

The total production life cycle can be divided into different stages; 1) broodstock, 2) fry, 3) pre-growout and 4) grow-out. This farm design will only cover a grow-out facility. The basic farm layout will be worked out in production schedules with stocking densities, loads and feeding strategies.
The fish production is based on a fixed week to week production schedule for a continuous production approach. As the farm consists of a combination of consecutive growth stages, the number of fish and the capacity in the production facilities should be a nice fit; predictable and reliable. For each new farm a specific plan needs to be made in accordance with this strategy.

A first scope calculation has been made based on the expected production level (50 ton tilapia) and the general growth characteristics of the selected fish species. Within the framework of aquaculture a farm is either extensive (0 - 0.1), intensive (0.1 - 0.5) or super intensive (0.5 – 1.5), in terms of kg fish per m^3 tank volume per day. Predefining a general farming intensity is part of the strategy. The design of the recirculation farm described in this project is based on an intensive production but without the use of technical liquid oxygen.

The farm will be designed to have an operational range of intensive farming (125 kg of tilapia per m^3/year, equals 0.35 kg/m^3/day). If the strategic production goal equals the maximum production capacity, it requires that staff, fish, feed and technology are always to perform at 100%. More realistic would be to expect, especially at a set-up stage, a farm to operate 10 - 15% under its maximum performance, or in this case 100 kg/m^3/year. Throughout the year all kind of variables could influence the production.

The table below shows (in green) the range of productivity for the climate resilient fish farm. Although the farm is designed for an average production of 50 ton, a low-end level of 36 ton and a high-end level of 64 ton per year are the outmost minimal and maximal points.

Table a: General farm design indication table

PRODUCTIVITY FISH FARMING		level 1	level 2	level 3	level 4	level 5	level 6	level 7	level 8	level 9	level 10	level 11	level 12	level 13	level 14	level 15
Productivity per day	kg/m3/d	0,0	0,1	0,1	0,2	0,2	0,3	0,30	0,35	0,4	0,5	0,5	0,6	0,6	0,7	0,7
Productivity per year	kg/m3/y	1	15	35	55	70	90	105	125	145	160	180	200	215	235	255
Extensive																
Intensive																
Super - Intensive																
Production goal	MT /year	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Farm tank volume	m3 tanks	50.000	3.335	1.430	910	715	560	480	400	345	315	280	250	235	215	200
Selected System volume	m3 system					400	400	400	400	400	400	400				
Year production range	MT /year	0	6	14	22	28	36	42	50	58	64	72	80	86	94	102
Production per year	MT/m3/y	0,0	0,0	0,0	0,1	0,07	0,09	0,11	0,13	0,15	0,16	0,18	0,2	0,2	0,2	0,3

The table below summarises a first impression of preliminary values of technology figures related to the expected production figure of 50 ton in an RAS system on this level (8) of production intensity.

Table b: General preliminary technical specifications

HANDLING FISH FARMING		level 1	level 2	level 3	level 4	level 5	level 6	level 7	level 8	level 9	level 10	level 11	level 12	level 13	level 14	level 15
Growth cycle	weeks	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Maximum density	kg/m3					50	50	50	50	50	50	50				
Tank number	-					8	8	8	8	8	8	8				
Tank size	m3 total 400					50	50	50	50	50	50	50				
Harvest	ton / week					0,5	0,7	0,8	1,0	1,1	1,2	1,4				
Harvest moments	1x per ..wk					5	4	3	3	2	2	2				
Feed Conversion	kg / kg					1,4	1,4	1,4	1,4	1,4	1,4	1,4				
Feed load	kg / day					104	133	155	185	215	237	266				
Biofilter MBBR	m3					6	8	9	11	13	14	16				
Water replacement	m3/h					1,1	1,4	1,6	1,9	2,2	2,5	2,8				
Electricity	kWh					20	20	20	20	20	20	20				

1) Design steps RAS system	Step 1 Growth: Fish Production Strategy
Stocking weight	50 gram
Final, harvest weight	350 gram
Time interval	22 weeks
Feed conversion	1.3 - 1.4 kg feed / kg fish
Maximum density	60 kg /m³
Mortality	0.5 - 2 % over this period

In order to make a good production forecast and be able to design an appropriate lay-out, the fishes growth in time needs to be studied. This tilapia production plan is based on the 'average growth curve' as found in growth trials or combined findings by farmers in Jamaica. The total production time is divided into smaller intervals. Every growth interval has its own specific production specifications according to which tank size, water purification and water quality needs to be optimised.

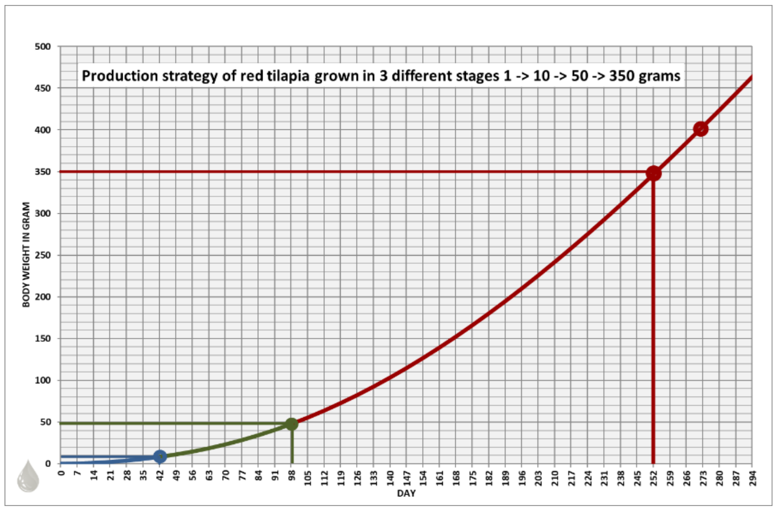


Figure a: Production stategy and growth intervals

For this complete farm design, the growth line as shown above has been used as technical input. Farm load, conversions and efficiencies are calculated based on these values. Under practical conditions adjustments will be made by the farmer for feed, temperature, genetic variation, harvesting moments and other management decisions.

Tilapia growth can generally be broken down into three distinct phases: exponential, linear and plateau. Young fry are ravenous eaters and they can consume feed that is equivalent to up to 25% of their body weight on a daily basis. As a result, the fish grow very fast when measured in percent of body weight per day. This phase is referred to as the exponential phase (<200 gram). During the linear growth phase the growth remains fairly linear. The duration of the linear growth phase differs significantly from one species and strain of tilapia to another. Some inferior tilapia strains may show growth deceleration at sizes below 300 gram. Cheap fingerlings can thus become more expensive in the long run due to poor genetics.

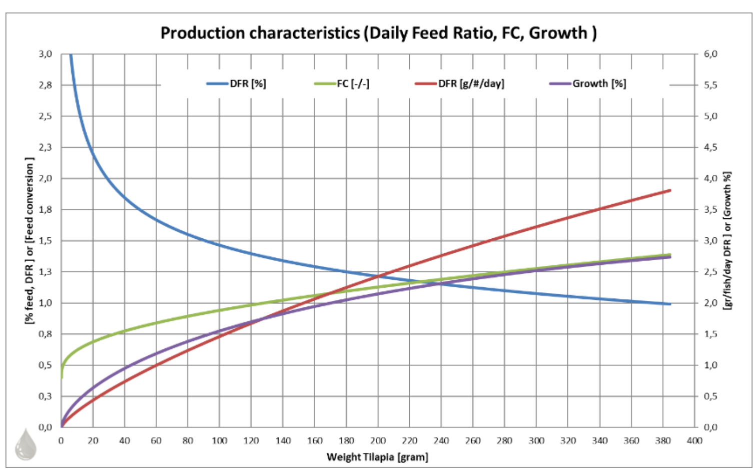


Figure b: Production characteristics red tilapia growth range from 0 tot 400 gram (DFR ~ daily feed ratio in % or in gram/fish/day; FC ~ Feed conversion)

2) Design steps RAS system	Step 2 Culture Plan: Capacity calculations and schedules
Production goal	MT 50 per year
Growth stage	50 – 400 gram
Growth phases	1 period of 22 weeks
Stocking harvesting scheme	22 weeks all in – all out
Maximum feed load	40 kg feed per day per tank

The production cycle of tilapia is divided into three segments: Hatchery, Pre grow-out and Grow-out phase. The final growth phase is the **grow-out** phase. This is basically the "major feed volume" component of the aquaculture farm. It begins when the fingerlings are transferred from the juvenile tanks to the grow-out tanks. Once the fish reach a size of approximately 200 grams, they eat more and convert less efficiently, which results in roughly the same amount of growth daily. In order to maximise growth, the fish should be provided with as much high quality diet as possible in the shortest period of time.

The total time for the Red Tilapia to reach a market size of 2 - 350 gram generally takes 7.5 months on average. Detailed production of tilapia from 2 – 50 – 350 gram during the grow-out period is summarised in the table below. In a similar farm system the output will be 40 - 50% higher for Silver tilapia (86 tons) compared to the Red tilapia (59 tons).

Table a: Two production stages for Red and Silver Tilapia and capacity for the production stages

	PHASE	Pre grow-out Red Tilapia	Grow-out Red Tilapia	Pre grow-out Silver Tilapia	Grow-out Silver Tilapia
1	Tanks [number]	3	8	3	8
2	Volume per tank [m³]	21	63	21	63
3	Total tank volume [m³]	63	500	63	500
4	Initial weight [gram]	**2**	**50**	**2**	**50**
5	Harvest weight [gram]	**50**	**350**	**50**	**350**
6	Growth period [days]	84	154	56	105
7	Growth period [weeks]	12	22	8	15
8	Input [kg / year]	400	8500	600	12500
9	Production [kg / year]	8100	50150	11900	73500
10	Harvest [kg / year]	**8500**	**58650**	**12500**	**86000**
11	Productivity [kg / m³]	128	117	189	147
12	Max. density [kg / m³]	20	60	22	60
13	Feed conversion [kg / kg]	1.2	1.4	1.2	1.4
14	Feed per year [kg]	9720	70210	8100	102900
15	Feed per day [kg / d / tank]	8 avg. 14 max	24 avg. 40 max	13 avg. 20 max	35 avg. 56 max

The 34 weeks grow-out period is divided into 2 blocks, one of 12 weeks (2 - 50 grams) and another of 22 weeks (50 - 350 grams). The fish will be stocked in the 63m^3 tank with a higher number of individuals in order to maintain enough stock towards the end of the culture period, to compensate for losses.

3) Design steps RAS system	Step 3 Waste production: fish & feed composition and oxygen
Fish composition	Calculate N, P, COD, retention
Feed composition	Calculate N, P, COD, feed
Digestibility	Calculate N, P, COD, faecal
Oxygen consumption	Calculate oxygen consumption

Production of fish inevitably causes production of waste. Examples are faeces production, excretion of ammonia (NH_3) and carbon dioxide (CO_2). This waste is excreted into the water in which the fish live, thereby deteriorating the water quality. A constant water flow is thus needed to remove this waste and to supply oxygen (O_2) to the fish. In order to calculate the required flow rates one needs to know the amount of waste produced per unit of time.

To find the amount of waste that needs to be treated, a calculation has been made regarding the retention and digestibility of the feed ingredients. Also, the composition of the tilapia in terms of Protein, Fat, Energy, Ash and COD (chemical oxygen demand) has been calculated. This can be done in accordance with the equations relating the body composition to the body weight of the fish (figure below). For the tilapia the composition is well known. The equations in the figure below can be used for farm biological engineering purposes.

With increased body weight the tilapia also contains more fat and protein, which results in a higher energy level. As all life sizes are present within a farm, a calculation is made of average body composition and waste production.

Chemical Oxygen Demand (COD)

COD is the amount of oxygen needed to oxidise 1 kg of material, and can thus be used as a common value to characterise the organic fractions of fish, feed, waste and bacterial material.

