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Optimizing Aquaculture Experimental Station Operations Using Regulation Tanks

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ABSTRACT

In aquaculture, the supply of fresh water is essential for the optimal physiological development of species, which implies having a reservoir that stores water in adequate quantity and quality for replenishment. The study aims to design the regulation tanks applying technical, economic and environmental criteria for the correct operation and sustainable use of the Aquaculture and Marine Research Center (CENAIM) experimental station. The expected outcomes include optimized operational efficiency, cost-effectiveness, and enhanced sustainability. This research will contribute to the development of best practices for aquaculture facilities, promote sustainable resource use, and support advanced marine research capabilities. The methodology consisted of three stages: i) data collection and processing, ii) design of technical proposal and (iii) proposals for strategies for the efficient use of the system. The results raise the issue of implementing two reservoirs lined with high-density polyethene geomembrane that take advantage of the available area in the CENAIM without affecting the mangroves. The Reservoir 1 have an area of 4,750m^2, a height of 1.50m and a capacity of 9,500m^3, while Reservoir 2 occupies an area of 11,200m^2, a height of 1.50m and a capacity of 14,560m^3. The design of reservoirs connected by trapezoidal channels would allow the reduction of eutrophication, carbon footprint and dependence on non-renewable energy by taking advantage of gravitational potential energy, eliminating the need for electric pumps to transport fluid between reservoirs.

1. INTRODUCTION

Fresh water is an essential natural resource on the blue planet [1]. It is used in all domestic, industrial, municipal and agricultural activities because it involves people who require the vital liquid [2, 3]. Preserving its consumption and rational use is one of the targets of the SDGs (Sustainable Development Goals). The SDGs are 17 global goals set by the UN in 2015 that seek equitable and sustainable development for all by 2030 [4].

In the aquaculture case, the water management is also fundamental. It varies according to the farming system, whether extensive or intensive. Aquaculture water management is vital for organisms' health and environmental sustainability [5, 6]. The monitoring and controlling water quality considers physical, chemical and biological parameters [7]. This action involves monitoring water quality, reusing it through recirculation systems, treating it to remove impurities and pathogens, and managing effluents to avoid contamination [8, 9].

In some countries, such as India, Ecuador, Vietnam, Indonesia, Thailand, China, Bangladesh, the United States, Mexico, and Brazil, aquaculture is positioned as a fundamental axis of the economy [10, 11]. Providing an effective and sustainable water circulation system is essential to guarantee the physiological development of crop species so that the receiving body receives the wastewater product of this activity without major affectations and contamination [12]. Typically, this recirculation system includes making a reservoir or regulation tank.

A reservoir is a natural or artificial hydraulic work that stores water collected from different sources [13, 14]. It can be a body of water or even be fed by a drinking water system to organize the distribution and consumption of the population [15]. Most reservoirs are a set of dikes, pipes and regulating devices [16], whose design must prioritize sizing to provide water of quality and in adequate quantity to meet the water demand required by the client [17]. The reservoir is also called regulation tanks because they have the capacity to manage and balance the flow of water.

The reservoir type depends on the water source collected, the implementation area's natural topography and demand. The main types of reservoirs are submerged and diversion [16]. Submerged reservoirs require excavation below the natural level of the ground, being fed by groundwater or rainwater. It is recommended that these structures be located in valleys or riverbeds, while diversion reservoirs are supplied in sloping terrain so that they are provided by gravity or pumping [9].

The regulation tank construction varies according to need. The reservoirs, whose depth varies between 0.50 and 1.50 meters, take advantage of photosynthesis and allow the temperature to remain stable, avoiding the proliferation of aquatic plants at the bottom [18]. Additionally, it is advisable to use a coating, such as bentonite or some geo-synthetic, to avoid water loss by infiltration into the soil so that the storage water receives treatment before recirculation [19].

In the last decade, geo-synthetics, and in this case, geomembrane, has had a greater boom due to its properties and ease of installation [20]. There are four types: low-density polyethene (LDPE), high-density polyethene (HDPE), polyvinyl chloride (PVC), and polypropylene (PP) [21]. HDPE is the most outstanding for reservoirs in aquaculture for its low price, high durability, and resistance in the weather under high chemical conditions or in contact with wastewater, which makes them easily adapt to changes [22].

