Achievement of Sustainable Groundwater Exploitation through the Introduction of Water-Efficient Usage Techniques in Fish Farms in Armenia

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Abstract

Due to high quality, the artesian groundwater is the main source of water for the fisheries in Ararat Valley, Armenia. Approximately 1.6 billion m^3 of groundwater were extracted in 2016, half was used by fish farms. Yet, inefficient water use, typical for low-intensity aquaculture systems in Ararat Valley, has become a key environmental issue in Armenia. In addition to excessive groundwater exploitation, which along with other sectors of groundwater use in this area resulted in a reduction of the artesian zone by approximately 67% during the last 20 years. Negative environmental impacts of production are magnified by the discharge of large volumes of wastewater into receiving water bodies. In turn, unsustainable use of artesian groundwater in Ararat Valley along with increasingly strict policy measures on water use had a devastating impact on small and/or medium scale aquaculture: over the last two years approximately 100 fish farms have permanently ceased operations. The current project takes aim at the introduction of efficient and environmentally-friendly fish farming practices (e.g., recirculating aquaculture systems) in Ararat Valley fisheries in order to support current levels of fish production and simultaneously reduce negative environmental pressure of aquaculture facilities in Armenia. Economic and environmental analysis of current small and medium scale operational systems and subsequently developed environmentally–friendly and economically sustainable system configurations will be presented.

Keywords-aquaculture, groundwater, recirculation, sustainability.

1. Introduction

The artesian aquifer in Ararat Valley is one of the most significant potable groundwater basins of Armenia. These waters, historically used for drinking and irrigation purposes, are a strategic reserve of high quality groundwater resources and remain suitable for drinking purposes without additional treatment. As a result of fish production being included in the list of priority areas of development and poverty reduction programs in Armenia since beginning of 2000s, a significant number of private fish farms have developed in the Ararat Valley. These farms typically use high quality potable groundwater resources as the main source of water for the fisheries.

Inefficient water use, typical for low-intensity aquaculture systems in Ararat Valley, has become a key environmental issue in Armenia. Approximately 1.6 billion m^3 of groundwater has been extracted in 2016, half was used in low-intensity aquaculture farms for fish production. Because of these unsustainable water use practices, water yield of more than 300 artesian wells has decreased by approximately 90%. More than 200 wells have lost self-emission capacity due to reduced ground water pressure in last 20 years (ASPIRED, 2016). Moreover, a devastating impact of increasing water scarcity on small and/or medium scale aquaculture has been observed. Over the last two years approximately 100 fisheries have permanently ceased operations, adding to growing poverty levels of the countries' population and specifically fish farmer communities.

To support current levels of fish production and to reduce the negative environmental pressure of aquaculture facilities in Armenia, more efficient and environmentally-friendly practices should be developed. Keep in mind that the ultimate goal is to protect artesian aquifers of the Ararat Valley from further depletion. Sustainable Fisheries for Enhanced Water Resources in Armenia (SFEWRA) project seeks various opportunities for reducing water consumption by the fish-farming industry, which at this moment is one of the largest consumers of artesian water in Ararat Valley. There are a number of

technologies that according to broader international experience may be applied in the fish-farming business to improve water efficiency.

This report was developed in the scope of the SFEWRA project with the combined efforts of International Center for Agribusiness Research and Education (ICARE) experts and a fish farm owner aiming at the development/installation of the RAS model in one fishery operating in Ararat Valley to produce fish on an economically competitive basis while using environmental-friendly practices. The main approaches of the design are maximizing groundwater resource efficiency by implementation of recirculation and re-use systems, with incorporation of water treatment units and re-use of water in order to decrease extraction levels and maximize the economic benefits of the system by increasing rainbow trout production. Also, production of valuable plants in aquaponic systems, and bio-fertilizer can be additional sources of revenue.

First section of this paper describes overall status of ground water resources in Ararat Valley, Armenia. Second section of this paper presents the current production methods used by fish farms, including water quality analyses. The third section describes proposed production modifications including configuration of recirculation units and re-use units describing estimated costs for proposed modifications, followed by general conclusions.

2. Overview of current production mode of selected fishery

2.1. Short Description of the Fish Farm

Name of the company	Makich Muradyan SP (Hereinafter MakM Company)
Address	Ararat Valley, Republic of Armenia
GPS coordinates	40° 5'35.60"N 44°19'23.27"E

The fish farm is located in Ararat Valley in Armenia. It is mainly engaged in producing rainbow trout by providing a complete production cycle. The fish farm has 7 basins (1 is an octagonal concrete pond (A), and 6 are earthen ponds (B-G)) out of which only 3 (A, B, C) is currently operational (Pic. 1, details in Appendix 1 Table 1).

Pic. 1 GPS view of the farm

The farm launched its operations with 120 l/s water extraction in early 2000s, availability of which has decreased (See Graph 1 in Appendix) over the years due to inefficient exploitation of groundwater resources by fish farms and other sectors in the region.

With a typical water withdrawal of 40 l/s (or approximately 1.3 mln m^3 per year) from deep-well groundwater, the farm currently produces only 4 tons of fish/year. Due to low stocking density (≈1.73-2.22 kg/m^2), no aeration is implemented in the fish ponds. The operating raceway mode allows passively aerated water to be re-used in other fish ponds. The water leaves the fish farm practically clean, with average ammonium concentrations of 0.13 mg/l, nitrite concentration of 0.06 mg/l and total dissolved solids of 1008 mg/l, and is discharged into a receiving water channel.

Current inefficient water-use practices are due to the lack of investment availabilities for implementation of more efficient and environmentally-friendly fish farming technologies(e.g., semi-closed RAS

configuration). In the scope of the current project, a more effective water use model with 60% water recirculation was developed and proposed to MakM fish farm.