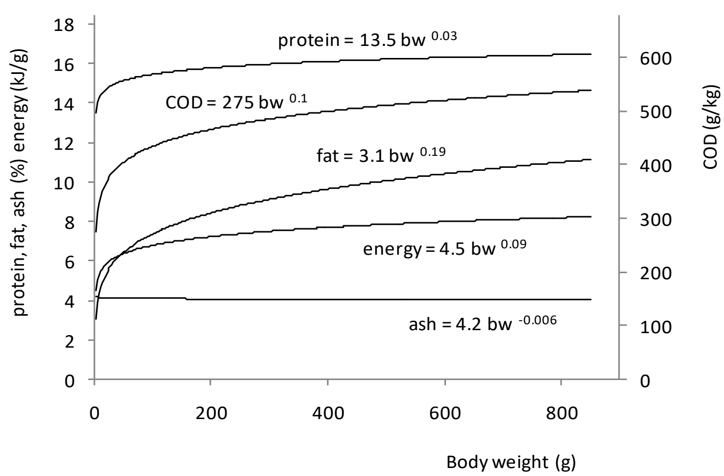
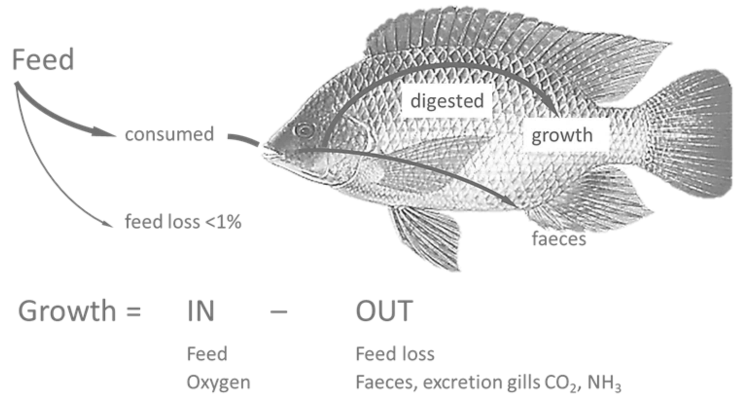


Figure: Body composition related to weight of tilapia

These organic fractions consist of protein, fat and carbohydrates. The COD can be calculated from the composition of the organic matter as the sum of 1.38 * protein, 2.78 * fat and 1.21 * carbohydrates. The protein is not oxidised completely, as organic nitrogen is not oxidised within a COD analysis. But organic nitrogen can also be oxidised by bacteria, as can NH_4-N can be converted into NO_3-N. This theoretically requires 4.57 g O_2 /g N. Adding this to the amount of COD will give the total oxygen demand (TOD). In the process of feed utilisation and growth, the fish themselves also oxidise part of the feed related organic matter. The oxygen consumption of the fish (respiration) can directly be expressed in COD.

The total oxygen requirement can be calculated from the farmed amount of fish, their growth and their daily feed level, waste and waste distribution. Besides that, the oxygen consumption of the system (bacteria, ammonia conversion and biological degradation) also needs to be calculated.



With the compositions of the fish and the feed, a model (not detailed in this report) can be filled in how the feed is converted into fish and waste. Within this model an assumption is made of the feed conversion and digestibility at specific body weight. For the oxygen consumption of fish the following equations are used, based on the energy deposition and maximum production.

Oxygen consumption of fish	$\mathbf{COD_{respiration} = (ME_m + [1- kg] \times ED) / OCE}$
$\mathbf{ME_m}$	= energy maintenance, for tilapia 65 kJ/kg$^{0.8}$/d
ED	= energy deposition (growth in energy, kJ/fish/d)
kg	= marginal efficiency of energy deposition, for tilapia average 0,77
OCE	= oxygen caloric equivalent, 14.2 kJ/g O_2

For the respiration, first the ED needs to be calculated: assume 22 kg average feed, 16 kg growth per day for 9090 tilapia with an average body weight of 191 gram. In the calculation of mass balances of 8 tanks, 8 different cohorts have been used. This represents the load of 1.7 ton x 8 tanks = 13.6 ton standing stock.

ED = 16 (kg growth) x 7.4 MJ/kg = 118 MJ/d

$\mathbf{COD_{resp}}$ = [(65/1000 x 0.191$^{0.8}$ x 9090) + ((1-0.77) x 118)] / 14.2 = 13 kg COD/d

The 13 kg COD per day means that for the respiration of the fish an oxygen system should be able to provide around 0.54 kg O_2 per hour to be diluted into the water of one tank.

In the models the fish have been fed 27 kg/d thus for respiration 13 / 21 kg feed = **620 gr O_2 /kg feed**

From the mass balance and digestibilities of the compounds, it can be calculated that a kg feed contains 1117 grams COD. After digestion, a part of the COD remains in the fish as growth and a part of it is excreted. This part can be converted by microorganisms which demand 62 gr O_2 /kg feed.

The total oxygen consumption of around 0.852 kg O_2/kg feed can be divided in:

682 g for feed and respiration and conversion biological organic matter (from step 3)
170 gram for nitrification process (from step 5)

4) Design steps RAS system	Step 4 Flow rates: Total load, limiting factors, concentrations
Holding facility	Flow through, Re-use, RAS with/without denitrification
Fish density	Load tolerances
Limitations	Maximum concentration, k-values, P-values
Water quality	Inlet water concentration

A constant flow of water through the fish tank is required in order to remove the waste and replenish the oxygen to such an extent that the water quality remains constant. A general formula to calculate the required flow rates is:

Recirculation flow **Q = abs [k * P / ΔC]**

Q = flow through the respective compartment (m^3/time)
k = a factor correcting for daily variation in waste production or consumption (k ≥ 1)
P = production (or consumption for O_2) of waste (g/time)
ΔC = the difference between $\mathbf{C_{limit}}$ (the limiting (=outflow) concentration of the waste substance in question) and $\mathbf{C_{in}}$ (the inflow concentration of that waste substance), both in g/m^3.

Flow rates		Fish range	Farmers choice	k-value	P-value
Temperature	°C	24 – 28	27		
pH	-	5.5 – 7.5	6 – 6.5		
NH3-N	g/m^3	0.01 – 0.1	0.01		
TAN (0.7% =NH_3/TAN)	g/m^3		1.5	1.4	28 g/kg feed
NO_2-N	g/m^3	0.05 – 1.0	1		
NO_3-N	g/m^3	100 – 200	165	1.0	
O_2	g/m^3	4 – 6	4.5	1.2	- 380 g/kg feed
CO_2 [380 x (RQ0.9 x 44/32) = 471]	g/m^3	10 – 25	15	1.2	471 g/kg feed
COD dissolved	g/m^3	100 - 300	200	1.0	
Suspended solids	g/m^3		25		

Different water flow rate calculations required for a RAS system **$Flow_{TAN}$ = abs [k * P / $C_{limit, TAN}$-$C_{in, TAN}$]**

TAN related $Flow_{TAN\text{-}flow}$ = abs [(1.4 x 28) / (1,5)] **= 26 m^3 /kg feed**
= ΔC = (1.5 mg/l $_{lim,outlet}$ - 0 mg/l_{inlet}) ~1.5

RAS related $Flow_{TAN\text{-}RAS}$ = (based on nitrification, see below) **= 47 m^3 /kg feed**

Oxygen related $Flow_{O2}$ = abs [(1.2 x - 380) / (-3.0) **= 152 m^3 /kg feed**
= ΔC = (6.5 mg/l_{inlet} - 3.5 mg/l_{outlet}) ~ 3.0 (if no aeration in the tanks)

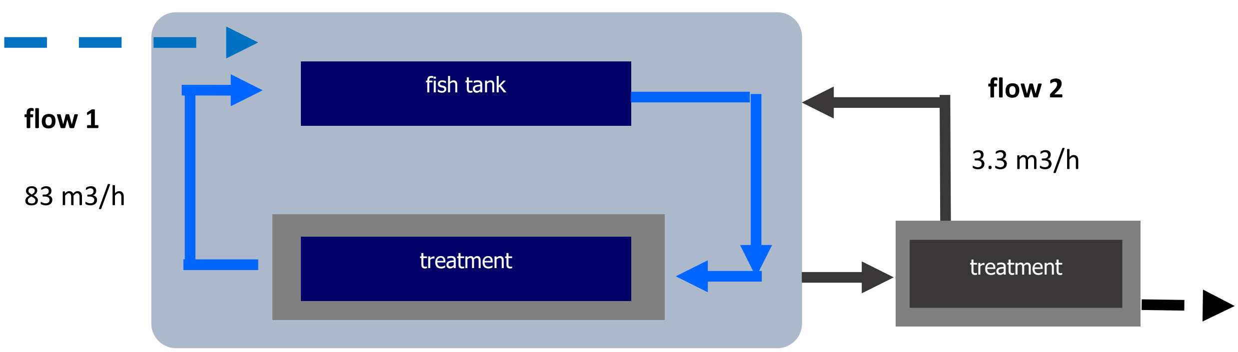
Carbon dioxide $Flow_{CO2}$ = abs [(1.2 x 470) / (10,0) **= 56 m^3 /kg feed**
= ΔC = (15 mg/$l_{lim,outlet}$ - 5 mg/l_{inlet}) ~10.0

From the flow rates above, the maximum is chosen for the design. With this flow the minimum values and the daily fluctuations can be dealt with. For the farm system, with max 40 kg of feed x 50 m^3/h = 2000 m^3/day = 83 m^3/hour, exchange between the fish culture area tank and the biofilter is required.

Based on the 4 levels of flow rate calculations in general the highest outcome will be used to base the design upon. In this particular set-up, taking into account that there will be aeration in the tank, a flow through the biofilter of 50 m^3/h per kg of feed will give sufficient flow to meet the required quality parameters.

For the farm FLOW 1 equals max 40 kg of feed x 50 m^3/h = 2000 m^3/day = 83 m^3/hour per fish tank
For the farm FLOW 2 equals max 40 kg of feed x 2 m^3/h = 80 m^3/day = 3.3m^3/hour per fish tank

Figure: Adapted flow schedule for submerged biofilter RAS system



5) Design steps RAS system	Step 5 Treatment: Nitrification and solid removal
Tank number	1 (expressed per tank)
Tank volume	1 x 62.5 m^3 (total volume 500m^3 because 8 x 62.5m^3)
Feed load; oxygen required (1kg/kg feed)	40 kg feed x (682+170 gr O_2) = **34 kg O_2/day needed/tank**
Flow recirculation (m^3/kg feed)	50 m^3/kg max feed = 2000 m3 per day = **83 m^3/h**
Particle removal section	Sedimentation filter
Flow refreshment water	20 m^3/day (500 litre/kg feed)
Flow towards sedimentation	2 m^3/kg feed = 80 m^3 per day = 3.3 m^3/h
Nitrification	Submerged moving bed biofilter (50% of oxygen demand)
Denitrification	Partly in biofilter and in settlement filter <15%
Oxygenation system	Aeration in the tank 100% (50% of capacity 1,40 kg/hour)
CO_2 stripping	Through bubble aeration 100%

The waste of the fish and uneaten feed needs to be filtered out of the main water flow. For this purpose a sedimentation filter can be used. The amount of effluent from the sedimentation generally accounts for the amount of water renewal (0.5 m^3/kg feed). The amount of replaced water also levels the nitrate concentration that cumulates within the system.

Bioreactor for nitrification RAS system

An important part of the recirculation system technology is the biofilter. The function of this biofilter is mainly to convert the ammonia excreted by the fish into nitrate by bacterial conversion. Although nitrification is the main purpose, the biofilter also has the capacity to convert organic matter which is trapped in the bioactive layer.

In order to support the biological conversion of the waste products of the fish, a biological reactor is necessary. In conventional RAS systems this bioreactor is placed outside the tank in a recirculating water stream. In this particular example another approach has been used. The bioreactor is placed in the centre of the tank. The water is forced through the biofilter by several airlift pumps. The bottom of the bioreactor is perforated in order to move water from the fish area into the reactor.
A bioreactor is also used in order to maintain an adequate retention of bacteria in the biological filter with a high hydraulic loading rate. The principle is called MBBR, which stands for Moving Bed Bio Reactor. The bottom of the bioreactor is made of polyethylene panels and is filled with aeration discs.

The bioreactor needs an effective volume (m^3) to be able to hold PE bio-elements up to 40%-60%. The bio-elements act as carrier for nitrifying bacteria, which take care of the conversion of ammonia to nitrite and nitrite to nitrate, to attach and grow on. The higher the surface area of the element, the higher the nitrifying capacity. A turbulent environment and high oxygen flux rate through the biofilter provides a functional aerobic environment for the nitrifying bacteria, but also create an oxygen rich environment for the fish.

The biological process of nitrification, the biological conversion from **ammonia** (NH_3) to **nitrite** (NO_2) to **nitrate** (NO_3) can be described by the following overall chemical reaction equation.

1g NH_3-N + 4.25g O_2 + 5.88g $NaHCO_3$ -> 0.26g COD + 0.98g NO_3-N + 2.72g CO_2

For every 1 gram of ammonia-nitrogen (NH_3-N) to be converted, 4.25 gram of oxygen (O_2) is consumed. Besides that carbon / alkalinity (HCO_3^-) is consumed. The bacteria grow and produce organic matter (COD). A part of the oxygen is used for the formation of nitrate (NO_3) and a part is used for the produced carbon dioxide.

<u>In general per kg of feed: 40 gram N x 4.25 gr = 170 gram oxygen is needed for nitrification</u>

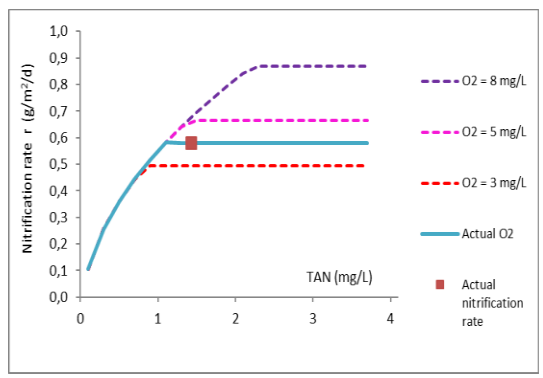
The protein in fish and in feed contains 16% nitrogen. The tilapia feed has, for example, a content of 38% protein. This results in 380g x 16% = 61 g of nitrogen in the feed. Taking mass balance calculations into account, 19 gram will be stored in fish tissue, 6 gram will be released in the faecal fraction and 35 gram will be excreted into the water as ammonia though the gills.