Wastewater from aquaculture activities comprises organic matter, nutrients, suspended solids, chemicals, and salinity, among other dissolved substances [23]. Its treatment is essential, either for its recirculation or final disposal. Bacteria are vital in wastewater treatment because they naturally break down organic matter and nutrients, such as nitrogen and phosphorus. In this context, understanding the nitrogen cycle is important.

The nitrogen cycle is a biological and chemical process actively involved in the development of life in ecosystems, as it makes available vital nutrients for forming proteins, deoxyribonucleic acid (DNA) and other organisms. This process consists of: i) transforming the diatomic gas (N_2) into ammonia (NH_3) or ammonium ion (NH_4^+) by nitrogen-fixing bacteria (N), ii) transforming ammonia (NH_3) or ammonium ion (NH_4^+) into a more soluble and available form of nitrogen (N), such as nitrites (NO_2^-) and then into nitrate (NO_3^-) [24, 25]. Subsequently, iii) nitrates (NO_3^-) are assimilated by plants through the soil and by animals through plants or other animals, iv) plants and animals are broken down by bacteria after their death, forming ammonia (NH_3) and other derivatives [26]. v) in water-saturated soils with low oxygen, denitrifying bacteria transform nitrates (NO_3^-) back into diatomic gas (N_2), releasing them into the atmosphere. Finally, vi) nitrates (NO_3^-) leach into groundwater and surface water [25].

An alteration in the nitrogen cycle balance can increase or decrease nitrogen, which is harmful since it can generate eutrophication or water pollution [27]. Worldwide, many water bodies have become eutrophic, which can threaten their status as a water resource [28]. The waters of these bodies are used, without prior treatment, for domestic, agricultural and livestock use by the people who live near them [29].

The source of the catchment is an ideal option that allows maintaining water quality control for the species, in addition to the fact that this does not depend on whether the supply capacity will be throughout the year or by seasons [30]. Additionally, this source becomes the first indicator of the water quality that the crop will receive to comply with SDGs 6 Clean water and sanitation, 12 Responsible production and consumption, 13 Climate action and 14 Life below water of the agenda for 2050 [4].

The Marine and Aquaculture Research Center (CENAIM) is located in a rural area called El Palmar in Santa Elena, Ecuador, with 14.5 hectares. The CENAIM experimental station has four sectors (A, B, C, and I) that add up to 84 pools fed from an existing reservoir surrounded by mangroves (Figure 1). Mangroves, recognized for their unique properties and environmental benefits, are conservation areas that provide critical habitats for diverse species, protect coasts from erosion, treat water from some pollutants and act as carbon sinks. However, according to national environmental regulations, mangroves are conservation areas with strict restrictions on civil construction, representing a challenge for research.