2.2. Water quality characteristics

Within the scope of this project, all preconditions were identified for water recycling and/or water-efficient practices. This also includes producing an applicable elaborated business model based on achievable best management practices. The business model includes semi-closed re-circulation systems, as well as integrated aquaculture systems, (e. g. aquaponics, field irrigation with discharge waters, etc), physical, biochemical and chemical analyses for inlet and outlet water quality were carried out. Total of 22 water quality parameters for analysis were chosen taking into account the N-75 Decision of the Government of Armenia on water quality norms (N-75 RA Government Decision, 2011) (particularly for aquaculture and irrigation purposes), as well as chemical, physical and biological parameters for RAS and irrigation systems accepted by FAO (Ayers & Westcot, 1985).The list of water quality parameters is presented below:

- Temperature
- Alkalinity
- Ammonia
- Carbon Dioxide (CO_2)
- BOD_5
- Chlorine
- Copper
- Hardness
- Molybdenum
- Nickel
- Nitrate
- Nitrite
- Oxygen, dissolved (DO)
- pH
- Phosphate
- Potassium
- Iron
- Sulfate
- Zinc
- Turbidity
- Total dissolved solids (TDS)
- Conductivity

2.2.1. Quality of inlet water

One of the most important requirements for a successful aquaculture facility site is a high quality water source (Timmons & Ebeling, 2013). Two of the most often used water sources for RAS are groundwater and municipal water supplies. Both normally have the quality, quantity, and reliability required, so the

actual choice between them is based on availability of water and economics. Surface waters are generally not used, due to the higher risk of contamination by pollutants, fish eggs, insect larva, disease microorganisms, and wide seasonal temperature variations. A major advantage of groundwater is the constant temperature throughout the year. The chemistry of groundwater is directly dependent on the geology of the area surrounding the water source (Timmons & Ebeling, 2013). Ararat Valley fish farms are solely relying on artesian groundwater resources, due to its high quality characteristics. The description of most important water quality parameters of groundwater used by MakM Company is presented below (see result of water quality characteristics in Table 2 in Appendix).

Dissolved Oxygen (DO): Dissolved oxygen is the most important and most critical parameter in aquaculture production systems (Timmons & Ebeling, 2013). For chosen farm DO=9.5mg/l, which lies on acceptable range for aquaculture (DO>5mg/l).

Temperature: Groundwater temperature is 15.2°C, which is appropriate for breeding cold-water species, including rainbow trout.

Ammonia/Nitrite/Nitrate: Nitrogenous compounds, such as **a**mmonia, nitrite, and nitrate, are highly soluble in water and are the strongest inhibitors of fish growth present in natural environments. Ammonia exists in two forms: non-ionized NH_3 and ionized NH_4^+ (ammonium), collectively assigned as Total Ammonia Nitrogen (TAN). The relative concentration of the two forms of ammonia is primarily a function of water pH, salinity, and temperature. non-ionized ammonia is toxic to fish at low concentrations (96-hr LC50 varies widely by species between 0.08 mg/l- 2.2 mg/l NH_3/N) (Timmons & Ebeling, 2013). In general, freshwater fish are more tolerant than saltwater fish. Nitrite is an intermediate in the oxidation of ammonium to nitrate. Nitrite toxicity on fish depends on chlorine concentrations, and can get as low as 0.1 mg/l NO_2^-/N (Timmons & Ebeling, 2013). For rainbow trout, a range from 0.24 to 11 mg/l NO_2^-/N is reported (W. Lewis and D. Morris, 2011). Nitrate is the end-product of nitrification and is the least toxic of the nitrogen compounds, with a 96-hr LC50 value usually exceeding 1000 mg/l NO_3^-

/N. In all cases concentrations of nitrogenous compounds in inlet waters were below the reported inhibitory levels for fish, suggesting the suitability of groundwater for fish farming (see Table 2 in Appendix).

pH, Alkalinity/Hardness: These are the fundamental parameters for suitability of water for fish production. Ararat Valley groundwater pH is 7.4, which is in the acceptable range of 6.5 – 8.5 (Timmons & Ebeling, 2013). Alkalinity of freshwater generally ranges from less than 5 mg/l in soft water to over 500 mg/l for very hard water, and is determined by the geology of the aquifer. The total hardness of natural waters ranges from less than 5 to over 1 0,000 mg/l $CaCO_3$ (Timmons & Ebeling, 2013). Waters have traditionally been classified as soft (0-75 mg/l), moderately hard (75-150 mg/l), hard (150-300 mg/l), or very hard (> 300 mg/l). The groundwater used for farming in MakM farm is soft (1.26 mg/l hardness as $CaCO_3$), with a suitable alkalinity range for fish farming (280 mg/l).

Carbon dioxide: Most of the carbon dioxide in an aquaculture water column is produced by animal respiration and the decomposition of organic matter. The concentration of carbon dioxide in groundwater can range from 0 to 100 mg/l, depending on the biological activity in the aquifer recharge zone. An upper limit of 15-20 mg/l carbon dioxide is recommended as a steady state maximum for finfish (Timmons & Ebeling, 2013). Carbon dioxide concentration for inlet water was found to be 29 mg/l which is slightly higher than the required concentrations. The farmer is dealing with high carbon dioxide concentrations by allowing the water to equilibrate to ambient in a small basin before entering the fish tanks.

2.2.2. Quality of outlet water

Water quality analysis in the targeted fish farm reveals that discharge water leaves the aquaculture system virtually clean (see Table 2 in Appendix for detailed analysis), suggesting intensification and subsequent water recirculation and/or reuse as a main approach to address low water efficiency.

In the current farm no dramatic changes in dissolved oxygen content, water temperature, pH, alkalinity and hardness have been detected. Carbon dioxide concentrations decreased to 25 mg/l.

Slight increases in dissolved nitrogenous compounds, e.g. $NO3^-$/N concentrations of 4.7 mg/l and $NO2^-$/N concentrations of is 0.02 mg/l took place.

Phosphates were present in outlet waters with a concentration of 0.73 mg/l. Out of all metals analyzed, potassium (8.0 mg/l) was present in environmentally important concentrations.

The data on outlet water quality from MakM farm suggests the potential for both water reuse and recirculation. Since outlet water leaves the farm containing only very low concentration of wastes, intensification of farming can offer a better water use and efficiency approach and economic benefits.

Taking into account discharge water quality of MakM Company, 3 different directions can be proposed for efficient water use – reuse/intensification in aquaculture, recirculation and re-use in irrigation.

