DOI: 10.24850/j-tyca-2025-06-10

Articles

Implementation of a pumping system using a hydraulic turbine without electric power consumption

Implementación de un sistema de bombeo utilizando una turbina hidráulica sin consumo de energía eléctrica

Camilo Andrés Tovar-Trujillo[1], ORCID: https://orcid.org/0009-0009-6860-9078

Juan Gonzalo Ardila-Marín[2], ORCID: https://orcid.org/0000-0003-4461-7195

Jean Carlos Acosta-Vargas[3], ORCID: https://orcid.org/0009-0003-5266-1556

[1]Universidad Surcolombiana, Neiva, Colombia, ca.andres_08@hotmail.com

[2]Universidad Surcolombiana, Neiva, Colombia, juan.ardila@usco.edu.co

[3]Universidad Surcolombiana, Neiva, Colombia, jean.acosta@usco.edu.co

Corresponding author: Jean Carlos Acosta-Vargas, jean.acosta@usco.edu.co

Abstract

Due to the increasing food demand in Colombia and worldwide, it is imperative to mechanize the agricultural sector and implement new technologies to improve production. The GEOMAAC Engineering Technology Centre has implemented a hydraulic-powered pumping system at La Esperanza farm (Rivera-Huila) to address the water needs during dry seasons. The pump transports 70 m³/day of water to a reservoir located at 32.32 meters in height for storage and distribution, ensuring sufficient forage for livestock. Two pumping systems were compared: The ZM Maxxi pump and a conventional electric pump. Although the ZM Maxxi has a higher installation cost, the conventional electric pump incurs an annual electricity consumption cost of 12 146 112 COP ($USD 2 958). The use of the ZM Maxxi, which utilises renewable energy, allows for annual savings of this amount. After conducting economic and design studies, the ZM Maxxi was selected, and its installation was carried out. The pump delivers 68 570 litres of water daily, benefiting the higher areas of La Esperanza farm and allowing the investment to be recouped in the medium term

Keywords: Hydraulics, alternative pump, renewable energies, irrigation systems, pumping.

Resumen

Debido a la creciente demanda alimenticia en Colombia y el mundo es urgente mecanizar el campo e implementar nuevas tecnologías en el sector agrícola para mejorar la producción. El Centro Tecnológico de Ingeniería GEOMAAC implementó un sistema de bombeo con energía hidráulica en la finca La Esperanza (Rivera-Huila) para suplir la necesidad hídrica en épocas de estiaje. La bomba transporta 70 m³/día de agua a un reservorio a 32.32 metros de altura para su almacenamiento y distribución, lo que permite obtener suficiente forraje para la ganadería. Se compararon dos sistemas de bombeo: la bomba ZM Maxxi y una electrobomba convencional. Aunque la ZM Maxxi tiene un mayor costo de instalación, la electrobomba tiene un costo anual de consumo de energía eléctrica de 12 146 112 COP ($USD 2 958). El uso de la ZM Maxxi, que utiliza energía renovable, permite ahorrar este monto anualmente. Tras los estudios económicos y de diseño, se seleccionó la ZM Maxxi y se procedió a su instalación. La bomba entrega 68 570 litros de agua diarios, que benefician la parte alta de la finca y permiten recuperar la inversión a mediano plazo.

Palabras clave: hidráulica, bomba alternativa, energías renovables, sistemas de riego, bombeo.

Received: 14/10/2024

Accepted: 14/03/2025

Available ahead of print: 31/03/2025

Version of record: 01/11/2025

Introduction

Agriculture is no longer limited to transferring resources for the promotion of industrialisation but has become a sector capable of playing important roles in economic development (Bermeo-Mayancela, 2022). In Colombia, the agricultural sector generates about 20 % of employment in the country, and almost 50 % in the rural sector (Leibovich & Estrada, 2008).