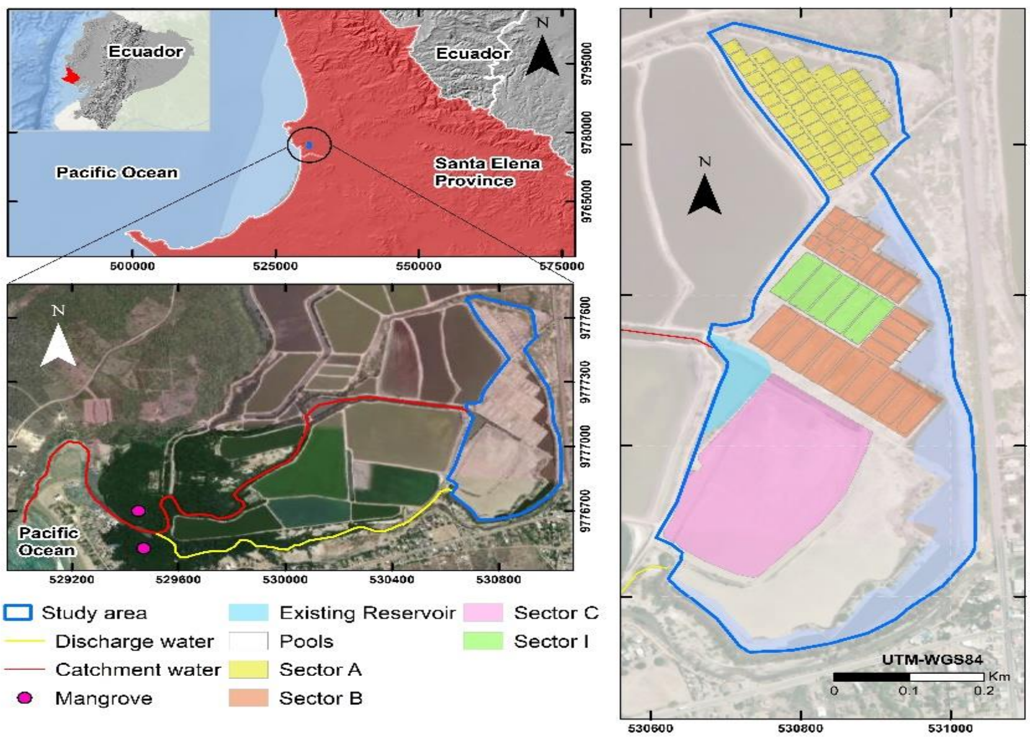

Figure 1. Location of the CENAIM experimental station

Therefore, the study aims to design the regulation tanks applying technical, economic and environmental criteria for the correct operation and sustainable use of the Aquaculture and Marine Research Center (CENAIM) experimental station. This study is necessary because the water entering the reservoir does not meet the quantity and quality required for the growth and development of the shrimp that live in the experimental centre's current pools. This study's objective is to support CENAIM's mission and vision, which seeks to improve and sustainably develop aquaculture and marine biodiversity in Ecuador through scientific research, technological development, training, and dissemination.

The technical ones involve the sizing, the type of coating membrane and the effluent flow rate. The economic criteria include the cost of excavation and supplies necessary for the construction of the tanks. The environmental criteria allow little impact of the civil works on the mangroves that surround the pools and allow the correct operation and sustainable use in terms of long-term availability of the water resource needed by the marine species that inhabit the pools of experimental station of the Centre for Aquaculture and Marine Research (CENAIM).

2. METHODOLOGY

The methodological approach focuses on the experimental analysis of aquaculture that lacks water resources and anomalies within some physical-chemical parameters such as BOD, nitrogen and dissolved oxygen in the pools. Which is aggravated by its geographical location and coastal environment, it presents high levels of salinity. Therefore, the inclusion of recirculating regulator tanks is important.

In this research, the methodology applied three stages: i) data collection and processing, ii) design of technical proposal, (iii) proposals for strategies for the efficient use of the system (Figure 2).

2.1 Data collection and processing

The review of previous studies provided by CENAIM consisted of a topographic survey, geophysical prospecting studies and technical specifications of the pumping station pumps. The topography and bathymetry allowed us to corroborate that the measurements of the pools and reservoir have mostly remained the same compared to the last survey.

Additionally, the study employed an analysis using the Likert-type scale considering 14 parameters that affect direct or indirect, as detailed in Table 1. The Likert-type scale was selected in this study because it is a valuable tool in research due to its simplicity, ability to measure attitudes and perceptions, ease of statistical analysis, flexibility, and reliability. These features make it a popular and effective choice for a wide range of studies, allowing researchers to obtain detailed and meaningful information efficiently and economically [31]. The selected alternative continued to stage II of the design.