Reuse and/or intensification in aquaculture: As can be seen in Table 2 in the Appendix, oxygen saturation, which is one of the most important parameters in fish farming, is at high levels both for water delivered from the well and for discharge waters, with values between 9.5 and 8.1 mg/l, respectively. This demonstrates that after dischargewith currently low breeding intensity, the effluent water is still rich in oxygen. Suitable temperature, pH, alkalinity and hardness further prove the suitability of water for reuse for more fish production in serial manner and/or intensification of fish production methods. The concentrations of Carbon dioxide, although slightly higher than preferable levels for fish, can be easily handled by degassing in small standing ponds, a practice currently used by the farmer. The concentrations of nitrogenous compounds do not reach inhibitory levels, suggesting the potential for reuse for growth of more tolerant species, such as Cyprinids.

Recirculation: Since only TAN concentrations are slightly high in the wastewater discharged from MakM farm, recirculation of water can be the most beneficial practice for reducing groundwater

extraction. Given the current concentrations ammonium and solids, a simple settling pond for solids removal and a simple denitrification biofilter installation to remove solid waste and ammonium will suffice. Temperature and pH levels which are of major importance when organizing the nitrification process once the system is switched to recirculation mode fall in the acceptable range of 10 to 35 °C for nitrification and pH range of 7.0 – 7.5 recommended by a Guide to Recirculation Aquaculture (Bregnballe J. , 2015). Along with slightly higher TAN concentration, alkalinity values are on the range for promoting nitrification. Oxygen can become the rate-limiting factor in certain biofilters, because of the low levels in the influent and the competing demands of the heterotrophic bacteria. In the current setup at MakM farm, discharged water contains acceptable levels of oxygen for nitrification. As long as there are no potentially harmful compounds to inhibit nitrification, farmer will benefit more from recirculation technology with simultaneous intensification of production.

Reuse in irrigation: Due to the absence of metals and presence of the compounds that are necessary for stimulating plant growth, for instance phosphorus, potassium and nitrogen in aquaculture wastewater can be used for plant growth, including aquaponic production. This will benefit farmers economically.

Since the current project aims at introduction of water efficient and water saving practices, the reuse and recirculation systems will be presented in this report.

3. Introduction of Recirculating Aquaculture Technologies (RAS) in MakM Company

3.1. General concepts of recirculation

Over time, conventional aquaculture methods, such as outdoor pond systems and net pen systems, are not sustainable due to significant environmental issues. On the other hand, indoor fish production using RAS is sustainable, infinitely expandable, environmentally compatible, and has the ability to guarantee both the safety and the quality of the fish produced throughout the year (Timmons & Ebeling, 2013). In a RAS, water flows from a fish pond through a treatment process and is then returned to the tank, hence the term recirculating aquaculture systems. RASs provide opportunities to reduce water usage and to improve waste management and nutrient recycling. Moreover, fish in RAS systems can be grown at high density under controlled environmental conditions (Nazar, Jayakumar, & Tamilmani, 2013).

RAS water is cleaned by filtration systems which adequately remove corresponding pollution to restore water quality to acceptable levels and make it possible to recycle back with makeup water for replacement of water that evaporates or leaks from the system. Thus, the secret to RASs is the removal of wastes from systems at a cost that allows the operator to generate profit.

Aquatic production system wastes generally fall into 2 categories: particulate/solid matter (sludge) and dissolved composites such as nitrogenous compounds (NH_3^+, NO_2^-, NO_3^-), phosphorus (primarily PO_4^{3-}) and carbon dioxide (CO_2). Stocking density often is a primary determinate in the level of these wastes in RAS and rapid removal of particulate and dissolved wastes from recirculating systems is of upmost importance if recirculation is addressed.

Solids removal: Uneaten feed, feed fines, fish fecal matter and dead microorganisms are all sources of solids production within recirculating systems (Chen, Coffin, & Malone, 1997). Solids control is one of the most critical processes that must be managed in recirculating systems, because solids decomposition

can degrade water quality and thus directly and indirectly affect fish health (Mirzoyan, Parnes, & Singer, 2008). The volume of solid waste produced is dependent on stocking density and feed rates. Increasing solid waste production requires a corresponding increase in biofiltration unit efficiency for particulate matter removal.

Nitrogen removal: In aquaculture environments, nitrogenous compounds, e.g., TAN, nitrite and nitrate, are of primary concern as components of waste products generated by rearing fish. There are four primary sources of nitrogenous wastes:

- urea, uric acid, and amino acid excreted by the fish;
- organic debris from dead and dying organisms;
- uneaten feed, and feces; and
- nitrogen gas from the atmosphere.

Ammonia, nitrite, and nitrate are all highly soluble in water and are inhibitory / toxic for fish at different concentrations. Ammonia, nitrite and nitrate typically are dissolved compounds and will require biofilter units for removal. The process of ammonia removal by a biological filter is called nitrification, and consists of successive oxidation of ammonia to nitrite and finally to nitrate by aerobic bacteria. The reverse process is called denitrification and is an anaerobic process where nitrate is converted to nitrogen gas (Timmons & Ebeling, 2013).

Although not normally employed in commercial aquaculture facilities today, the denitrification process (removal of nitrate) is becoming increasingly important, especially in systems where stocking densities increase and water exchange rates are reduced, resulting in excessive levels of nitrate.

Currently, to help maintain good water-quality conditions in RAS, aquaponic solutions can also be integrated for nitrate (and in some cases solids) removal from RAS wastewater. The detailed RAS configuration for MakM Company is discussed in next sections.

3.2. Description of proposed model and technological processes

As stated above, the current project aims to transform current monoculture raceway configurations with 40 l/s water extraction volumes into an intensive, environmentally-friendly fish farm with 30 l/s water extraction volumes. Implementation of two mainly complementary approaches will increase water resource efficiency – introduction of recirculation and reuse systems. The system will be intensified to grow 70 tons of fish (trout, sturgeon and carp) per year instead of current 4 tons along with production of high market value plants from aquaponic systems and organic bio-fertilizer from dried sludge and will incorporate nitrogen and solid treatment units into the existing farm configurations.

The proposed system is based on an existing raceway configuration. The system will be modified to include a **semi-closed recirculation system (RAS unit)** with 60% water recirculation efficiency and a parallel raceway configuration where some of the effluent water from the semi-recirculation unit will be reused (**Re-use unit**).

The earthen ponds will be converted to concrete tanks, to address the environmental requirements of EU fish markets (the susceptibility of fish in earthen ponds to persistent organic pollutants due to leaching is negated by the use of concrete ponds).