Changing the protein content of the feed, the type of ingredients and the protein digestibility might cause a shift within the mass balance figures and therefore not only affect fish growth but also the oxygen necessary for bioconversion and nitrification.

The nitrification reaction rate for the bacteria is often expressed as g/m^2/d, the m^2 being the indication of square meters available on the micro-carriers of a moving bed filter. The diffusion of TAN (total ammonia) and O_2 into a biofilm is a ½ order reaction or **√** **'**concentration'. The efficiency can be limited by the ammonia diffusion into the biofilm or by the oxygen diffusion into the biofilm. The nitrification rate of bacteria needs to be calculated in order to find the required biofilter size for the system. The efficiency of conversions can be described with the equation below.

A **moving bed filter** is filled with microcarriers with a specific surface of 700 m^2/m^3. The bio-elements used in the RAS system have a density of 0.9 – 0.95 kg/l and will thus float. The advantage is that in case of malfunction of the blower, the beads will float and not clog the filter.
The beads are kept in motion by a blower.

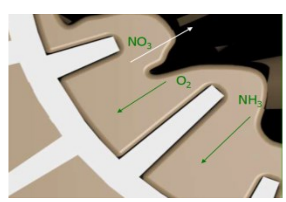
The bioreactor has been designed to incidentally convert an equivalent of maximum of 40 kg of feed per day. The calculated r, conversion efficiency, can be applied within a regular RAS farm set-up. Within the normal operational range (20°C-30°C), the effect of temperature on this conversion efficiency is small.

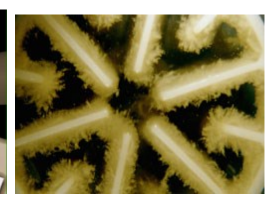


Nitrification rate is **r (g/m2/d) = a x √ (TAN) + b**

Two constant factors can be applied:
a = 0.65 and b = -0.1. With a C_{limit} = 1.5 mg/l and O_2 = 4.0 mg/l, the rate limiting factor is the substrate [O_2/TAN] > 3.6. See figure.

The nitrification rate can be calculated as follows:
r = 0.65 x **√**(C_{limit} /k) – 0.1
  = 0.65 x **√**(1.5/1.4) – 0.1 = **0.58 g/m^2/d**





In the tilapia farm 0.98 kg N (28 g/kg feed x 35 kg fish feed /day) gives 980 / 0.58 / 750 =

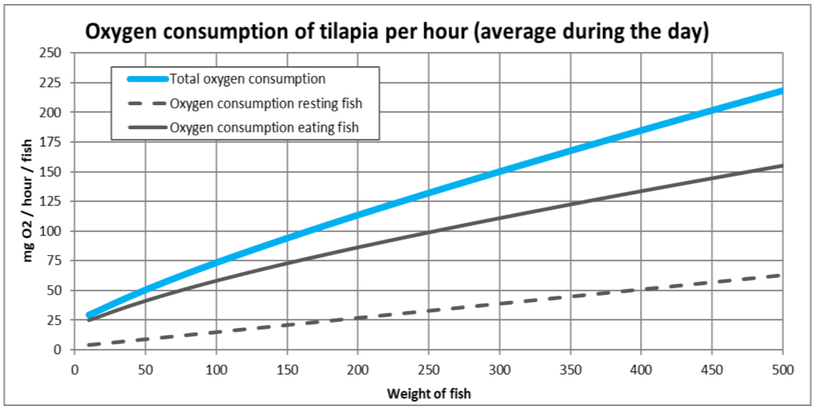
2.25 m^3 of filter material required.

The filling rate of a moving bed reactor is 60%, so a total reactor volume of **3.75 m^3.**

Flow = [P / ΔC] = 980/ 0.59 ~ 1661m^3/d ~69m^3/h ~ **47 m^3/kg feed.**

Oxygenation

The tilapia growth depends on the ambient diluted oxygen concentration. Above a concentration of 3,5 mg/l of diluted oxygen in the water, the fish has no oxygen limitations for its growth. The consumption of the individual fish, the number of fish and the aeration efficiency combined, will limit the stocking density of fish in the culture tank. A combination of high temperatures (reduced solubility of oxygen) with a high density of fish can result in a sudden drop in available oxygen and might cause growth retardation. The warmer the water, the less oxygen carrying capacity the recirculated water has.



Tilapia needs an increasing amount of oxygen per kg of bodyweight as they grow.
The blue line in the figure shows a four times (50 - 175 mg/fish/hour) higher demand for oxygen per hour per fish of 350 gram compared to 50 gram fish. Up to 25% of the total oxygen consumption level is needed as a maintenance level.

Figure: Oxygen consumption of tilapia

A tank aeration system is designed to supply the maximum total oxygen demand. In emergency situations the emergency oxygen system should at least be able to cover the highest maintenance levels.
The major part of the oxygen needed will be supplied by aeration (fine bubbles). More oxygen from the air bubbles will diffuse into the water if the concentration difference (C_{limit}-$C_{O2.actual}$) becomes bigger. The aeration efficiency should therefore be adjusted to the minimum oxygen level required for a good tilapia farming environment (3.5 mg/l O_2).

For the design of an aeration system, the number of fish, size, minimum oxygen level and water depth should be known in order to be able to calculate the amount of necessary air and water flow. Additional calculations on fine bubble diffusers (not detailed in this report) show that under these farming conditions and at **a water depth of 1.30m, at least 110 m^3 / hour / 60m^3 tank by 33 round plate fine bubble diffusers is required.**

The amount of air is determined by corrections of efficiencies for temperature, saturation levels, water quality, water depth, tank specifications and aerator characteristics. Standard oxygen transfer coefficient is converted into actual oxygen transfer efficiency (AOT) and results in 0.9 kg O_2/kW. With rounded figures a m^3 meter of air weighs around 1 kg and contains 21% of oxygen. Per 110 m^3 of air 23100 gram of oxygen is added of which 1600 gram will dilute into the water. Thus 7% of the oxygen in the air will become available for the fish.

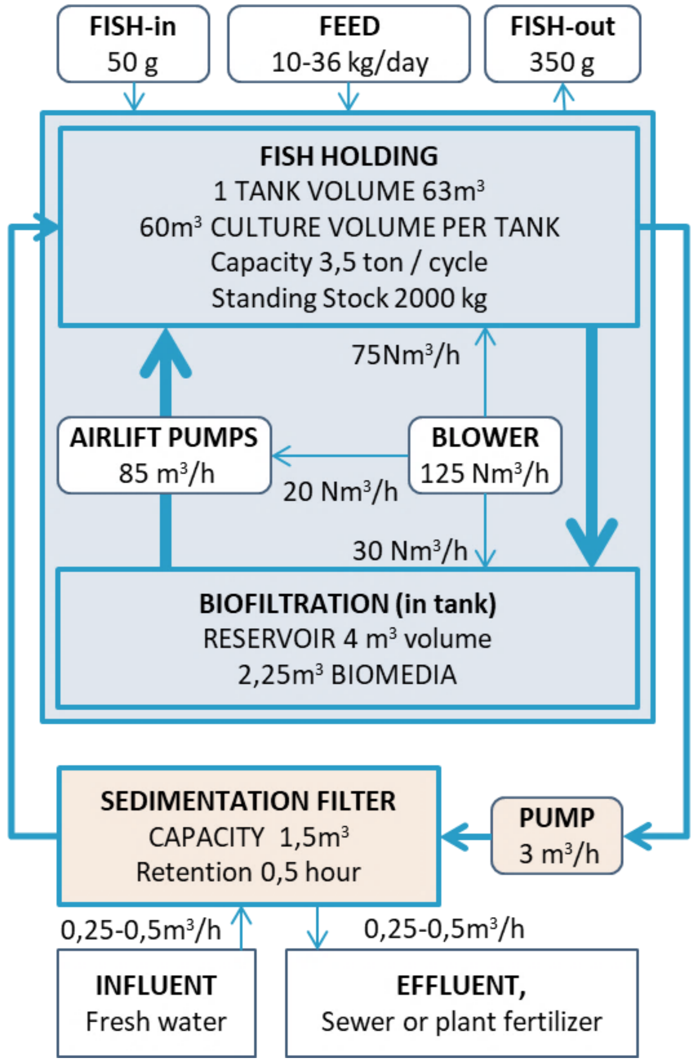
The total farm needs to be equipped with a blower with frequency converter and capacity of 125 m^3/h x 8 tanks = 1000 m^3/h at 180 mbar.

The biological-technical design has been calculated based on the characteristics of fish production, waste production, technical requirements on water flows, biological filtration capacity, oxygen requirement and carbon dioxide production/removal.

This bio-technical detailing, optimizing and combining the outcome of several integrated models, has been done by the team members using their software and design experience.

This report provides the outcome of these studies. The following preliminary design has been defined by the team members for the lay-out and basic set-up of the farm.

Figure: Flow schedule PID

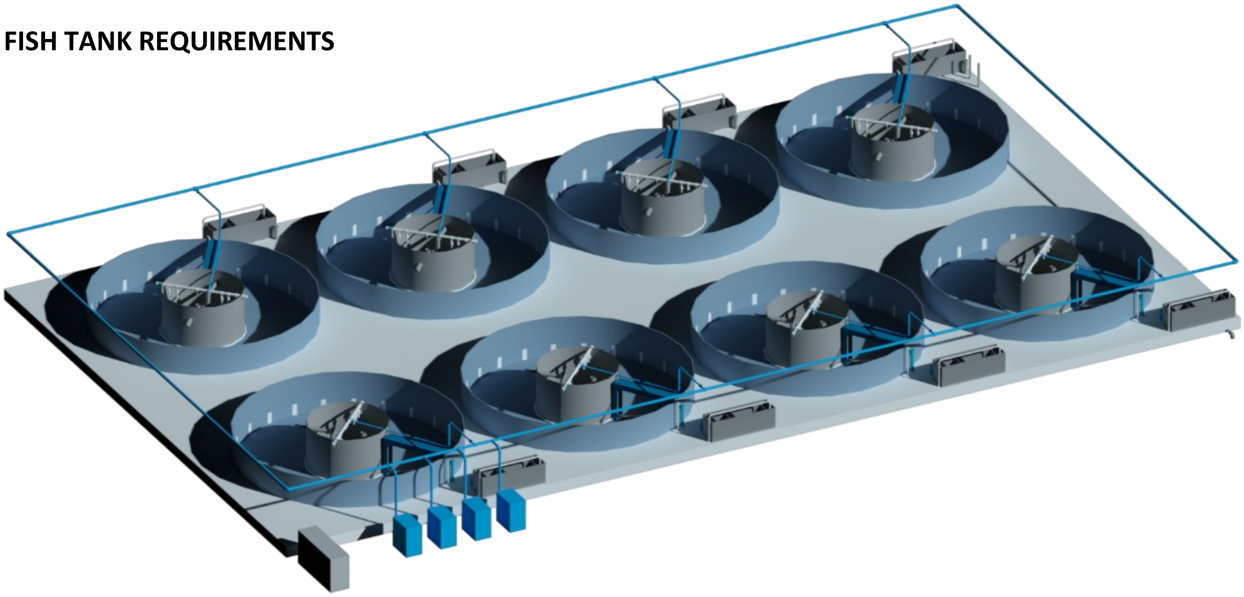


	FUNCTIONAL REQUIREMENT		Design choice for units
1	Fish holding tank	effective 60 m³	Plastered concrete or corrugated steel liner tank
2	Oxygenation capacity	add 1.6 kg/h	Aeration by air bubbles roots blower (in total 1000m³/h)
3	Recirculation water flow	> 80 m³/h	Airlift pumps to create circular flow
4	Degassing	30-40 kg CO_2/day	Aeration by air bubbles
5	Water supply	0.25 – 0.75 m³/h	Borehole water ambient 20ºC (in total 2 – 8 m³/h)
6	Biological water treatment	reactor 4 m³	Moving bed bioreactor (750-800 m²/m³)
7	Waste water treatment	2-3 m³/h	Packed up-flow sedimentation
8	Energy supply	24h / 24h	3 phases, capacity 8.5 – 12.5 kWh for RAS systems
9	Superstructure:	Visual check on water surface High humidity, non-corrosive Access for feeding and handling fish	Cover building, avoiding direct sunlight

3.3.3 Technical layout and infrastructure

In the primary design, terms of reference will be prepared for the major farm topics and for the infrastructure on the farm site. During detailing, these terms of reference can be used to structure the overall project or can be used for quotations or builders specifications.

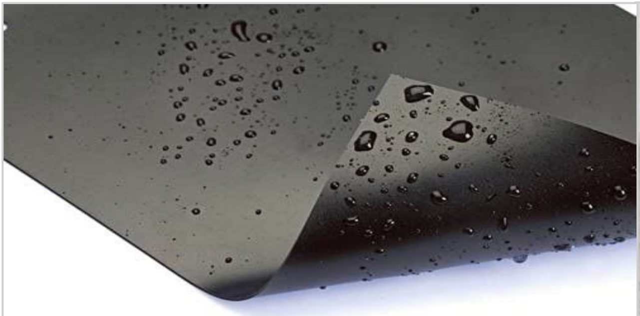
FISH TANK REQUIREMENTS



Tank Diameter 8.00m x depth 1.60m. Ground level -0.40m.
Corrugated steel with aqualiner or poured reinforced concrete blocks or stones with smooth waterproof plaster.