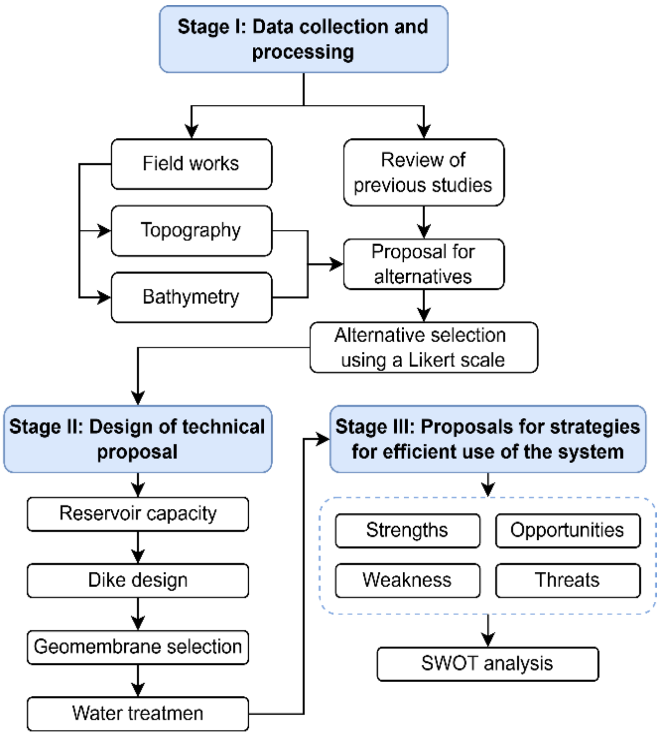

Figure 2. Methodological scheme for the technical reservoir

Table 1. Description of the parameters of the multifactor matrix

	Parameters	Definition
1	Construction cost	All inputs that generate an economic value to the construction site, such as raw materials, machinery, e g.
2	Operating cost	All inputs that generate an economic value to keep the site in operation.
3	Maintenance cost	All inputs that generate an economic value after completion of the work for maintenance and restoration.
4	Construction period	The parameter is the start and end time of the work, established by the schedule.
5	Construction area	Location of the construction site.
6	Ease of maintenance	The time it takes to put the site back into operation after maintenance.
7	Component service life	Estimated duration of the components of the work.
8	Technical difficulty	Obstacles preventing the work from being carried out.
9	Modularity and future scalability	Ability to redesign the work, adding elements so that the interaction between them meets the project's needs.
10	Available technology	Exploiting existing technology.
11	Pollution of water bodies	Affecting water resources, altering the life cycle of the species typical of this ecosystem.
12	Impact on flora and fauna	It affects the terrestrial resources, altering the species' life cycle typical of this ecosystem.
13	Water availability	Bodies of water near the project site.
14	Quality of water supply	The physical, chemical and biological parameters should comply to meet the species' physiological needs.