Three out of 7 ponds will be used as a foundation for RAS configurations; the other 4 will be used in water reuse units after modification (Figure 1 in Appendix). Each tank will have an independent flow control.

There are numerous designs for RAS (Timmons & Ebeling, 2013) which generally work effectively to accomplish the following:

1. Nitrogen management
2. Solids removal
3. Aeration

For the current project, the aforementioned list will be accomplished using the following mechanisms.

Nitrogen management: Nitrogen removal will be achieved by nitrification/denitrification units. TAN will be nitrified by 4 submerged rotating biological contactors – 2 of which will be located in TP1, 1 will be located in TP2 and 1 will be located in TP3. Since NO_3^- is inhibitory to trout in only fairly high concentrations (<200 mg/l N), the estimated NO_3^- levels will be below inhibitory concentrations in TP1, TP2 and TP3 during maximal production (Figure 1 in Appendix). An aquaponic platform (Figure 2 in Appendix) will be installed after TP3 to remove NO_3^- along with NH_4^+, P and K, produced in TP1, TP2, and TP3. NO_3^- concentrations in culture water will be further reduced by dilution of recycled water with freshly pumped groundwater.

Solids removal: Solids removal will be achieved by 2 filters: a low-cost quartz sand filter (in B2 unit) will remove solids generated in TP1; and a drum filter (installed after TP3, before the aquaponic unit) that will remove solids generated in TP2 and TP3. An additional 3 l/s water will be captured by dewatering the backwash sludge from both solid filters on mechanical screens.

Aeration: To allow high fish stocking densities, the TP1, TP2 and TP3 will be equipped by 4, 1 and 2 paddle-wheel aerators, respectively, working in parallel only during the maximum capacity stage. A fountain-type aerator will be placed after the sand filter to oxidize NH_4^+ produced by degradation of captured solids. Another fountain-type aerator will be placed in passive aeration unit (C2) to degas newly extracted groundwater of naturally occurring CO and N_2 and simultaneously enriching it with O_2 before entering TP1. Passive aeration of water will take place at the entrance of each tank due to stepwise water flow.

In the reuse system, due to dilution of water in fingerling ponds and relatively low sensitivity of sturgeon and carp species to the water quality, no treatment for nitrogen and solids will be required.

3.3. Water flow management

Groundwater with a flow rate of 30 l/s will enter C1 basin which is equipped with a fountain aerator. After degassing of water of naturally occurring carbon monoxide and nitrogen gasses and subsequent aeration by fountain aerator, water will be directed to the RAS-unit at 25 l/s and another 5 l/s to the hatchery (H1) that will supply water to the fingerling ponds in re-use units (FP1-FP5).

Semi- closed recirculation system (RAS unit)

The entire RAS unit will support rainbow trout (*Oncorhynchus mykiss*) as a monoculture production process. The highest fish production rate is expected in TP1 (1351 m^3 volume) with 15,000-18,000 units fish with marketable size of 800 g-1200 g each. The TP1 will receive 25 l/s groundwater and 15 l/s re-circulated water. The TP1 will be divided into 2 parts by the use of 2 rotating biological contractor submerged nitrifying systems that will simultaneously convert NH_4^+ into nitrate NO_3^- using microbial communities attached to the plastic beads substrate inside the filters, and oxygen supplied by 4 paddle-wheel aerators placed inside the basin. The placement of rotating biological contractors and aerators will create a circular water flow in TP1 and a unidirectional water flow through the entire system.

From TP1, water will flow through a quartz sand filter (B2), where separation of solids will take place. The filter will be operated at least twice a day, and will direct the backwash (containing mainly solids) to a solid collection channel using a pump. The effluent water from the sand filter will flow to B1 basin equipped with a fountain aerator. This aerator will further oxidize the pollutants, but more importantly will aerate the water for the second culture basin TP2 (280 m^3 in volume). In addition to receiving aerated water from B1, TP2 will be equipped by a paddle-wheel aerator to be used at very high fish densities. The estimated annual fish production in TP2 is 8000-12000 units, with marketable fish size of 800 g-1200 g.

Water from TP2 will further flow to TP3 (231 m^3 in volume), with annual fish production of 7,000-10,000 units. This basin will be equipped with 2 paddle-wheel aerators.

After TP3 water will flow to an installed drum filter, were solid separation will occur, from here nitrogen (and dissolved P and K) rich water will flow to the aquaponic unit (A1). This unit will serve as a biofilter for the removal of nitrogenous wastes (and dissolved P and K) by plants growing in A1 platform. The plants will be chosen by their market value to increase the economic sustainability of the system.

Out of 40 l/s of circulating water (25 l/s groundwater and 15 l/s re-circulated water) with expected loss of 3 l/s for sludge backwash (assuming no losses for evaporation), 37 l/s water will be pumped into passive aeration unit C2, from which 15 l/s water will return to TP1. This suggests a water recirculation efficiency of approximately 60%, with 22 l/s of water being directed to the re-use unit (SP1). The backwash sludge from both sand and drum filters will be combined in the sludge collection channel, constructed parallel to TP2 and TP3 basins. The sludge then will move to specially designed screens, where it will be dewatered and dried to be used as a bio-fertilizer. This step will allow an additional estimated 3 l/s water reclamation (assuming no losses for evaporation), which will also be supplied to the re-use unit.

Re-use Unit

The first component of the re-use component of the proposed model is the H1 hatchery. It is designated for growth of fingerlings from eggs (200,000-400,000 fingerlings with the sizes of up to 10 g, with an annual production of 1 ton). The hatchery will receive 5 l/s degassed and aerated groundwater from C1. After flowing through H1 and passing through WC1 (first water collection unit) the water will be directed into F1-F5 fingerling growth ponds with total volume of 420 m^3. This system will grow 50,000 -300,000 rainbow trout, sturgeon, and common carp fingerlings annually (marketable size of 20-100 g). Only passive aeration and water treatment in these units are expected. The effluent from fingerling ponds will further move to a second water collection unit (WC2), where it will be mixed with 22 l/s denitrified and passively aerated water from C2 before being moved to SP1, sturgeon pond. This pond is expected to have 15 tons a year of sturgeon with 1.8-2.0 kg final marketable weight.