Foundation Load walls and water level 1500kg/m^2.
Smooth concrete foundation of 200mm or stabilised gravel bed.

Liner Smooth plastered concrete or HDPE liner or PVC liner, drinking water quality.
Protective cloth, bottom felt.




Bioreactor HDPE central cylinder 2800mm with perforated plates.
Aeration bottom plate. Coarse bubble aeration disks, Jaeger, EPDM 250mm.
HDPE Hx bio-elements 750 m^2/m^3.
PVC air manifold and pipes with PVC valves.
Airlift pumps, static, powered by compressed air.

Solid removal Sludge collection pipe with outlet box with screen and level control.
Packed bed, up-flow sedimentation filter multi bay system (3 phases).
Submerged waste water pump, motor type 0.30 kWh, for sedimentation unit.

Blower Roots blower, total 1000 Nm^3/h at 200mbar, 4x motor type 2.2 kW.
Shaft power 2.10 kWh per tank, 3 phase.
Sound protection cover.
Stainless steel air manifold for air distribution on 10m/s, rubber coupling.

Switchboard Main power supply 3 phase grid and control.
Frequency converters and soft starters for roots blowers.
Emergency stop near blowers and control.

Emergency Diesel generator 15-20 kWh.
Pressure reducer and diffuser pipe for oxygen bottles i.e. 50l x 6 pcs.

	Terms of reference: Control	Status
1	Alarm system (sound, analogue phone dialling, digital phone dialling)	Power failure signalling
2	Night watch, emergency service contracts	24 hour service
3	Light, gradual intensity	Day-night illumination
4	Electricity, automatic switch for net or generated power	24 hour available
5	Test routines and maintenance services for emergency equipment	Day/week/month schedules
6	Checks in the farm:	
	pH, oxygen level, ammonia, nitrite, nitrate, alkalinity, CO_2, temperature water	Water quality control
	Water level, pressure, power, thermal relay, temperature air	Technical control

SUPER STRUCTURE REQUIREMENTS

One of the key issues affecting aquaculture system productivity is the maintenance of a constant environment. Most important is water quality, but controlling the environment surrounding the aquaculture equipment is also important. There are a number of reasons for this, the most obvious being the control of temperature. Other reasons are protection of assets from physical damage by the environment (storms, wind, rain, sun etc.), theft, working conditions etc. There is a range of "housings" for aquaculture operations but the choice will differ between species, sites and budgetary constraints.

The intensive production tanks cannot stand in the open air, They need to be covered, taking the following functionalities into account:

1) protection of the equipment from water, wind and UV light
2) reduction of evaporation and heat loss
3) protection from the sun to eliminate algae growth
4) protection from birds
5) create day-night light regime with a light bulb in order to be able to feed 16 hours per day

	FUNCTIONAL MATERIAL REQUIREMENTS	Status
1	Water proof, non-corrosive, non-rotting	Non-corrosive material
2	UV stable at equator conditions	Expected lifetime 5 -10 year
3	Known technical specifications and UV stability	No experimental materials
4	Non-transparent or adjustable	Block sunlight 70-90%
5	Light weight	Less supporting steel required
6	Low cost building per m^2	Range 25-40 €/m^2
7	Non-toxic	No use of toxic paints or coatings
8	Hygienic	Easy to clean and maintain
9	Exchangeable cover, shade net or canvas	Applicable if needed due to lifetime or damage

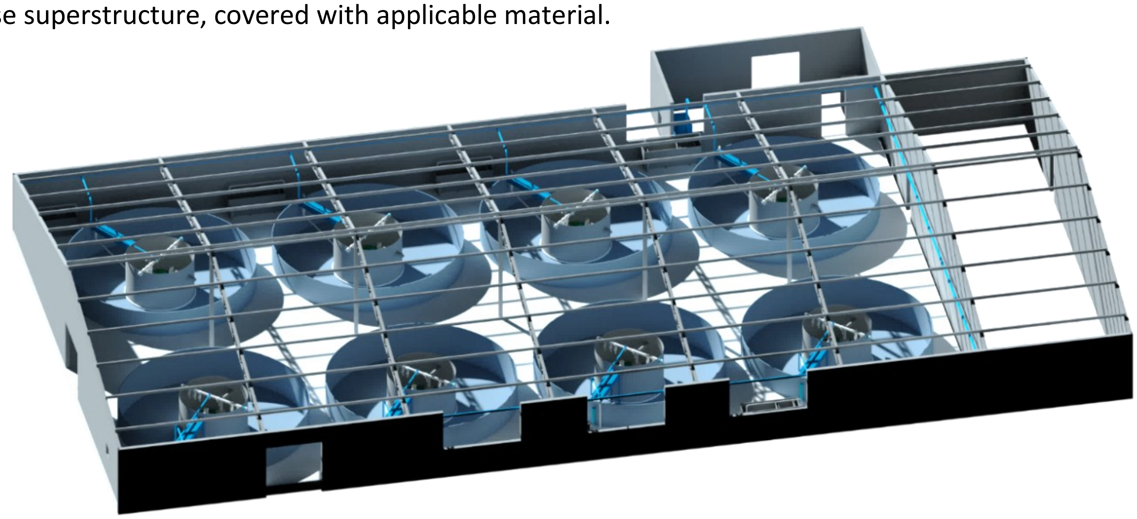
In order to minimise the costs for the tank cover, the surface area of the structure should be minimised. The support for the cover is attached to the construction fundament.

In order to have access to the bioreactor and control valves, a walkway is placed from the side of the tank to the side of the bioreactor. The walkway can be made from aluminium, as it is light and non-corrosive.

Foundation Tank area 36m x 21m, plus 4m x 8 technical room, plus 4m x 21m facilities.

Smooth concrete foundation of 250mm or compacted/stabilized soil.
Base level -500mm initial floor (level on which the tanks are installed).
Work level 0mm (elevation around the tank of 0.4m filling and 0.1m concrete).

For farm situations where more systems are combined, the tank cover can be constructed as a shelter house superstructure, covered with applicable material.



Structure Span of 21m (or double span of 10.5m), roof slope 20º height wall 3 meter.
Hot dip galvanized steel framework of powder coated steel.


Roof Coated corrugated (inside and outside) steel, or PVC liner cover 500-650g/m^2, sealed, hemmed on sides, treated anti-UV, or corrugated fiberglass panels, or U-PVC panels.


Side walls Side walls are made of non-transparent panels to fill in the required heights.
Side entrances with hygiene measures.

High temperature and humidity limit the choice of materials to be used in the superstructure. General requirements are listed below. Based on this list a range of materials is selected which could be applied.

	Terms of reference: General	Status
1	Walls and ceiling need to be resistant to high humidity	HR 99% year round
2	Steel construction needs to be resistant to high humidity	HR 99% year round
3	All windows double glazing and plastic frames	No wood
4	Main entrance door, overhead sliding door	4000 mm width
5	Doors in storage rooms / compartments	2500 mm width
6	Walking doors	1000 mm width
7	Plan: Feed storage	wall height 3m floor 25m^2
8	Plan: Chemical storage	wall height 3m floor 10m^2
9	Plan: Technical room	wall height 3m floor 15m^2
10	Plan: Office with kitchen facility	size 30m^2
11	Plan: Toilet area with shower and dress rooms	size 30m^2
12	Farm floors: concrete with slip proof structure	waterproof, slip proof
13	Farm floors: slopes towards drain or waste water gutters	slopes of 1-2 cm/m
14	Office and toilet area floor: tiles or other type of hygienic flooring & walls	tiles hygienic flooring & walls
15	Area around the farm needs to be fenced, no free entrance	full fenced area
16	Around farm building: 1m width gravel or path with bricks	1m width pavement
17	Control program for rats and other pests indoor and outdoor	pest control program
18	General static load of floor 3000 kg/m^2	3000 kg/m^2

The whole technical installation can come into contact with water with the following quality characteristics:

Medium: aquaculture water	Unit	Operational minimum	Operational maximum	Design criteria minimum	Design criteria maximum
Humidity (air)	% rel.	70%	95%	50%	100%
Temperature	ºC	15	35	10	40
pH	-	5	8	3	12
O2 saturation	% sat	20%	200%	0%	100%
NH_4 diluted	mg/l	2	150	0	200
NO_3 diluted	mg/l	200	1200	0	1500

Feed Storage – The feed needs to be stored properly to maximize its quality. Badly stored feed will quickly reduce in nutritional value and will lead to wastage. It may also affect the taste of the fish or cause disease to the fish.

Important points to consider when storing aquafeed:

- Dark and cool storage.
- Rodent-proof storage.
- Stacking in maximal 10 layers of bags.
- Gap left between wall and stack.

	Terms of reference: Feed	Status
1	Ventilated storage room for fish feed and dry goods	25m^2

2	Off the ground pallets with feed bags: # 1m x 1.2m	12# with free area
3	Feed in stock for 8 weeks (75 tons feed annual)	12 tons
4	Feed type 2 mm 2% of volume	0,3 ton
5	Feed type 3 mm 8% of volume	1 ton
6	Feed type 4 mm 90% of volume	11 ton

The building should be big enough to store the required amount of feed over a certain period of time with enough space for personnel to load, unload and move feed. If stacking bags of feed is done professionally, shelf life of the feed will be as long as possible. Feed should be neatly stacked, easy to count, and with a gap between feed piles. A gap between the wall and the stack will allow air to circulate. If the stack is close to the wall, bag contents may rise in temperature and micro-toxins like aflatoxin could build up, which would spoil the feed. Stacks should also be placed on pallets, raising the stacks off the ground.

The building needs to be cool and dark (avoiding direct sunlight and rain). Upon construction, it is important to ensure that there is ventilation through holes in the highest parts of the building wall. Furthermore, the building should be rodent-proof, either by the building being sealed, by regular traps or by installing rodent poison.

3.4 Environmental and social requirements

3.4.1 Environmental impact and social considerations

Location – The design will be made to fit the Jamaican temperature zones. Because of the influence of the sea the outside temperatures are high and relatively stable, which is favourable for fish farming. In this case the technical and environmental data for Kingston should be applied.

On a farm site a lot of infrastructure might already be available. It is important that the existing infrastructure is checked. For a good farm location the following points of attention and site checks should be made:

	LOCATION / SURROUNDINGS	Status
1	Existing agricultural building	Needs to be assessed on functionality
2	Existing manager / night watch house	Available within 15 min. range?
3	Existing analogue and digital communication	Necessary for alarm and monitoring
4	Lockable building and grounds	Lockable front, behind fences
5	Ability to control access of suppliers / visitors	Can entrance be watched?
6	Ability to access for freight (feed, fish, equipment)	Open area with access road?
7	Availability of electricity	Present? Check capacity
8	Availability of borehole water	Investigate? Quality? To be checked
9	Connection to sewage systems	Municipal sewer? Check capacity
10	Possibilities to store or drain wastewater fish farm	Water storage? Fields available?
11	Availability of refrigerated storage for destruction	Presence? Check on site
12	Availability feed and chemicals storage	Presence?
13	Possibility of disturbances by noise or vibration	More sources in area; check
14	Possibility of gasses or odours/smells	More sources in area; check
15	Possibility of rats and pests (located near water)	Need for pest control
16	Possibility of unintended guests	Is the building site closed?
17	Possibility of water inconvenience (level, rain)	Unknown; check local

Farmer – The resilient farm, an RAS system, can be operated by two trained people. At busy moments such as harvest times, more people are involved. The farm needs to be guarded 24h/24h. One system only requires 4-8 hours of maintenance, control and feeding per day, but a fish farm needs fulltime surveillance, 24 hours, 7 days a week. Preferably this is covered by technical staff, who can solve technical problems on the spot or react immediately to alarms. Generally speaking, a farm manager lives on site, with a maximum travelling distance of 15 minutes.
The farmer and the nightguard need to be trained for the daily work, for the maintenance tasks and for emergency situations.

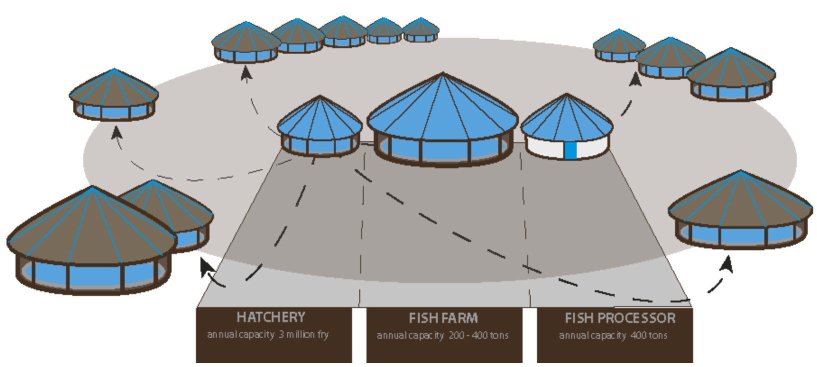
	Terms of reference: Staff	Status
1	1 Highly skilled worker - site manager responsible for operation (often owner)	1 Farmer / owner
2	1 Skilled worker in fields of aquaculture, biology or intensive animal husbandry - daily routines and technical works, 24h coverage	1 BSc aquaculture
3	2 or 3 unskilled workers - site operation	3 Staff members
4	1 Electrical engineer in support team	On request
5	1 Engineer / aquaculture professional in support team; 1 MSc aquaculture	On request
6	1 Veterinarian in support team	On request

Community – The farmers using the Resilient Fish farm concept could set up networks of innovative fish farms for rural communities with limited resources and basic infrastructure. A social network model would enable the rapid construction of a network of small community fish farms around one central aquaculture facility. This business model is based on a community of fish farmers operating in a cooperative environment with centralized management support and production coordination.
The central facility consists of a hatchery, fish farm and a processing facility. The central farm creates enough critical mass to support a full scale hatchery and a full scale processing facility. Besides their own production capacity they are able to not only supply local, small satellite farms (e.g. capacity of 1 single tank 6000-7000kg per annum) with goods and service but also to serve as a production and sales network. Also a complete farm could be subdivided in 8 parts. Every tank could have a separate owner (small farmer) who will invest 3,500,000 in his tank and sharing the general facilities (rented or co-invested).