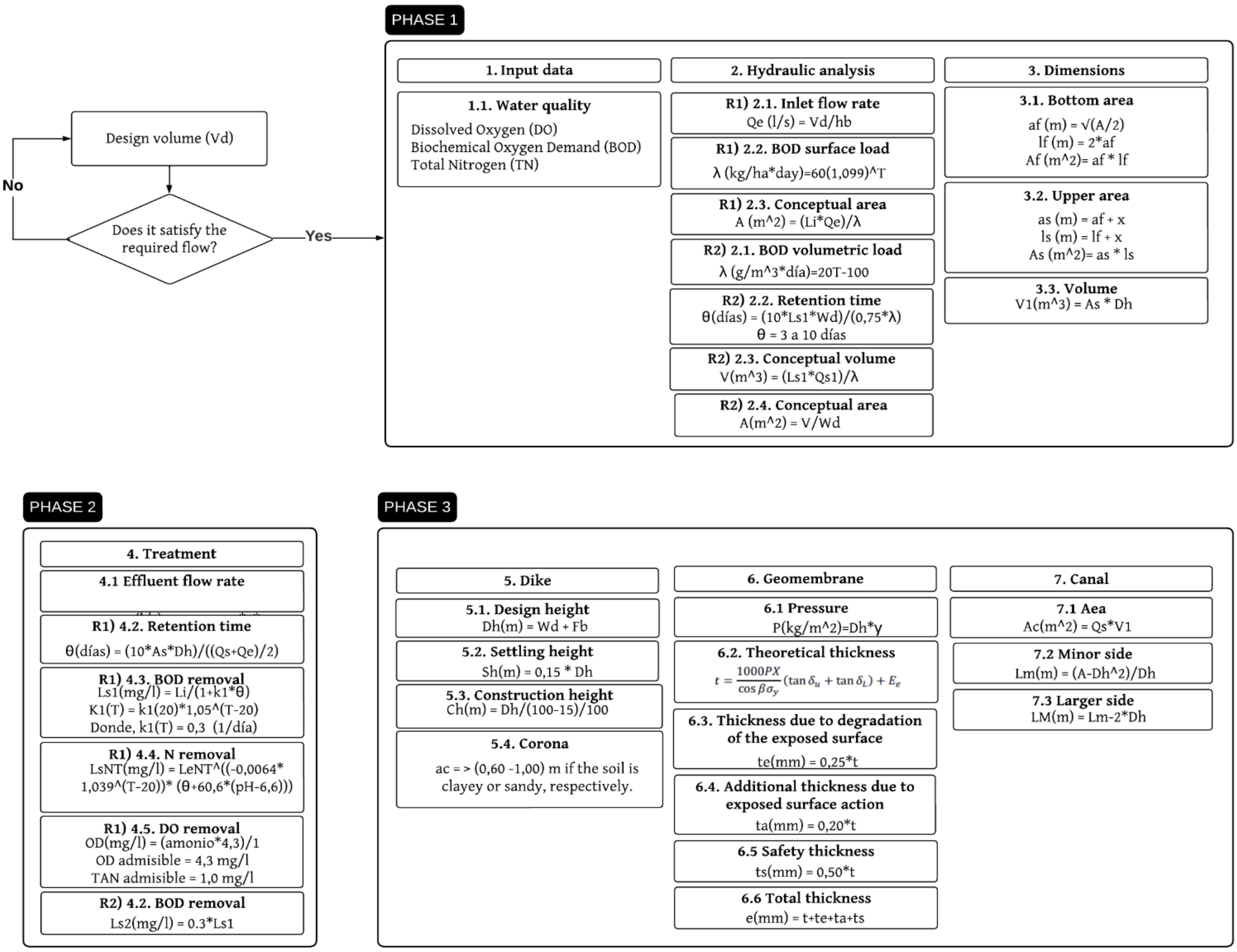

Figure 3. Design scheme of technical proposals for the recirculation and efficient use of water in the system

2.2 Design of technical proposal

The design of the regulation tanks must meet the demand and quality of water required by aquaculture species so that it has optimal growth and physiological development. In the Figure 3, a design scheme made in three stages is shown:

(1) In stage 1, using the input data and the established hydraulic analysis allowed the dimensions of each reservoir to be determined.
(2) The stage 2 designated the type of treatment each reservoir will receive before reusing the water.
(3) In stage 3, the dam was designed using the amount of geomembrane required to cover the reservoirs and the estimation of the flows that each one will transport from one reservoir to another.

Certain criteria were important in selecting the type of membrane: resins free of polyethene and additives, resistance to UV rays, essential due to the high temperatures in "El Palmar," high physical durability, chemical and thermal resistance, and low cost (important for OPEX cost).

2.3 Proposals for strategies for the efficient use of the system

A SWOT analysis was carried out to establish effective strategies and actions for the development of the species. This analysis consisted of analysing the internal and external factors described in the project to identify the elements that can contribute to the success of the project, as well as those that have the potential to hinder or jeopardise the achievement of the proposed objectives.

3. RESULTS

3.1 Design alternatives

The information collected was fundamental to compare the dimensions found in the studies shared by CENAIM concerning the survey carried out, which can be observed in detail in Table 2.

The alternatives proposed were three:

(1) Alternative 1: Redesign of the reservoir with wastewater treatment.
(2) Alternative 2: Design the water recirculation system with a purification system.
(3) Alternative 3: Redesign of the collection system.

Table 2. Detailed information on pool sections

Section	Number of Pools	Size [ha]	Total Area [m^2]	Total Volume [m^3]
A	49	0.03	18.037,26	9.018,63
B	29	0.03-0.3	29.269,17	14.634,59
C	1	5.00	45.561,70	22.780,85
I	5	0.25	10.529,37	5.264,68

Table 3. Multifactor matrix for choosing the optimal alternative

Alternative / Assessment Parameter	Factor	Alternative 1		Alternative 2		Alternative 3	
		Score	Total	Score	Total	Score	Total
Economic Aspect							
Construction cost	10%	3	0.3	3	0.3	2	0.2
Operating cost	10%	5	0.5	5	0.5	5	0.5
Maintenance cost	10%	3	0.3	3	0.3	3	0.3
Technical Aspect							
Construction period	4%	5	0.2	4	0.16	4	0.16
Construction area	5%	5	0.25	5	0.25	5	0.25
Ease of maintenance	10%	4	0.4	3	0.6	3	0.3
Component life	5%	5	0.25	5	0.25	5	0.25
Technical difficulty	5%	5	0.25	5	0.25	5	0.25
Modularity and future scalability	5%	4	0.2	4	0.2	4	0.2
Available technology	8%	5	0.4	5	0.4	5	0.4
Water availability	5%	4	0.2	4	0.2	4	0.2
Water supply quality	8%	5	0.3	5	0.3	5	0.3
Environmental Aspect							
Contamination of water bodies	8%	5	0.4	3	0.24	2	0.16
Impact on flora and fauna	7%	5	0.35	4	0.28	4	0.28
Total	100%		**4.3**		4.23		3.75

The optimal proposal was selected using the multifactorial Likert matrix, which allows it to be assessed using numerical factors (Table 3).