After sturgeon growth, water will flow to second common carp pond (CP2) (1400 m^3) and then subsequently to first common carp pond (CP1) (542.5 m^3), both designated for growth of common carp with average annual production of 10 tons for CP2 and 5 tons for CP1 (marketable size is 2.5-3.0 kg). CP1 will receive an additional 3 l/s reclaimed water from a sludge drying unit. Since carp are not very sensitive to aeration and water pollution, high stocking densities with no specific water treatment (nitrification/de-nitrification) requirements are expected.

The water after carp growth will be pumped into a receiving water drain. There is a possibility of designing the same semi-closed RAS system here, which is not included in this current project.

3.4. Nitrogen transformations and expected concentrations

Since feed level is adjusted with fish size, the maximum stocking density in ponds and maximum fish size (body weight) was considered for calculation of TAN (detailed calculation is presented in Table 4 in Appendix).

Taking into account the fact that 1 kg of feed will be transferred into 30g TAN (Timmons & Ebeling, 2013), and a feeding rate of 1% of fish weight with 3 feedings per day, the maximum amount of TAN produces per day in the ponds will be calculated as follows:

$$m\,(TAN) = \frac{Feeding\ rate * total\ maximum\ weight\ of\ fish\ in\ ponds * \ 30g\ TAN\ per\ kg\ of\ feed}{number\ of\ feedings}$$

(1.1)

Using equation 1.1, maximum of 2,160 g TAN will be produced in TP1 per feeding, 1,440 g in TP2 and 1,200 g TAN in TP3 per feeding. Given the differences in fish pond volumes, the max TAN concentration will be observed in TP3, equaling 5.19 mg/l and the minimum concentration in TP1 (1.60 mg/l), in all cases higher than acceptable 1 mg/l for trout farming. Since non-ionized ammonia is toxic to fish, the concentration of non-ionized ammonia nitrogen for pH 7.3 and 15^{o}C, characteristic values for the given

farm, were calculated. For all 3 ponds the levels of non-ionized ammonia nitrogen were lower than the 96-h LC50 of 0.05 mg/l (Timmons & Ebeling, 2013).

To overcome the unfavorable levels of TAN in fish ponds, 2 rotating biological contractor (RBC) bio-filters, along with 4 paddle-wheel aerators will be placed in TP1, 1 RBC bio-filter along with 1 paddle wheel aerator will be placed in TP2, and 1 RBC bio-filter along with 2 paddle-wheel aerators will be placed in TP3.

Due to the constant oxygenation of water and inherent alkalinity produced in the farm because of fish waste production, ammonia will be transformed into nitrate. Given the stoichiometry of TAN oxidation to nitrate (Timmons & Ebeling, 2013), 1 mol TAN will result in the production of 0.967 mol NO_3^-. This translates into 5.37-17.43 mg/l NO_3^- (max and min concentrations) in TP1 and TP 3 respectively. Nitrate is the end product of nitrification and is the least toxic of all nitrogen compounds, with a 96-h LC50 value usually exceeding 1000 mg NO_3^-/N /l. As nitrate levels in all ponds are lower than reported inhibitory levels (1000 mg/l), we can ignore it from further calculations.

The current analysis aims at understanding the feasibility of semi-RAS configuration in a selected fish farm as a means to reduce groundwater extraction. Although the entire system configuration includes additional water re-use to grow trout fingerling, sturgeon and carp, the environmental effects of the discharge water from a re-use system and its potential to be treated is not addressed in the current study.

3.5. Recirculation efficiency

Given the fact, that groundwater resources in Ararat Valley, Armenia are seriously depleted, the sustainable use of current groundwater resources have become one of the most crucial priorities for this country. Hence, modification of most of the current methods of fish farms operating in Ararat Valley, Armenia will contribute to a more sustainable and efficient water use.

In general, this fishery with only projecting intensification of the production methods (with annual production of 70 tons) without any application of RAS models will consume 1,261,440 m^3 of groundwater annually (or 40 l/s will be extracted from groundwater wells). With application of RAS and re-use units, the fishery will consume total 946,080 $m^3$of groundwater annually (30 l/s will be extracted from groundwater wells). Due to modification of the system, groundwater extraction rates will be reduced by 10 l/s (or by 25%), saving approximately 315.36 thousand m^3 of water every year.

The *Recycling rate* was calculated according to the "Inland aquaculture Engineering" guide of FAO using (1.2) equation (FAO, 1984):

$$Z = \frac{Qr}{Q} = \frac{\text{supplemental water or makeup water, l/s}}{\text{recycled water , l/s}} \quad (1.2)$$

With 25 l/s water flow into the recirculation system out of 30 l/s water extracted (5 l/s will be directed into the hatchery, the start of the re-use Unit), after treatment, 15 l/s water will flow back to the system ensuring a 60% water recirculation efficiency.

3.6. Estimated cost of farm modification

The cost of RAS models depends on many circumstances, such as the number, type, theoretical filter capacity, pumps, aerators, construction type, etc. The cost of the proposed model was calculated taking into account the following that are needed in the operation of the model:

- 7 Paddle-wheel aerators (4 aerators for TP1 (highest stocking density), 1 for TP2 (TP 2 will receive aerated water from B1), 2 for TP3)
- 2 Fountain aerators (will be located in C1 and B1)
- 1 drum filter (will be located in aquaponic unit for water filtration and sludge removal)
- 4 rotating biological contactor (2 will be located in TP 1, 1 in TP 2, and 1 in TP3)

- 1 Water pump (Will be used for pumping water from aquaponic unit (A1) to passive water aeration unit -C2)
- 1 air pump for aquaponics
- 1 air pump for waste water disposal
- Other (materials for passive aeration systems, quartz sand filter, nets for sludge processing, materials for aquaponics construction)

The total investment for intensification of the farm is 31,300 USD (including infrastructure reconstruction/renovation costs).