The central farm is the regional support centre for the satellite farms, providing them with:

- high quality 'fingerlings'
- high quality fish feed
- production monitoring and quality control
- service and technical assistance
- market access as large supplier
- training and support for new farmers

The satellite farms should be located nearby a central farm in order to minimise transport distances and service time. Through this business model the community of satellite fish farms can rely on a supportive network of professionals which support the owners of the intensive aquaculture farming systems.



The intensive farming of fish – particularly tilapia – enables the communities to develop businesses to grow and sell a valuable fresh product and excellent protein source locally.

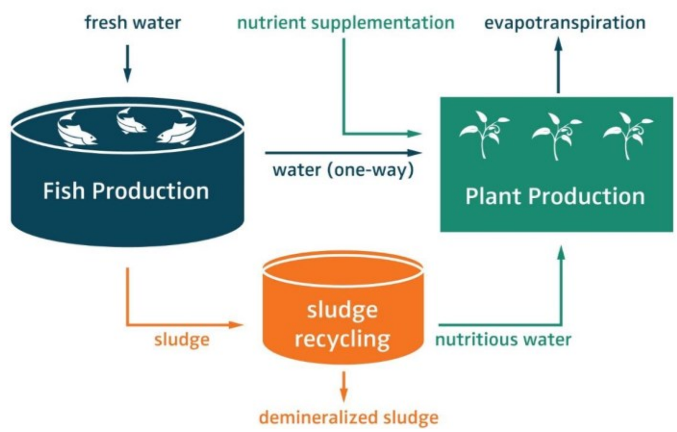
Waste – The environmental impact of fish farming can be reduced by valorisation of the waste water, which contains a lot of nutrients. The big advantage of the RAS systems is that concentration of organic waste and nutrients in the effluent water is high and can therefore be applied in crop production. Permission might be necessary to use the local farm effluent water. The waste water contains valuable minerals for crop but cannot be used as drinking water for livestock such as goats or cows.

Extra horticulture production can generate a second revenue stream to the farmer. Generally speaking, 1 kg of fish feed in the farm can co-generate 1,3 kg of fresh vegetables. Several types of crops have already been cultured in combined fish/crop culture (aquaponics, hydroponics).

Water, nutrients, and energy are becoming more and more scarce, leading to insufficient food production. Hence, there is a need for sustainable food production methods. Aquaponics can play a vital role in addressing the issue of sustainable food production. Aquaponics is a combination of recirculating aquaculture system (RAS) and a hydroponic system (HPS), in which plants are grown without soil.
By combining aquaculture with hydroponics, the waste of the RAS can be used as a nutrient source for the hydroponic system (HPS), thus reducing the need for adding nutrients from an external source.

Plants assimilate nutrients from the water, lowering nutrient concentrations, and therefore ensuring proper water quality for the fish.

A disadvantage of a conventional aquaponic system is that water characteristics in the fish and plant compartment are not identical. Therefore, optimal conditions can only be achieved if optimal conditions for fish and plants are identical, which is rarely the case.



A different approach is a decoupled aquaponic system (DAPS), in which water is not circulating between the RAS and HPS, but only flows from the RAS to the HPS. The RAS is subsequently topped off with fresh water.

In combination with a RAS system the multi-loop combination offers a lot of advantages:

- Optimal conditions for both fish and plant production
- Remineralization of fish faeces in anaerobic reactors, creation of biofertilizer
- Main water loss only via plant evaporation
- Water saving
- Nutrient saving or saving on fertilizer

3.4.2 Design criteria for water, electricity and financial

Water – In order to sustain the overall water quality of the fish environment, the facility requires access to sufficient volumes of high quality (i.e. potable) water with continuous availability. As the water in a recirculation system (RAS) is used for a long time, the farming process demands a high water quality input.

Three sources of water are suggested:

1) Boreholes accessing the local groundwater
2) Municipal water (if unchlorinated)
3) Surface water (after it has been treated to drinking water quality)

For the fish farm, water quality should be in line with regulations for drinking water for animal husbandry. The quality of borehole water must be well documented and evaluated before it is used in the fish farm. The capacity of the borehole and its availability the fish farm should be the same throughout the year. It is advised to have a spare borehole and not to use the borehole for other purposes. Preferably a water storage is installed. In some cases water needs to be aerated in order to remove diluted gasses before it is used.

The water consumption of the system should be in line with the fish production. This can be expressed as water consumption per kg of fish feed. The design should be in the range of 250-750 l/kg fish feed. The production facility operated in the assumed manner would result in water consumption of around 500 litre to produce a kg of fish. This is typical for an RAS farm of tilapia.

	Terms of reference: Water	
1	Borehole water approved as drinking quality for animal husbandry	Quality check
2	Capacity water minimal 10 m^3/h at 24h/24h	10 m^3/h at 24h/24h
3	Preferably spare capacity	Extra borehole and pump
4	Storage warm water 25m^3 of 25^oC or similar thermal capacity	Fast replacement
5	Drinking water connection for food processing	Connect to the facility
6	High pressure water cleaning for farm hygiene	Available on site

Electricity – The modular fish farm will consume and rely on 24h/24h electric power supply. Pumps and blowers should run continuously to create waterflow and oxygenation. The farm system design should entail minimum electricity use in order to prevent excessive electricity costs. In order to secure the provision of power to the system, a backup generator with fuel is required.

The electricity security measures consist of a backup generator on the main blower and a bottle of pure oxygen on site. A backup generator must be able to at least supply 50% of the installed blower capacity.

	Terms of reference: Electricity	Status
1	Available 3 phase and 0 – earth wire	3 x 380V
2	Continuous demand 24h/24h	11 kWh
3	Backup generator	25 kWh
4	Connection to main power grid	Direct connected
5	Individual groups for farm	Minimal 8 groups
6	All wires placed in galvanised or plastic cable gutter or support rack	Secured wiring
7	Indoor: Water proof light fixtures	Water proof light fixtures
8	Outdoor: Water proof light fixtures around the building	Water proof light fixtures
9	Lightning protection of building and electric circuit	Separate earth wire

The power consumption has the following characteristics:

		ITEM	Installed kWh	Units	Total installed	kWh per unit	Running time	Consumption
1	Growout	Roots blowers	2.2	4	8.8	2.1	100%	8.4
		Submersible pump	0.3	8	2.4	0.24	80%	1.9
2	Water supply	Borehole pump	5.5	1	5.5	4.4	25%	1.1
		Discharge pump	3.0	1	3.0	3.0	5%	0.2
3	Other	Light bulbs	0.05	10	0.5	0.05	70%	0.4
			TOTAL KWH INSTALLED		20.2	TOTAL KWH CONSUMPTION		12

4 PART IV D-5.4 MANAGEMENT AND OPERATIONAL PLAN FOR CLIMATE SMART FACILITY

4.1 Management plan for climate smart facility

The culture of Tilapia in RAS systems is technically advanced work. Beside having knowledge of fish culture, the operator should understand the complex interaction between technology and biology.

The daily operational management of the farm should be in the hands of an aquaculture technician, in close combination with a farm assistant and 2-3 skilled staff members. Basic computer, technical and mechanical skills should be included in the job descriptions. On request the farmer needs to be assisted by an electro technician and a veterinarian. The farmer should establish network connections with cooperative organisations, universities or governmental institutions for knowledge transfer, development and support.

During the workday the farm will be staffed by 2 persons. During the night 2 nightguards will cover a 16 h shift. The fish farm will be a fenced enclosure. Biosecurity measures to prevent disease transfer is of high importance.

Regular daily work:	Checking fish behaviour Feeding Registering and removing dead fish Checking water quality Securing water levels, fuel levels, oxygen bottles
Regular weekly / monthly work:	Harvesting and stocking Data management, feeding schedules and stock calculations Cleaning sedimentation Calibration, inspection and maintenance of equipment Cleaning facility and hygiene equipment Testing generator and testing alarm Inventory management (feed, parts, consumables)

The farmer, the operational manager and the staff members should all be trained on these specific fields of intensive aquaculture (practical farm management, farming technology, operational management).

Biosecurity on the farm is very important. The measures described in the Hatchery plan are also applicable to the climate resilient farm.

4.1.1 Goals, capacity- and production plan

The production of the resilient fish farm can be estimated at 50 tons red tilapia or 72 tons silver tilapia. This large difference is caused by the variation in growth rates of the genetic strains, as described in chapter 3.1.1. The gross production or harvest / sales volume is higher, respectively 58 tons and 86 tons, because of the correction regarding the weight of the initial stockings. The production plan is based on the net production volume.

The table below includes, for the purpose of overview, also the pre-growth period of 12 weeks in which the fish grow from 2 to 50 grams. This can be realised in 3 extra tanks of around 21 m^3 each. The same RAS technology can be applied.

	Production plan	Pre grow-out Red Tilapia	Grow-out Red Tilapia	Pre grow-out Silver Tilapia	Grow-out Silver Tilapia
1	Tanks [number]	3	8	3	8
2	Volume per tank [m^3]	21	63	21	63
3	Initial weight [gram]	**2**	**50**	**2**	**50**
4	Harvest weight [gram]	**50**	**350**	**50**	**350**
5	Growth period [weeks]	12	22	8	15
6	Input [kg / year]	400	8500	600	12500
7	Production [kg / year]	8100	50150	11900	73500
8	Harvest [kg / year]	**8500**	**58650**	**12500**	**86000**
9	Productivity [kg / m^3]	128	117	189	147
10	Max. density [kg / m^3]	20	60	22	60
11	Feed conversion [kg / kg]	1.2	1.4	1.2	1.4
12	Feed per year [kg]	9720	70210	8100	102900
13	Feed per day [kg / d / tank]	8 avg. 14 max	24 avg. 40 max	13 avg. 20 max	35 avg. 56 max

Production capacity of the single tank is related to the size of fish harvested. Smaller fish can be harvested more often, can be stocked in higher numbers and can therefore result in higher annual production capacity. If the fish needs to be grown to a larger size, the stocking number needs to be reduced accordingly in order to reach a maximum density of 50 kg/m^3.

The table below shows different harvest rates for fish stocked at 50 grams:

Harvesting weight tank (max 50 kg/m^3)	Stocking number	Growth time weeks	Cycles per year	Annual harvest kg per tank
250	10000	12	4.3	10800
300	8400	14	3.7	9300
350	7200	16	3.3	8100
400	**6400**	**18**	**2.9**	**7300**
450	**5600**	**20**	**2.6**	**6500**
500	5000	22	2.4	5900
550	4600	24	2.2	5400
600	4200	25	2.1	5200

4.1.2 Production management

Stocking - The stocking ratio is 9250 male fingerlings of red Oreochromis hybrid per tank of 63m^3. During the growth period of 22-24 weeks a natural mortality occurs. In this stocking plan the tanks are stocked slightly higher in numbers in order to maintain the forecasted harvest volumes (9000 fishes and 3200-3500 kg per tank).

The production of fish should be aligned to a strictly maintained stocking plan. Minimising the variations will maximise the production. For the resilient fish farm the table below gives guidance with regard to time to grow, stocking densities, amount of daily feed, expected feed conversion and expected growth.