From the multifactor Likert matrix analysis, Alternative 1 was obtained with a score of 4.3 out of 5. Therefore, alternative 1 is the optimal solution for the problem posed, which proposes the redesign of the reservoir with biological wastewater treatment. In addition, it was indicated to place an HDPE geomembrane to avoid losses due to infiltration through the soil.

3.2 Design of technical proposal

In stage 1, the input data for reservoir one and reservoir two were obtained, as shown in Table 4.

The hydraulic analysis was carried out for each reservoir, where the results obtained are observed in Table 5.

In addition, other parameters determined the dimensions of each reservoir, as shown in Table 6.

Table 4. Inlet water quality parameters

Parameter	Unit	Reservoir 1	Reservoir 2
Dissolved oxygen	mg/l	3,8-6,2	0,43
Biochemical oxygen demand	mg/l	4,3-23,2	6,96
Total nitrogen	mg/l	1,3-2,2	0,27
Temperature	°C	14,4-33,1	14,1-33,1

Table 5. Hydraulic analysis of the reservoirs

Parameter	Unit	Reservoir 1	Reservoir 2
Inlet flow Rate	l/s	262	261
Surface Load	Kg/Ha*day	233	-
Volumetric Load	g/m^3*day	-	188

Table 6. Geometric design of the reservoir

Parameter	Unit	Reservoir 1	Reservoir 2
Height of the Water Mirror	m	1,50	0,80
Dimensions	m	50x95	95×80×50×70×140
Area	m^2	4.750	11.200
Volume	m^3	9.500	14.600

In the second stage, the reservoirs received a treatment before reusing the water. Reservoir 1 received an aerobic-anaerobic process treatment, commonly used in facultative lagoons. Reservoir 2 received an aerobic process treatment, commonly used in maturation lagoons, which takes advantage of the effluent from reservoir one, which has a dissolved oxygen level of approximately zero. So, combined with carbon dioxide, water, sunlight and aquatic plants, it transformed into glucose and released as dissolved oxygen, as observed in Table 7.

In stage three the parameters and measurements used for the design of the dikes are shown Table 8.

Table 7. Output parameters according to type of treatment

Parameter	Unit	Reservoir 1	Reservoir 2
Effluent flow rate	l/s	261	257
Nitrogen (N)	mg/l	0.37	0
BOD removal	mg/l	6,96	2,08
Dissolved Oxygen removal	mg/l	0,43	3,8

Table 8. Dike dimensions of the reservoirs

Parameter	Unit	Reservoir 1	Reservoir 2
Design height	m	2,0	1,3
Water height	m	1,5	0,8
Free edge	m	0,5	0,5
Settling height	m	0,3	0,2
Construction height	m	2,3	1,5
Crown	m	4,0-5,5	4,0-5,5
Slope	-	1:1	1:1

Table 9. Hydraulic design of canals

Parameter	Unit	Reservoir 1 and 2
Flow rate	l/s	262
Velocity	m/s	1,2
Slope	-	1:1
Tension	m	0,2
Area	m^2	0,2
Minor side	m	0,9
Larger side	m	1,3
Length	m	5-5,5

Based on the dimensions of the reservoir, it was obtained that the amount of HDPE geomembrane required is 5,200m^2 for Reservoir 1 and 12,700m^2 for reservoir two, both with a thickness of 1.5mm and the reservoir design used six channels. The hydraulic design of the channels is shown in Table 9. Of these, three channels connect the current reservoir to reservoir one and three channels connect reservoir one to reservoir two.

3.3 Proposals for strategies for the efficient use of the system

In Figure 4, the strengths, opportunities, weaknesses, and threats found in this project's development are described.