In July 2024, approximately 3.3 million workers were registered in the Colombian agricultural sector (UPRA, 2024). An integrated plan for the sector should take into account the relationship between agricultural mechanisation and natural resources, where the machine interacts with each resource and the resources with each other, where contamination of one affects the other (Díaz-Rodríguez, & Pérez-Guerrero, 2007). Technology is applicable in the areas of agriculture, allowing the reduction of time and costs of the different agricultural tasks (Santos, 2018), the producers must be open to good agronomic, technological and mechanisation practices (Gras & Hernández, 2016), however, a total use of the machinery has not been reached, mainly due to the high value of the equipment, since most of these are imported (Polanco-Puerta, 2007).

Most of the water in Colombia is collected and distributed by gravity; in very few cases, irrigation is collected and distributed by pumping, i.e. it has a system of pumps and energy consumption for its operation (Palacio-Castañeda, 2010). In La Esperanza (located in the municipality of Rivera-Huila), The largest existing demand is for crops, in descending order cocoa, managed pastures, transitory crops, domestic use, permanent crops and livestock use. For the periods of June, July and August there is no water available to satisfy the demand for the resource. The La Esperanza farm lacks alternatives for the improvement of its irrigation systems for its fodder crops for livestock, since, in times of low rainfall, the feed is deficient for these animals and consequently, the products derived from these animals do not have the same yield. In the upper part of the farm there is a reservoir that is fed by tributaries and fish farms that are very close to the farm, which is used by the livestock crops, given that most of the farm's agriculture is located in the lower parts of the area, where there is a dam that is fed by the Río Frío and maintains a good permanent level. Figure 1 shows the longitudinal profile from the dam to the reservoir, which has a height difference of 22 m and a distance of 652 m.