Table: Stocking plan for grow-out system of tilapia

	SYSTEM DIMENSIONS AND GROWTH PERFORMANCE TILAPIA							
	volume	63	m3/tank	tanks	1	#		
Time weeks	weight gram/fish	density kg/m3	stock kg/tank	stocking #/tank	feedload gram/fish	feedload kg/day/tank	FC	production kg /day
0	51	8	471	9.250	0,9	8	1,04	8
1	59	9	543	9.226	1,0	9	1,07	8
2	68	10	621	9.205	1,1	10	1,09	9
3	77	11	705	9.185	1,2	11	1,11	10
4	87	13	794	9.168	1,3	12	1,13	11
5	97	14	888	9.152	1,4	13	1,15	11
6	108	16	988	9.137	1,5	14	1,17	12
7	120	17	1092	9.124	1,7	15	1,18	13
8	132	19	1202	9.111	1,8	16	1,20	13
9	145	21	1317	9.100	1,9	17	1,22	14
10	158	23	1436	9.089	2,0	18	1,24	15
11	172	25	1561	9.079	2,2	20	1,25	16
12	186	27	1689	9.070	2,3	21	1,27	17
13	201	29	1823	9.061	2,4	22	1,28	17
14	216	31	1960	9.053	2,6	23	1,29	18
15	232	34	2101	9.045	2,7	24	1,31	18
16	249	36	2246	9.037	2,8	26	1,32	20
17	265	38	2395	9.030	3,0	27	1,34	20
18	282	41	2548	9.024	3,1	28	1,35	21
19	300	43	2704	9.017	3,3	29	1,36	21
20	318	46	2863	9.011	3,4	31	1,37	23
21	336	48	3026	9.005	3,5	32	1,38	23
22	355	51	3191	9.000	3,7	33	1,39	24
23	373	54	3359	8.995	3,8	34	1,41	24
24	393	56	3529	8.989	4,0	36	1,42	25
AVG		34	2096	9.056	2,6	24	1,3	17

Feeding - In order to avoid over- or underfeeding the fish, the right amount of feed must be calculated. The amount of feed that the fish need per day and the feeding rate (ration), is dependent on the fish's body weight. Fish adjust their food consumption to their metabolic energy requirement, so the amount of

feed to be given changes with time. The amount of feed required per ration can be estimated with the help of a feeding table or calculation spreadsheet and can be calculated as follows:
Daily feed amount = average fish size (weight) x feed rate (%) x total number of fish in the tank.

Feeding can be done by hand or with feeders with a timer. The best technical results can be obtained by spreading the feed because this gives the fish equal opportunity to eat. In a RAS system with illumination the daylength and feeding period can be artificially extended to 16 hours in order to increase productivity.

Harvest / Yield – The fish will be cultured in batches. In order to prevent disturbance in the farm, each batch will be harvested in one time. No market size fish will be held back in the facility because this may disturb the production planning. On average, a harvest will take place every 3 weeks. The amount of harvested fish will be 3150 kg (350 grams x 9000 pieces). Harvesting will be done by grouping and netting. After lowering the water level a seine net can be used to group the fish. To secure freshness and to secure a humane slaughtering, the fish will be loaded in tubs with melting ice water. These tubs can be transported to the processing area or loaded onto a truck for further processing. Live fish trade is possible but should happen outside the facility and with gear which will not be used indoors. Stocking young fish will follow the same 3 weeks interval.

4.1.3 Input and output quantities and costs

Fish - The farm design will be based on the initial weight of juvenile fish of 25 - 50 grams which can grow to market weight (350 grams for tilapia). These fish can be obtained either locally, from a pre-growout unit operating with a commercial strain of the tilapia niloticus, or from commercial (private or state-owned) hatcheries. The price of juveniles to stock the resilient farm is based on theoretical pricing, estimated at JMD 40 per piece of 50 grams or JMD 800 per kg.

Feed - The planned fish stocks in combination with a regular feed conversion of the red tilapia show that the production level and the design can be based on the average amount of 24 kg pf fish feed / day / tank, with a maximum of 40 kg of fish feed per day per tank. The daily feed capacity will be determined by the fish density and the daily feed consumption (the amount that the fish eat at a certain age).

The quality of the applied feed should be in line with industry standards for extruded floating pallets, which can be imported. The farm should use the tilapia feed line with a 32-38% protein level or similar imported feeds. In a RAS system the amount of waste relates directly to oxygen consumption, water usage and water quality. With low quality feed the systems will carry too much organic load.

STAGE	TILAPIA DIETS	Crude Protein (Min %)	Crude Fat (Min %)	Crude Fiber (Max %)	Moisture (Max %)	Ash (Max %)	Phosphorus (Min %)	Floating	Slow-Sinking	Sinking	SIZES (MM)
Starter	Finfish Starter w/ Vpak	55	15	1	12	12	1.8		•		Meal, #1 & #2 Crumbles
Fingerling	Finfish Starter w/ Vpak	50	15	1.5	12	12	1.8		•		1.5, 2
	Finfish Hi-Performance	45	16	1.3	12	10	1.4	•			1.5, 2, 2.5
Grow Out	Tilapia 40-10	40	10	3	12	6	1	•			3, 5
	Tilapia 36-6	36	6	4	12	7	1	•			3, 5
	Tilapia 32-3	32	3	4	12	9	1	•			3, 5
Broodstock	Tilapia 36-6 Broodstock	36	6	4	12	5	1	•			6.5

The feed prices for the on-growing feed types may vary due to feed composition, feed size and the production process. Prices for Zeigler starter feed ranged from USD 2.81 – 1.55 / kg in July 2020. The on-grower feed ranged from USD 0.69 - 0.83 / kg in this moment. This does not include sea transport (USD 0.13 / kg) and import costs.

4.2 Operational / Technical plan for climate smart facility

On several points the intensive aquaculture may outperform regular open pond farming technology and also appears an attractive alternative taking climate changes into account.

4.2.1 Efficiencies and consumables

Footprint – The intensive aquaculture has a small footprint compared to the extensive pond farms. The price of land increases worldwide. In many countries aquaculture in an extensive way is no longer feasible anymore due to competition with industrial, housing or agricultural activities.
The stocking of one RAS tank of 50m^2 can be compared to the normal stocking of an acre (4000m^2) pond in Jamaica. In both cases about 8000 - 9000 fish are stocked and harvested.

In the resilient farm RAS design, the footprint to produce 1 kg of fish is 80x smaller than in an extensive pond farm.

Feed conversion – The farm can be more efficient by applying higher energy feed. In a capital-intensive farm a higher fish production level will lead to a lower cost price. In RAS fish farming the capacity is restricted to the amount of feed, due to the fixed amount of biological conversion capacity of the biofilter. Extra production can be generated by feeding higher energy diets. Under controlled conditions this can also be a smart choice, because although the price of feed may be higher, the feed cost per kg of fish may be lower, as illustrated in the table below. Selection of the optimal feed composition and feed conversion can result in 15-20% lower feed costs / kg of fish.

Feed type Protein – Fat level	Price of feed / kg USD	Feed conversion rate (expected)	Feed costs / kg of fish	Remarks
50-15	1.90	1.00	1.90	
45-16	1.68	1.10	1.85	
40-10	0.96	1.20	**1.15**	Lowest cost price point
36-6	0.87	1.40	1.22	
32-3	0.82	1.60	1.31	
28-4	0.75	1.80	1.,35	Actual pond practise

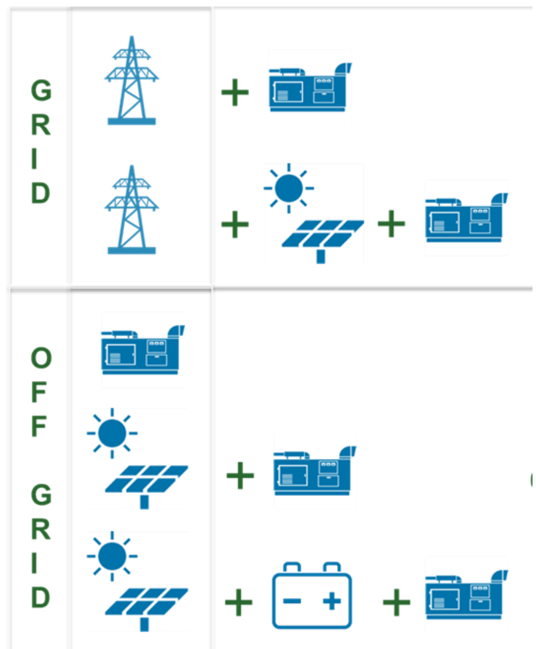
The amount of feed to produce 1 kg of fish can be 33% lower in the resilient farm RAS design.

Labour – The resilient farm will employ 3 staff members. The production per man-year of employment is high, about 15 tons of fish per man and year employed. In pond farming operations this seems to be around 10 tons per year.

4.2.2 Operational & technical measures on climate changes

Electricity – In ponds, paddlewheel aerators are often used to compensate for oxygen drops or to increase oxygen transfer, in order to be able to increase stocking densities. The specific aeration efficiency of paddlewheels is relatively low and thus the cost for adding oxygen to the water is high. In the RAS system bubble diffusers and Roots blowers are combined to generate a high oxygenation capacity with minimum use of electricity. The selected roots blower is more expensive than the centrifugal ring blowers but it will consume less energy.

The electricity consumption can partly (33% - daytime fraction) be generated by the use of PV panels to generate on-site electricity. The daily consumption rate is constant during the day and the night at a 12-15 kWh level.



Taking into consideration the actual electricity prices, solar application may be able to reduce the overall operational cost. The extra investment for the solar application would be USD 25-30000 for an output of 12kW capacity.

For emergency situations a generator will always be part of the technical installation and can be combined with grid power, solar power and if desirable, a battery storage.

Water – In a RAS system the water exchange is determined by the amount of nutrients accumulated in the water. These need to be flushed out, which is often done in a combination of cleaning the sedimentation and a small continuous water exchange. From the biological conversion nitrate will be the major end product and can be used to indicate the level of combined organic load and nutrients in the water.
Water exchange is needed to maintain a concentration below 500mg/l NO_3^-. This equals an exchange of 250 - 750 litre/kg of produced fish.

This can be compared with regular pond practises, where 20000 - 50000 litre /kg of fish produced.
The amount water to produce 1 kg of fish can be 97.5% - 99% lower in a resilient farm RAS design.

4.3 Business plan on the economics of the climate smart facility

Summary Fish Farming v15 v2

FISH FARM

Annual fish production	**51,195 kg**			
Annual sales volume	**59,727 kg**			
	JMD / kg		%	JMD
Annual fish turnover, sales value	**750**			**44,769,120**
Annual operating expenses	657			33,622,905
Net margin before tax revenu	**93**		**25%**	**11,146,214**
Net profit after tax and interest	27		17%	7,802,350
Production costs operation	JMD / kg	%		JMD
fingerlings	140	19%		7,190,609
feed	205	28%		10,508,249
electricity and water	100	14%		5,122,791
labour	84	12%		4,320,000
other	32	4%		1,644,311
Operatial cost price	**562**	**78%**		**28,785,960**
Financing costs operation				
depreciation	61	8%		3,109,333
interest short capital	4	0%		179,912
interest on long term capital	30	4%		1,547,700
Financing cost price	**94**	**13%**		**4,836,946**
Annual tax				
Corporate tax	**65**	**9%**		**3,343,864**
Cost price of production	**722**	**100%**		**3,109,333**

PROPERTY

Needs	JMD	%	
Building and infrastructure	13,720,000	27%	
Hatchery system	-	0%	
Growout system	27,552,000	54%	
Fixed assets	**41,272,000**		
Working capital	9,593,383	19%	
Financing needs	**50,865,383**	100%	

PROPERTY

Contribution	JMD	%	
Shareholders' equity	-	0%	
Loan capital, bank long term	20,636,000	41%	50%
Other funds	-	0%	
Equity privat capital, operation	30,229,383	59%	
Financial contribution	**50,865,383**		

4.3.1 Market, sales and forecasts

Technical and Financial assumptions Farming

ITEM	Units	Value
Tank size (approx. liters)	liter	63,000
Stocking weight (average)	g/fish	50
Harvesting weight (average)	g/fish	350
Survival rate	%	97.5
Number of fish stocked / tank	#	9231
Number of fish harvested/tank	#	9000
Number of tanks (or equavalent units with similar volume)	#	8
Production cycle	days	154
Production cycles/Year	#	2.4
Average rate of weight gain - g/day	g/day	1.9
Juvenile fish	JMD/fingerling	40
Live fish transport (monthly)	JMD/trip	10000
Tilapia start 1,5 mm, 2mm 50-15	292	5%
Tilapia hi 45-16 2,5	259	5%
Tilapia 40-10 3mm	148	70%
Tilapia 36-6 3mm	134	20%
Feed price average (price and volume ratio)	JMD/kg	158
Feed Conversion Ratio (FCR)	#	1.3
Annual feed consumption	kg	66,553
Water use	JMD/m3	5
Oxygen price (bottles)	JMD/kg	50
Oxygen rental	JMD/month	n/a
Labour	JMD/h	400
Labour	number	3
Electricity price	JMD/kWh	47
Electricity usage	kWh/h	12

ITEM	Units	Value
Estimated Fees & License	JMD/yr	150,000
Estimated Insurance (1% of price at 75% of yea	JMD/yr	335,768
Estimated property taxes (0,75%)	JMD/yr	59,400
Miscellaneous expense (% Tot. Revenue)	%	1
Interest on operating capital	%	7.5
Interest on long-term capital	%	7.5
Employee fringe benefits	%	20
Beginning working capital	JMD	9,593,383
Water use (liters/second)	m3/hour	3.8
Total kg of fish produced per year	kg	51,195
Total number of fish produced per year	#	170,649
Average harvesting weight	kg	0.35
Total sales weight	kg	**59,727**
Harvesting price (bases of sales)	JMD	**750**
Sales of fish	JMD	44,769,120
Other sales	JMD	-
Total Revenu	JMD	44,769,120
Average standing stock	kg	10,938
Grants on the hardware investment farm	%	0%
Foreign long-term capital (investment)	%	50%