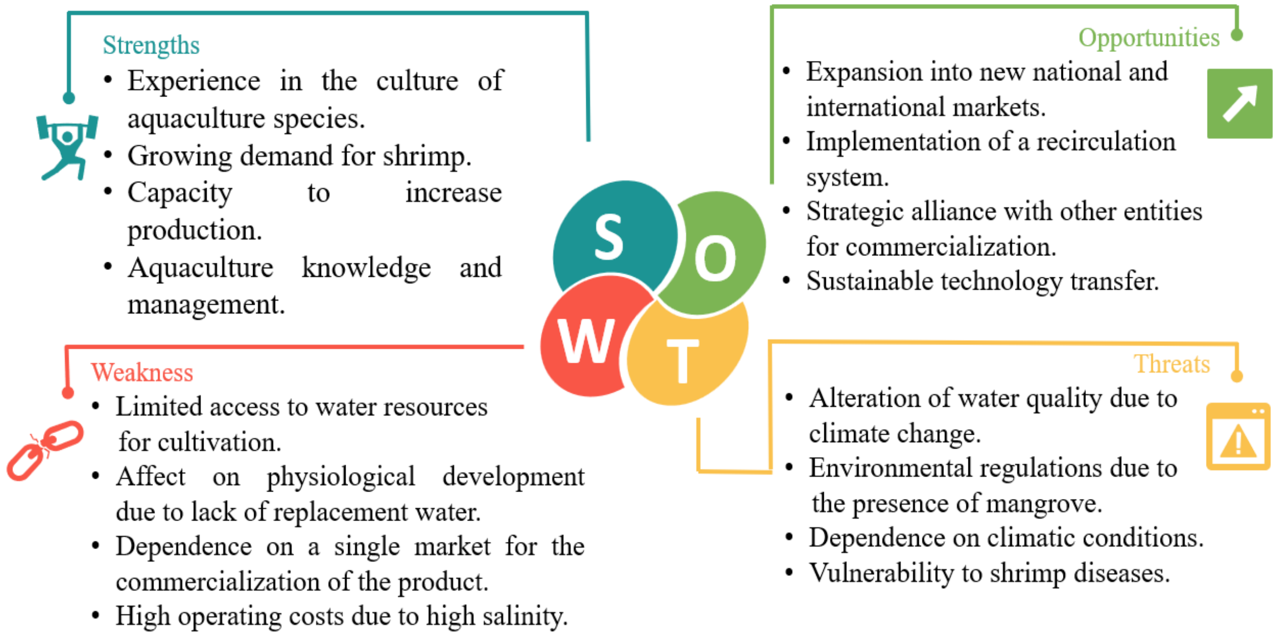

Figure 4. SWOT analysis of strategies for the efficient use of the system

4. DISCUSSION

This research proposes two reservoirs that meet the technical, economic and environmental parameters. The design includes a volume of 9,500m^3 for Reservoir 1 and 14,560m^3 in Reservoir 2, having a total volume of 24,060m^3. According to the SWOT analysis, there are environmental impacts in the study area because mangroves surround it, and its removal would affect the local ecosystem. In this context, the channels were designed in a trapezoidal shape, making it possible to take advantage of the land area and locate them in one of the already disturbed areas of the experimental station, thus preserving the mangrove and, at the same time, reducing the fill volumes for the embankments of the reservoirs.

The reservoirs are designed to promote species' growth through water recirculation, aiming at SDG 12 of Responsible Production and Consumption [12]. This process, common in aquaculture in other countries with reservoirs, ensures compliance with the volume, flow and quality requirements of water for optimal cultivation [10, 11]. According to previous studies [22], HDPE membranes in the tanks ensure durability and resistance to chemical conditions. The design of this proposal mitigates the problem of the average levels of pollution coming from the effluent of sector C. In addition, the elimination of nitrogenous compounds that pose challenges for aquaculture around the world in the pools promotes the proliferation of aquatic plants [32, 33].

The treatment process in Reservoir 1 (optional) is aerobic-anaerobic, so photosynthesis and surface aeration provide sufficient oxygen to treat the water [18]. On the other hand, [34] explained that different species have varying levels of tolerance to dissolved oxygen (DO). DO levels play a critical role in fish growth and welfare, with levels below 1-2mg/L adversely affecting fish growth and leading to fish death and compared with this study for the DO of Reservoir 1 meets to this rule letting to shrimp grow up in optimal conditions. However, in case of Total nitrogen parameter is still high in Reservoir 1 when Chen et al. [35] explain that the ammonia-nitrogen content exceeds 0,2mg/L, it can cause harm to aquatic organisms. While Reservoir 2 (maturation) carries out an aerobic treatment, which reduces the contamination that was not removed in Reservoir 1, guaranteeing a level of water quality suitable for use [17].

These results could bring some benefits, among the most important of which we have to reduce water consumption through the use of recirculation and treatment technologies, promoting a more sustainable use of water resources. Additionally, implementing more efficient water management and quality control systems can reduce costs associated with water treatment. However, this study has not yet proposed the use of advanced sensors and automated systems for reservoir management or using the data collected to develop predictive models that optimize water management and aquaculture production.