Profitability is always a major concern when considering a RAS. RASs require high initial capital investments with higher than normal O&M costs. Profitability often depends on serving niche markets with live fish. A secondary plant crop, which receives most of its required nutrients at no additional cost, improves the system's profit potential. The daily feeding of the fish provides a steady supply of nutrients to plants as required in aquaponics. The plants purify the culture water and can, in a properly sized and designed facility, eliminate the need for separate and expensive biofilters, a major capital expense and a minor operational expense. The profitability of recirculating systems can thus be improved substantially with the introduction of aquaponics, as long as there is a good market for the vegetable crop. The farm can also receive additional revenue from selling sludge as bio-fertilizer.

4. Conclusion

The proposed project, designed by a team of agribusiness, aquaculture system designers and environmental engineering experts of SFEWRA project aims at demonstrating increased environmental, social and economic sustainability of groundwater-based fish farms through introduction of an intensive aquaculture system simultaneously incorporating water recirculation and reuse methods.

The integration of a semi-closed RAS configuration, followed by water reuse for secondary production, will result in several environmental benefits. The major improvement in groundwater sustainability is a result of estimated water recirculation rates of 60%. Additional water efficiency will be achieved by the use of nutrient rich trout farm effluent water for aquaponics plant growth, subsequent reuse of nitrogen-free water for sturgeon and carp production, and incorporation of sludge treatment units allowing recirculation of an additional 3 l/s water extracted from the sludge.

Incorporation of an aquaponic system, capable of removal of N, P and K compounds, as well as solids removal and dewatering units will further increase environmental sustainability of the farm, reducing pollution of receiving water bodies.

The proposed system configuration, along with projected higher water-use efficiency, will contribute to a high economic sustainability of the farm. The market research-based business model estimates several economic benefits such as high revenues from: intensive production of diverse fish species (e.g., secondary production of sturgeon and carp); growth of high market value plants in the aquaponic system; and marketing of dried sludge as an organic bio-fertilizer.

The current project, where an extensive aquaculture system is transformed into a highly productive farm with high economic and environmental sustainability, will make the MaKM farm an excellent case to demonstrate the viability of designed business models and to follow for the other farms in the region.

4. Bibliography

ASPIRED. (2016). *Achieving Sustainable Groundwater Use in the Ararat Valley: the Role of the Fisheries Sector.* Yerevan.

Ayers, R., & Westcot, D. (1985). *Water quality for agriculture.* Retrieved December 10, 2015, from FAOStat: http://www.fao.org/DOCReP/003/T0234e/T0234E00.htm#TOC

Bregnballe, J. (2015). *A guide to Recirculation Aquaculture: An introduction to the new enviromentally friendly and highly productive closed fish farming system.* FAO and EUROFISH.

Chen, S., Coffin, D., & Malone, R. (1997). Sludge production and management for recirculating aquacultural systems. *World Aquaculture Society*, 303-315.

FAO. (1984). Recirculatig Systems and Re-use of Water in Aquaculture. *Inland Aquaculture Engineering*.

Mirzoyan, N., Parnes, N., & Singer, S. (2008). Quality of brackish aquaculture sludge and its suitability for anaerobic digestion and methane production in an upflow anaerobic sludge blanket (UASB) reactor. *Aquaculture 279(1)*, 35-41.

N-75 RA Government Decision. (2011, January 27). *On defining the standards for water quality of each water basin management area depending on local characteristics.* Retrieved March 2017, from http://www.arlis.am/DocumentView.aspx?gocID=65705

Nazar, A., Jayakumar, R., & Tamilmani, G. (2013). Recirculating Aquaculture Systems. *Central Marine Fisheries Research Institute (CMFRI)*.

Timmons, M., & Ebeling, J. (2013). *Recirculating Aquaculture.* New York: Ithaca Publishing Company.

W. Lewis and D. Morris. (2011). Toxicity of Nitrite to Fish: A Review. *Transactions of the American Fisheries Society*, 183-195.

5. Appendix

Graph 1. Groundwater availability in farm by different years, l/s

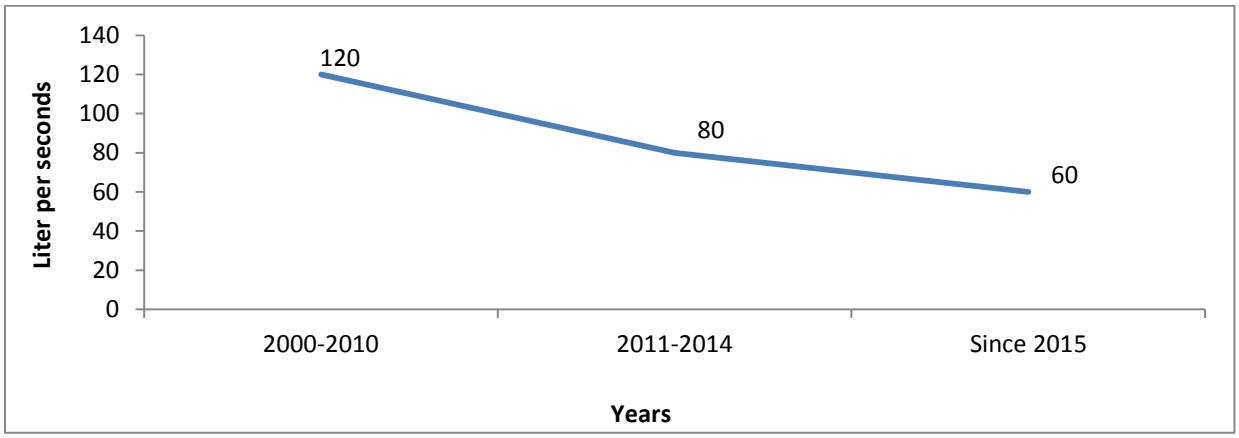

Table 1: Current operational mode of fish farm

	Trout Pond 1	Trout Pond 2	Trout Pond 3
Basin type and measures	Octagonal, concrete pond	Rectangular, earth pond	Rectangular, earth pond
Total volume of water, m^3	1351 m^3	280 m^3	231 m^3
Type of fish	Rainbow Trout	Rainbow Trout	Rainbow Trout
Stocking density (≈kg/ m^3)	2.22	2.14	1.73
Total annual fish production, tons	3 tons	1 tons	1 tons
Marketable mass, g/unit	800g -1200g	800g -1200g	800g -1200g
Water recirculation	None	None	None
Water re-use	Yes, re-used in Pond 2	Yes, re-used in Pond 3	No, discharged to drainage system
Aeration	Passive	Passive	Passive
Nitrification	None	None	None
De-nitrification	None	None	None
Sludge removal	None	None	None

*There are 4 other earth ponds – 2 earth ponds with dimensions of 42m x 15m each, 1 earth pond with 62 m x 12.5m dimensions and 1 earth pond with 40m x 50m dimensions which are not operating currently. It has its own hatchery.