4.3.2 Capital expenditures and operating expenses

Expenses and Cost price

ANNUAL EXPENSES:	Total cost	Fixed Cost	Variable cost	Per live kg	Percent total cost	Percent total Rev
Fingerlings	7,000,999		7,000,999	137	21%	16%
Live fish transport	189,610		189,610	4	1%	0%
Feed	10,508,249		10,508,249	205	31%	23%
Electricity	4,956,408	4,956,408		97	15%	11%
Water	166,383	166,383		3	0%	0%
Oxygen	-		-	0	0%	0%
Gas / Heat	-		-	0	0%	0%
Employee wages	2,160,000	2,160,000		42	6%	5%
Employee fringe	2,160,000	2,160,000		42	6%	5%
Fees & Licenses	150,000	150,000		3	0%	0%
Insurance	335,768	335,768		7	1%	1%
Property Taks	59,400	59,400		1	0%	0%
Miscellaneous expenses	895,382		895,382	17	3%	2%
Maintenance & Repairs	203,760	203,760		4	1%	0%
Depreciation	3,109,333	3,109,333		61	9%	7%
Interest on operational capital	179,912	179,912		4	1%	0%
Total Operating Expenses	**32,075,205**	**13,480,965**	**18,594,240**	**627**	**95%**	**72%**
Interest expenses long term capital	1,547,700	1,547,700		30	5%	3%
Total Expenses	**33,622,905**	**15,028,665**	**18,594,240**	**657**	**100%**	**75.1%**
Net profit before taks	11,146,214			187		**25%**
Taxes (corp rates %)	3,343,864			56		7%
Net profit after tax & interest	7,802,350			131		17%

Investment and Depreciation & Maintenance assumptions

Item Description	Initial investment	Est.Life (years)	Annual Depr (SL)	Repair and Maintenance	Salvage value 5 years
Hatchery building	-	20	-	-	-
Growout building	7,920,000	20	396,000	7,920	5,940,000
Facilities and storages	1,200,000	20	60,000	1,200	900,000
Grow-out tanks	-	20	-	-	-
Electric infrastructure	1,920,000	15	128,000	1,920	960,000
Generator	1,280,000	15	85,333	12,800	640,000
Water infrastructure	800,000	15	53,333	800	400,000
Climate control and heaters	600,000	15	40,000	18,000	300,000
Subtotal building and infrastructure	**13,720,000**		**762,667**	**42,640**	**9,140,000**
Mounting / installation and prof services grow out	3,200,000	10	320,000	-	160,000
Transport & import	4,400,000	10	440,000	-	220,000
Bassins growout	3,840,000	20	192,000	-	576,000
Water treatment growout	10,240,000	15	682,667	102,400	2,560,000
Aeration system growout	880,000	10	88,000	8,800	176,000
Control panel growout	1,248,000	10	124,800	12,480	187,200
Electric items growout	3,744,000	7.5	499,200	37,440	936,000
GROWOUT	**27,552,000**		**2,346,667**	**161,120**	**4,815,200**
Subtotal hatchery and grow-out	**27,552,000**		**2,346,667**	**161,120**	**4,815,200**
Funding /support grants	-	0%			
Total investment	**41,272,000**		**3,109,333**	**203,760**	**13,955,200**

4.3.3 Cashflow operation

Cash Flow Analysis for five year planning horizon

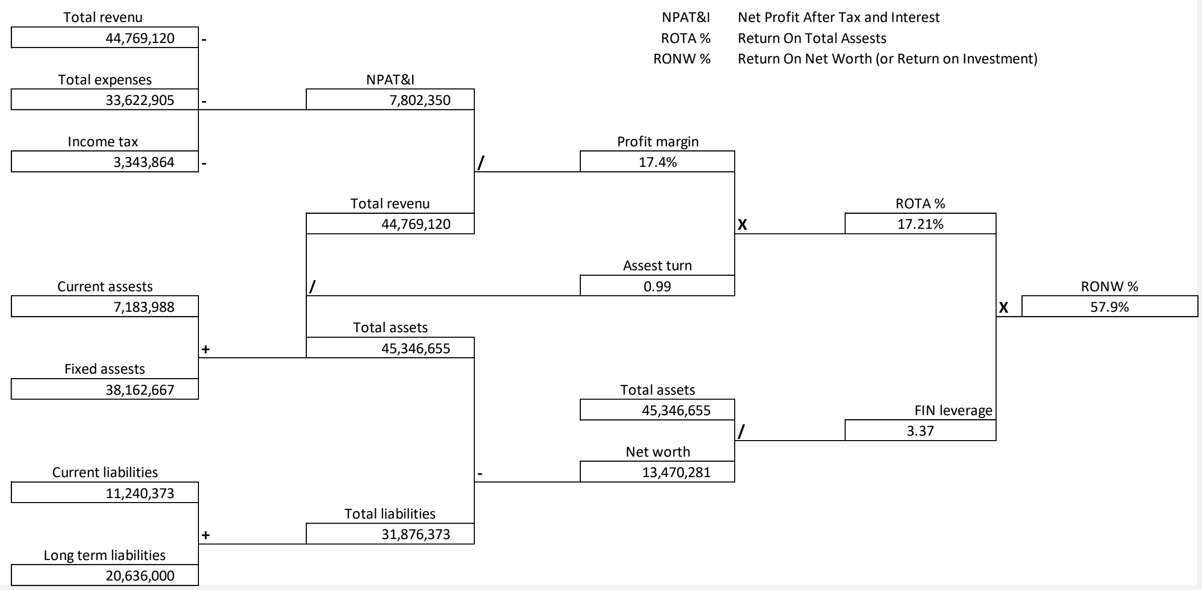
Item	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Output in terms of % of capacity	0%	80%	90%	100%	100%	100%
Product volume kg fish	0	47,782	53,755	59,727	59,727	59,727
Price JMD/fish ~ annual increase of 03%	750	750	768	788	807	827
Revenu fish	**0** +	**35,815,296**	**41,299,513**	**47,035,556**	**48,211,445**	**49,416,732**
Annual turnover		**35,815,296**	**41,299,513**	**47,035,556**	**48,211,445**	**49,416,732**
Fixed expenses		10,371,632	10,371,632	10,371,632	10,371,632	10,371,632
Variable expenses	+	14,875,392	16,734,816	18,594,240	18,594,240	18,594,240
Incremental cash expenses		**25,247,024**	**27,106,448**	**28,965,872**	**28,965,872**	**28,965,872**
Depreciation		3,109,333	3,109,333	3,109,333	3,109,333	3,109,333
Net before tax revenu		**7,458,938**	**11,083,732**	**14,960,351**	**16,136,240**	**17,341,526**
Est. income tax 30%	30%	2,237,682	3,325,119	4,488,105	4,840,872	5,202,458
After tax cash flow		**5,221,257**	**7,758,612**	**10,472,246**	**11,295,368**	**12,139,068**
Add back depreciation		3,109,333	3,109,333	3,109,333	3,109,333	3,109,333
Net operation cash flow		**8,330,590**	**10,867,945**	**13,581,579**	**14,404,701**	**15,248,402**
Initial investment	41,272,000					
Change in working capitat	9,593,383					
Estimated Salvage Value						13,955,200
Book value						25,725,333
Gain (loss)						11,770,133
Tax increase (decrease)						5,202,458
Net cash flow						19,157,658
Changing working capital						9,593,383
Terminal year non operating cash flow						**28,751,041**
NET CASH FLOW	**50,865,383**	**8,330,590**	**10,867,945**	**13,581,579**	**14,404,701**	**43,999,442**

Year one ending pro-forma balance sheet

ASSETS			**EQUITIES**		
Cash		-	Accrued expenses		-
Accounts receivable (8% of yearly turnover)		3,730,760	Accounts payable 16%		5,597,270
Inventory (15% of annual production)		7,183,988	Notes payable		5,643,103
Total current assets		**7,183,988**	Total current liabilities		**11,240,373**
Equipment	27,552,000		Long-term liabilities (% of invest.)	50%	20,636,000
Less DEPR	2,346,667	25,205,333			
Facilities	13,720,000		Total liabilities		**31,876,373**
Less DEPR	762,667	12,957,333			
Land		-			
Fixed assets		**38,162,667**	Net worth		**13,470,281**
Total assets		**45,346,655**	Total liabilities & net worth		**45,346,655**

Selected Ratios					
Net Profit %		24.9%	11,146,214	44,769,120	0.249
Return on total assets %		17.2%	7,802,350	45,346,655	0.172
Return on net worth % (ROI)	1.7	57.9%	7,802,350	13,470,281	0.579
Asset turnover		0.99	44,769,120	45,346,655	0.987
Leverage		3.37	45,346,655	13,470,281	3.366

Profitability Linkage model



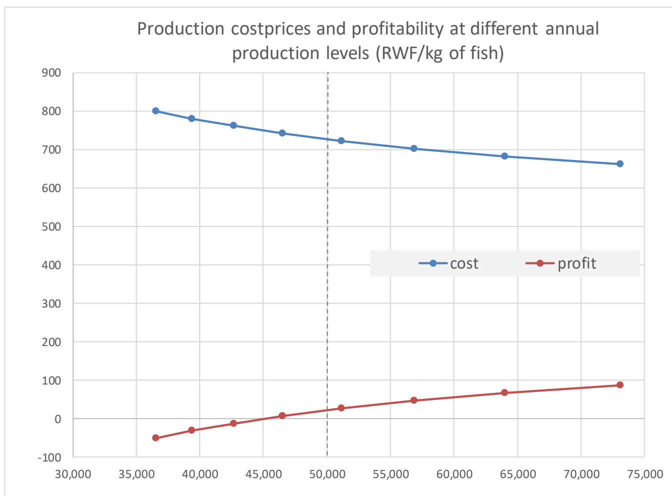
Scenario Fish Farming

Changes in feed prices

Feed price	Mutation	Total cost price	Net Profit
JMD /kg		JMD /kg	JMD /kg
111	-30%	679	71
126	-20%	693	56
142	-10%	708	42
158	**0%**	**722**	**27**
174	10%	737	13
189	20%	751	-1
205	30%	765	-16

Changes in production by slower / faster growth

Growth time	Mutation	Total cost price	Profit	production
days	%	JMD /kg	JMD /kg	kg/year
108	-30%	663	87	73,135
123	-20%	683	67	63,994
139	-10%	702	47	56,883
154	**0%**	**722**	**27**	**51,195**
169	10%	742	8	46,541
185	20%	761	-12	42,662
200	30%	781	-32	39,381
216	40%	801	-51	36,568