The main limitation of the study, by the production needs of the Center, is the need for more water sources that satisfy the quality and quantity of fresh water required for aquaculture species due to the increase in salinity by evapotranspiration. In this context, a future line of research would be to conduct geophysical studies to find new sources of fresh water which meet the quantity and quality necessary for the conditions of aquaculture species.

5. CONCLUSIONS

Based on a comprehensive analysis using the Likert scale whose approach encompasses the technical, economic and environmental part of the research carried out two regulation tanks were designed which meet the volume, flow and quality of water required for the optimal cultivation of aquaculture species. By current regulations, each reservoir has a biological treatment, the facultative (reservoir one) and the maturation (reservoir two).

The discharges comply with Annex I of Book VI of Unified Text of Secondary Environmental Legislation (TULSMA in Spanish acronym) (Table 3) and the quality parameters for aquaculture species of the CENAIM experimental station. Additionally, the treatment of each reservoir has a removal efficiency of 90% and a final BOD concentration of 2.09mg/l in the discharge, ensuring that the water is suitable for both preliminary reuse and final disposal in a receiving body.

Additionally, management guidelines were proposed for the efficient use of the system through the correct management of energy, which was exploited with the design of trapezoidal channels that transport the fluid from one reservoir to another, applying the principle of gravitational potential energy. Using canals makes it unnecessary to use electric pumps, guaranteeing the energy efficiency of an aquaculture system and mitigating the effects of climate change regarding the use of non-renewable energy.

This improvement's benefits can have multiple positive impacts in the short, medium and long term, including reducing water pollution and allowing for healthier ecosystems. It will also allow for water conservation, reducing waste, and promoting sustainable water resource practices. It will allow an increase in shrimp productivity, improving the profitability of aquifer operations and reducing operating costs. In the social part, community sustainability would be highlighted, contributing to the well-being of local communities, promoting a balance between economic development and environmental conservation.

On the other hand, there are three possible areas of research: the use of waste (sludge) from wastewater from swimming pools to improve the soil surrounding the mangrove forest or sustainable and durable materials that minimize the environmental impact and improve the useful life of the reservoir. Finally, the third line of research would be the integration of renewable energy sources, such as solar or wind, to reduce the carbon footprint of CENAIM.

Economically, the design has a reference budget of $296,589.48, with the construction and maintenance costs being the highest, while the operating expenses are the lowest due to the optimal recirculation design implemented. This budget considers the construction stage of the environmental management plan. The project's environmental consideration reveals that the existing infrastructure's area is used in such a way that the fill volumes for the reservoir embankments are reduced, and another part of the area is not used, avoiding the felling of the mangrove.

With all of this data, a water collection system would be implemented where the CENAIM experimental station would have greater flexibility, mitigating the effects of climate change on water resources and reducing the ecosystem alteration of the endemic species that inhabit them.

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NOMENCLATURE

A	Area, m^2
A_a	Anchors area, m^2
A_t	Slope area, m^2
A_b	Border area, m^2
BOD	Biochemical Oxygen Demand
Ch	Construction height of the Dike
D	Depth, m
Dh	Design height of the Dike, m
Ee	Additional thickness due to erosion during installation, mm
K_1	Removal constant (1/day)
L_s	Output BOD, mg/l
L_sNT	Nitrogen Removal, mg/l
DO	Removal of dissolved oxygen, mg/l
P	Pressure, Kg/m^2
Q_e	Inlet flow rate, l/s
Sh	Settling height, m
T	Temperature, °C
t	Theoric thickness, mm
te	Additional thickness due to degradation of the exposed surface, mm
ta	Additional thickness due to exposed surface action, mm
TN	Total nitrogen, mg/l
ts	Safety thickness, mm
e	Total thickness, mm
V	Volumen, m^3
X	distance at which the deformation is mobilized, m

Greek symbols

θ	Retention time, (5-30 days)
λ_s	BOD surface load, g/m^3*day
γ	Water density, kg/m^3
δ_u	Friction angle between the upper material and the membrane, °
δ_L	Friction angle between bottom material and membrane, °
σ_y	Geomembrane yield stress, kg/m^2
β	Angle between the horizontal and the inclination of the slope of the interior wall of the reservoir, °