Table 2. Inlet and outlet water quality analysis results of fish farm

Sampling time – October 2016	**Inlet water**	**Outlet water**	**Acceptable range for Aquaculture**
Dissolved Oxygen, mg/l	9.50	8.10	> 5
Temperature, °C	15.2	14.2	-
Ammonia (NH3), mg/l	0.08	0.13	0.02 - 0.4
Nitrate (NO3-N), mg/l	3.50	4.70	0-400 or higher
Nitrite LR (NO2-N), mg/l	0.01	0.02	< 1
pH	7.40	7.4	6.5-8.5
Alkalinity	280	270	50-300
Hardness, mg/l			< 100
CaCO3=	1.26	0.40	
Mg_2^+=	0.31	0.10	
Carbon dioxide, mg/l	29.00	25.00	< 20 mg/l
Turbidity, NTU	0.10	1.35	< 1.0
TDS, ppm	1060	1008	< 400
Conductivity, µS	1.46	1.39	300 – 1500
Chlorine, mg/l	0.04	0.00	< 0.003
Copper, Cu2+, µg/l	19.00	44.00	< 18
Iron, mg/l	0.03	0.08	< 0.15
Molybdenum (MoO4), mg/l	0.6	0.00	-
Nickel	0.000	0.000	< 0.1
Phosphate (PO4), mg/l	>2.5	0.73	
Potassium (K), mg/l	8.0	8.0	<5
Sulfate (SO4), mg/l	> 100 mg/l	> 100 mg/l	< 50
Zinc (Zn), mg/l	0.00	0.00	-
BOD5, mg/l	-	3.53	-