5 Tables, literature and references

5.1 Literature

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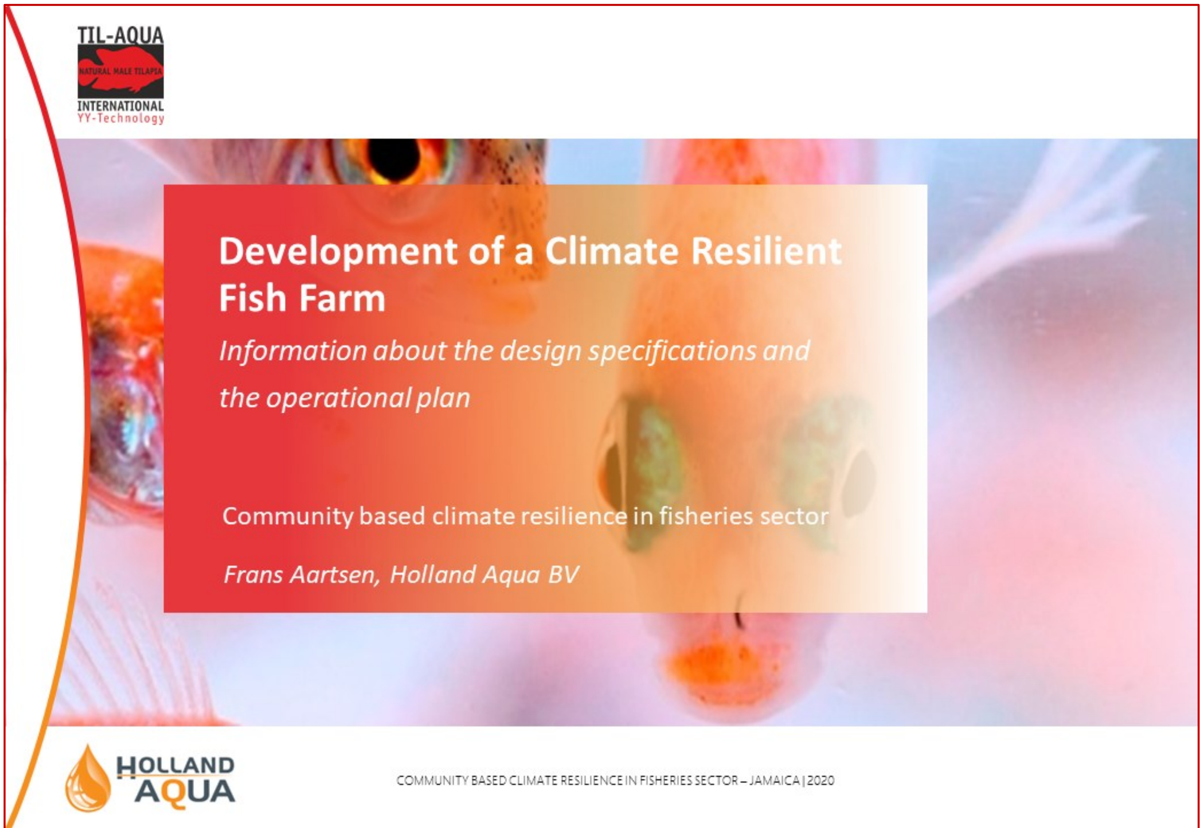
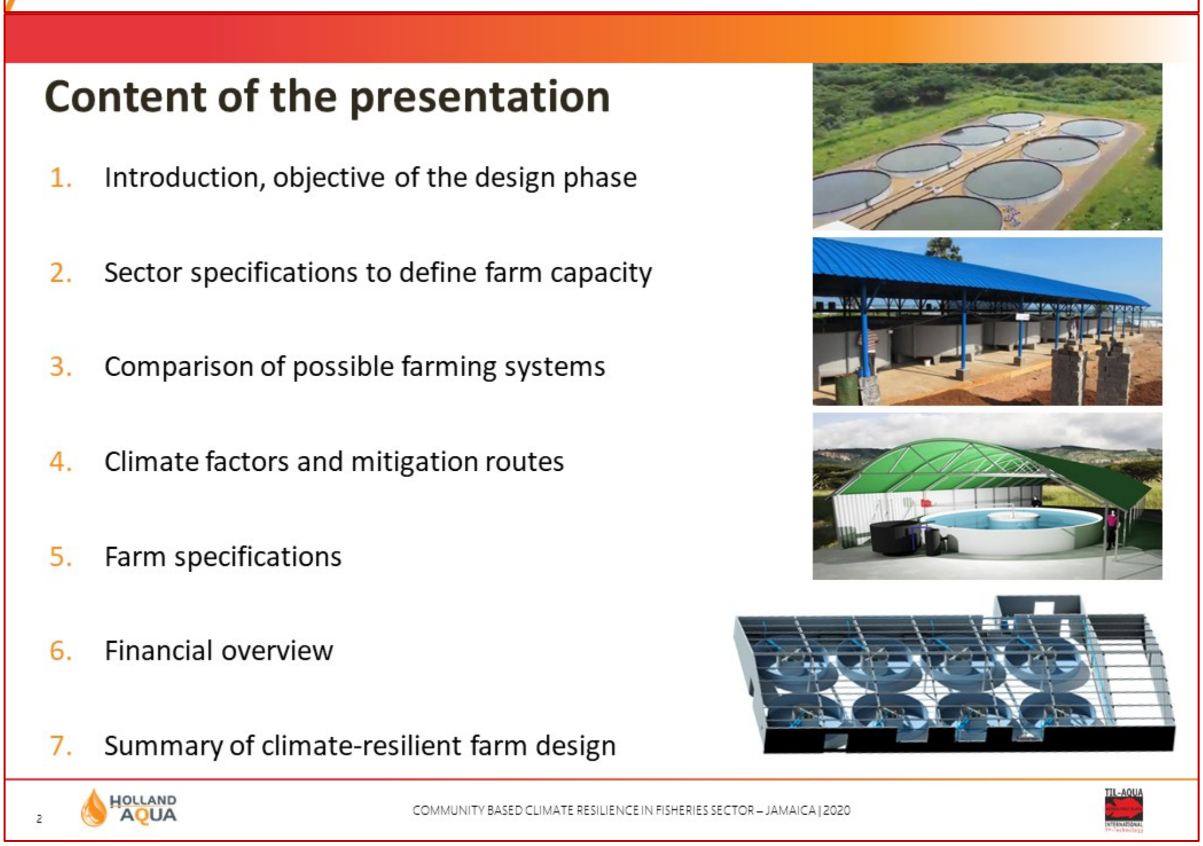
5.2 Presentation slides

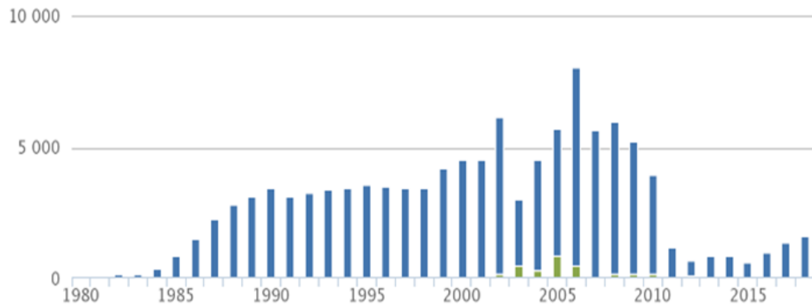




1. Introduction

The aim is to formulate a climate-resilient and sustainable farm concept that can be technically and financially verified against actual farm conditions in Jamaica.

This final study contains a technical and biological design, an operational plan and a business plan.



2. Sector specifications to define farm capacity

Number of farms in Jamaica in 2001, 2011, 2020 with a forecast towards 2030.

indicative numbers	2001	2011	2020	Forecast 2030
Total number of farmers	**400** (100%)	**179** (100%)	**48** (100%)	**45** (100%)
Small farms (1-4 acres)	300 (75%)	115 (62%)	29 (60%)	15 (33%)
Medium farms (5-20 acres)	76 (19%)	38 (21%)	11 (23%)	10 (22%)
Large farms (>20 acres)	**24** (6%)	**26** (14%)	**8** (17%)	**10** (22%) (+20)

Indication of the total production, divided over the 3 classes of farms in Jamaica.

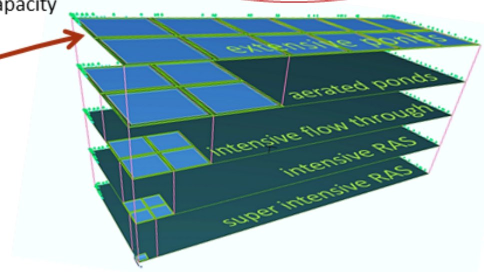
indicative volumes tons /y	2001	2011	2020	Forecast 2030
Total output tons / year	**4450** (100%)	**1152** (100%)	**1600** (100%)	**5000** (100%)
Small farms tons / year	500 (11%)	150 (14%)	100 (7%)	100 (3%)
Medium farms tons / year	950 (22%)	150 (14%)	200 (13%)	400 (9%)
Large farms tons / year	3000 (67%)	800 (72%)	1250 (80%)	**4400** (88%)

The conceptual design of the resilient farm is based on a production capacity range of the **medium type of farm (5 - 50 tons /year).**
For Small farmers a step forward, for Medium farmers securing climate resilient production and for Large farmers exploring new technology that may be useful.

3. Comparison of possible farming systems

Footprint of farming technology for production of 12.000 kg fish	Extensive ponds (no aeration)	Aerated ponds (part of the time)	Flowthrough or aerated tanks	Intensive RAS aerated ponds	Super-intensive RAS tank system aerated
Number of ponds or tanks	12	4	4	4	1
Ponds or tanks size m²	4.000	4.000	1.000	250	100
Total area m²	48.000	16.000	4.000	1.000	100
Total area hectares	4,8	1,6	0,4	0,1	0,01
Productivity kg/m²/year	0,25	0,75	3	12	120
Water consumption m³/kg	**22**	**24**	**49**	**1,2**	**0,4**
Investment land USD 2 /m²	96.000	32.000	8.000	2.000	200
Investment culture volume	156.000	52.000	43.000	10.750	10.325
Capex farm volume/kg	**13,0**	**4,3**	**3,6**	**0,9**	**0,9**

Compare: Footprint, Water consumption, Farm investment in USD / kg capacity

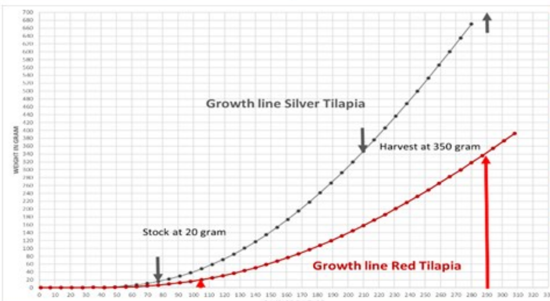


4. Climate factors and mitigation routes

Topic	Consideration	Measures to be included to make resilient farm design
1) WATER	Water saving > 90%	Water recirculation with physical & biological filtration
	Reduce evaporation	Smaller footprint / more intensive farming
	Secure intake water quality	Use of borehole water
	Minimise consumption rate	Target for <1 m³ / kg fish
2) WIND	Wind breaking	Wind shielding, dikes and trees
	Wind proofing	Superstructure indoor construction or cover
3) RAIN	Erosion	Use pond liner, wall protection or concrete
	Flooding	Overflow, secure enough drains
	Escaping fish	Fenced overflow, prevention
4) ELECTRICITY	Secure supply	Generator to backup grid power
	Price and usage	Use low energy consumption equipment
	Alternative source	Solar
5) LOSSES	Praedial Larceny	Reduce area to secure (prevents 5-10% losses)
	Predation	Reduce bird foraging (prevents 20% loss)

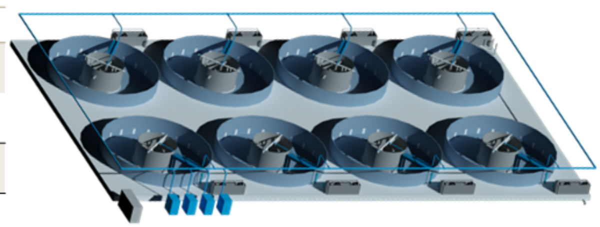
4. Farm specifications

Topic	Unit	Actual production level 2020, according to field reports Jamaica	Proposed production schedule for the resilient farm
Pond size	Ha	0.5 – 1.0 (5000-10000 m^2)	0.05 – 0.01 (tanks of 50 m^2)
Growth	grams	20 - 350	20 - 350
Days of cycle	days	180 -210	150
Density	#/m^2	2 - 3 (**max 0,6 - 1** kg/m^3)	170 (**max 60 kg**/m^3)
Survival	%	50 - 70%	85 - 95%
FCR	-	1.4 - 2.5	1.2 - 1.4
Yield	kg/m^2/y	0.75 - 2.5	120
Cycles	#/year	1-2	2.4
Water usage	m^3/kg fish	20	0.4 - 1



5. Farm specifications

Investment	
Building and infrastructure	13,720,000
Growout hardware	27,552,000
Farm investment (net value)	**41,272,000**
Farm working capital	**9,593,383**

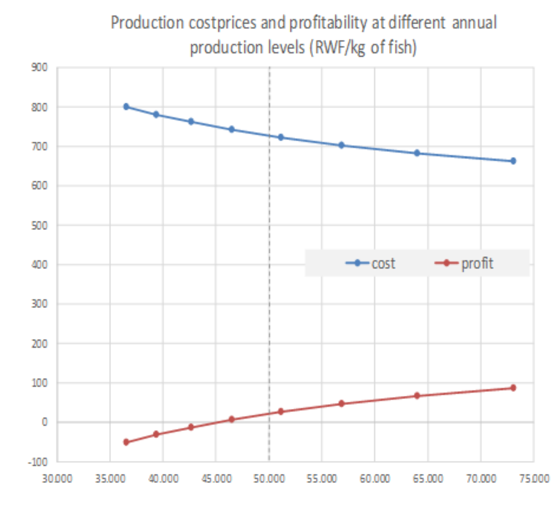


Type of farm	: 8 tank (50 m^3) Recirculation Aquaculture System (RAS)
Superstructure	: Framework with coated steel plate cover, or canvas liner
Type of tank	: 8 x corrugated steel frame with aqua liner
Oxygenation	: Fine bubble aeration, low energy roots blowers supporting > 12 kg O2/h
Biofiltration	: Moving bed bio reactor (MBBR) for ammonia removal within the tank
Solid removal	: Packed sedimentation reactor
Water consumption	: 500-750 liter per kg feed
Type of fish	: Tilapia red, Oreochromis niloticus **(50 - 350 grams in 22 weeks)**
Feed	: Daily 8 –36 kg, average 24 kg per tank and 200 kg of feed per day
Output	**: Tilapia red, net production 50000 kg, sales volume annual 58000 kg**

6. Production cost price

Production cost prices of market-size fish

Annual production costs	JMD / kg	JMD/Lb	%
Fingerlings	140	64	19%
Feed	205	93	28%
Electricity and water	100	45	14%
Labour	84	38	12%
Others	32	15	4%
Operational costs	562	255	78%
Depreciation	61	28	8%
Interest costs	34	15	5%
Corporate taxes	65	30	9%
Finance costs	160	72	22%
Cost price of production	**722**	**328**	**100%**



7. Summary of climate-resilient farm design

The farming principle that has been selected is **intensive recirculation** in order to minimize the interaction with the environment (no predators, less diseases, maximum controls) and to **prevent impact of changing climate factors** (droughts, rains, floods, tropical storms, rise of sea level).

Main takeaways:

- Footprint — 80 x smaller than ponds
- Fish density — 60 x higher
- Survival — 50% higher
- Growth — 20% faster
- Productivity per m^2 — 75 x higher
- Feed conversion — 33% reduction
- Labour intensity — 33% reduction
- Water consumption — 95% reduction, potential plant fertilizer

- Farm investment JMD 825 / kg capacity, which equals investment level of ponds.

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