Figure 1. Proposed model of RAS unit and Re-use unit

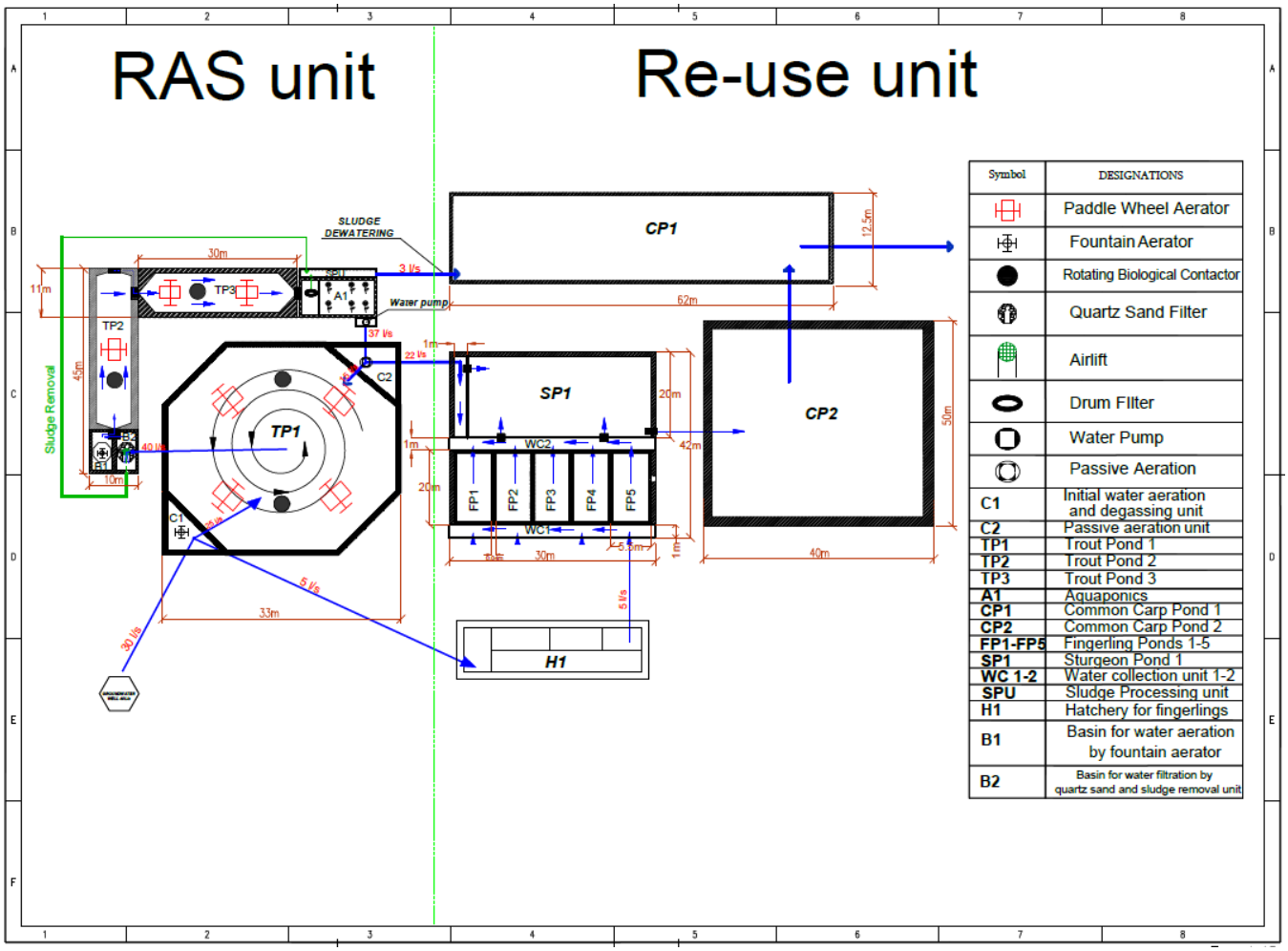

Figure 2: Aquaponics Configuration

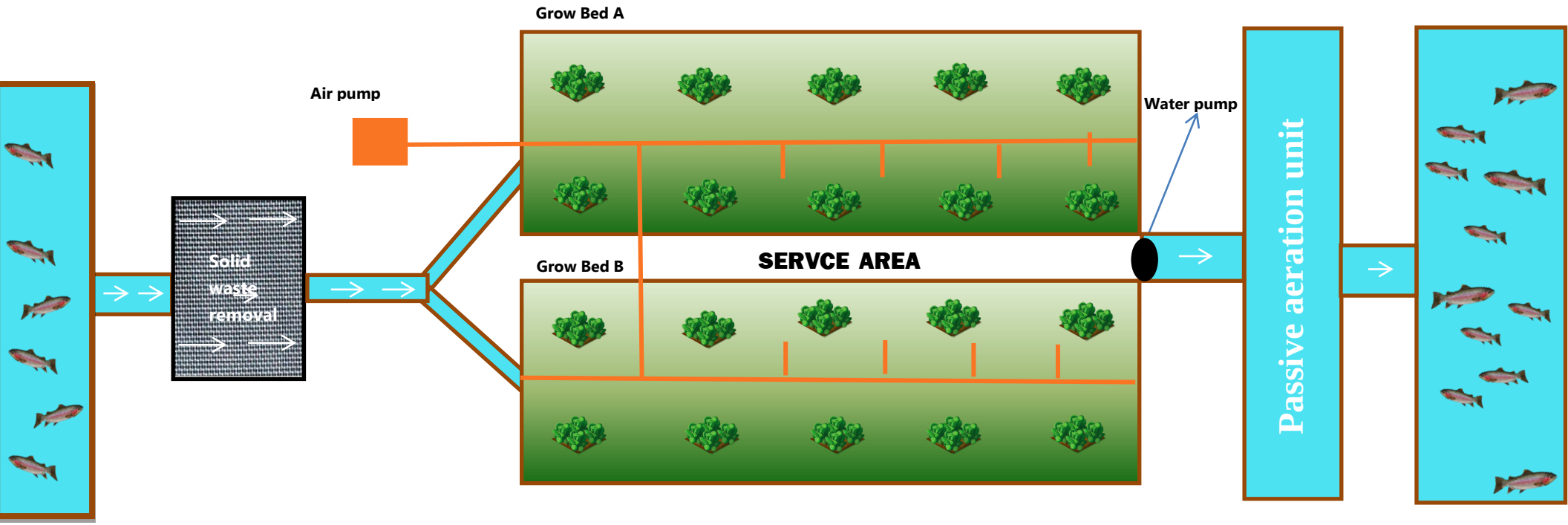

Table3. Proposed production mode for "MakM" farm

	Trout Pond 1 (TP1)	**Trout Pond 2 (TP2)**	**Trout Pond 3 (TP3)**	**Hatchery for fingerlings (H1)**	**Sturgeon pond (SP1)**	**Fingerling ponds (FP1-FP5)**	**Common carp pond (CP2)**	**Common carp pond (CP1)**
Basin type	Octagonal, concrete pond	Rectangular, concrete pond	Rectangular, concrete pond	Rectangular, concrete pond	Rectangular, concrete pond	Rectangular, concrete pond	Rectangular, earth pond	Rectangular, earth pond
Total volume of water, m3	1351	280	231	100	420	420	1400	542.5
Type of fish	Rainbow trout	Rainbow trout	Rainbow trout	Rainbow trout, sturgeon, common carp	Sturgeon	Rainbow trout, sturgeon, common carp	Common carp	Common carp
Average annual fish production, units/year	15,000-18,000	8,000-12,000	7,000-10,000	200,000-400,000	5,000 – 6,000	50,000-300,000	3,000-4,000	3,000-4,000
Marketable mass	800g-1200g	800g-1200g	800g-1200g	up to 10 g	1800g-2000g	20g-100g	2500g-3000g	2500g-3000g
Average annual production tons/year	21	6	5	1	15	7	10	5
Stocking density (≈kg/ m^3)	16 kg/m^3	21 kg/m^3	22 kg/m^3	10 kg/m^3	25 kg/m2	17 kg/m^3	7 kg/m^3	9 kg/m^3
Acceptable range (FAO)	15-25 kg /m^3	15-25 kg/m^3	15-25 kg/m^3	5-10 kg/m^3	50-80 kg/m^3	10-25 kg/m^3	4000 – 6000 fish/ha	4000 – 6000 fish/ha

Table 4. Proposed operational mode for "MakM" farm

	Trout Pond 1 (TP1)	**Trout Pond 2 (TP2)**	**Trout Pond 3 (TP3)**	**Hatchery for fingerlings (H1)**	**Sturgeon pond (SP1)**	**Fingerling ponds (FP1-FP5)**	**Common carp pond (CP2)**	**Common carp pond (CP1)**
Water recirculation	Yes	Yes	Yes	None	None	None	None	None
Water re-use	Yes, re-used in Pond 2	Yes, re-used in Pond 3	Yes, re-used in SP1 and CP 1	Yes, re-used in FP1-5 and in SP 1	Yes, reused in CP2	Yes, re-used in SP1	Yes, re-used in CP1	No, discharged to drainage system
Aeration	With paddle-wheel aerators	With paddle-wheel aerators	With paddle-wheel aerators	Passive	Passive	Passive	Passive	Passive
Nitrification	Yes	Yes	Yes	None	None	None	None	None
De-nitrification	Yes	Yes	Yes	None	None	None	None	None
Sludge removal	Yes	Yes	Yes	None	None	None	None	None

Table 5. Details of Nitrogen calculation

	Trout pond 1 (TP1)	**Trout pond 2 (TP2)**	**Trout pond 3 (TP3)**
Pond volume, m^3	1,351	280	231
Water retention time, h	9.38	2.10	1.73
Maximum number of fish per pond	18,000	12,000	10,000
Maximum marketable mass, kg	1.2	1.2	1.2
Total maximum weight of the fish, kg	21,600	14,400	12,000
Feeding rate, % of marketable mass	1.00%	1.00%	1.00%
Total feed, kg per feeding	72	48	40
Total Ammonia Nitrogen, g/feeding	2,160	1,440	1,200
Total Ammonia Nitrogen, mg /l (max after each feeding)	**1.60**	**5.14**	**5.19**
Un-ionized Ammonia Nitrogen, mg/l (at pH 7.3, 15C and 0 ppt salinity)	0.01	0.03	0.03