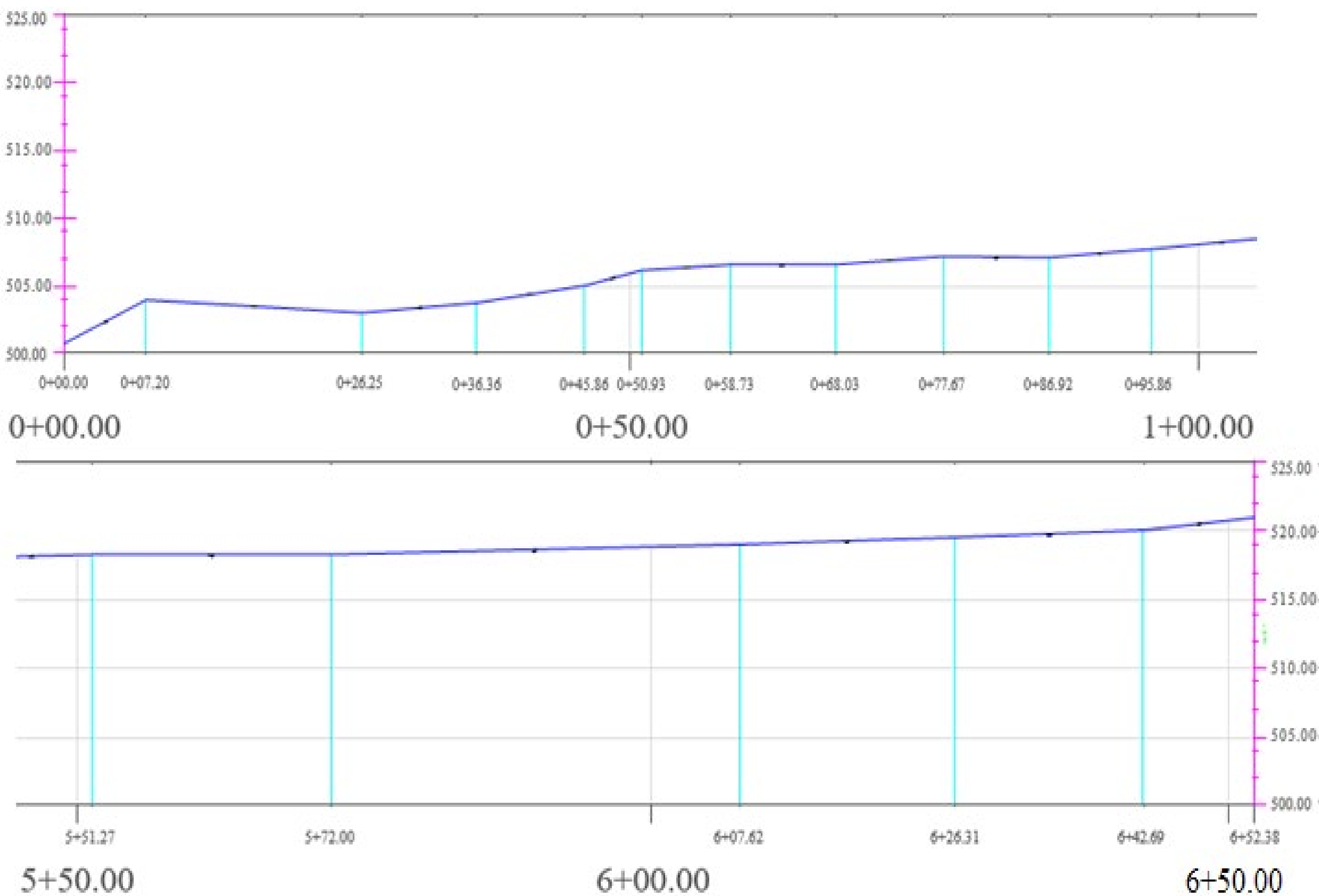

Figure 1. Longitudinal profile of the terrain (section of 0 a 100 m and from 550 a 652 m).

The use of the upper waters and their efficient use is of great importance to produce fodder crops for livestock, but in the dry season the reservoir does not maintain an adequate level for irrigation in the area. Based on these facts, the main problem was the low use of the upper part of the farm due to the fact that in the dry months there was not enough water for fodder production.

At the GEOMAAC S.A.S. Engineering Technological Centre, this project arose with the objective of implementing a pumping system without the use of electrical energy for the production of fodder for livestock on the La Esperanza farm, for which it was necessary to calculate and select a ZM® hydraulic pump appropriate to the site conditions in order to proceed with its installation, verify the start-up of the implemented system, and demonstrate the advantage of this system compared to others. The selection of the ZM® brands, for pumping with hydraulic energy, and Pedrollo®, for conventional pumping with electric energy, in order to make a comparison, is appropriate and necessary for the study, due to the fact that both manufacturers are accessible in the local market, which facilitates their implementation and maintenance. And limiting the analysis to only two manufacturers with markedly different technologies ensures a focused methodology, avoiding diluting the results in an overly broad comparison, which allows for a deeper analysis of each system, highlighting the advantages and limitations of each within the agricultural context.

Purpose of the project

The project sought the implementation of a pumping system without electricity consumption for the production of fodder for cattle on the La Esperanza farm. To this end, it was proposed to calculate and select the appropriate ZM® hydraulic pump for the site conditions, verify the implementation of the system and demonstrate the advantages of this system compared to a conventional alternative that would consume electricity.

In La Esperanza, in times of drought, the production of fodder for livestock was minimal. With the implementation of this hydraulic pumping system, which uses the hydraulic energy of the outgoing flow of the dam to pump water to the upper areas without consuming electricity, it was possible to improve the agricultural generation of the crop, which will mean an improvement in terms of yields and longevity of the crop, in addition, it will improve the quality of life of the inhabitants of the farm. Figure 2 shows a global scheme of the system developed in this project, with the aim of guiding the reader to improve their understanding of the sections that describe the design methodology and comparison between the two technologies described and the results and discussion that lead to the conclusions of this study.

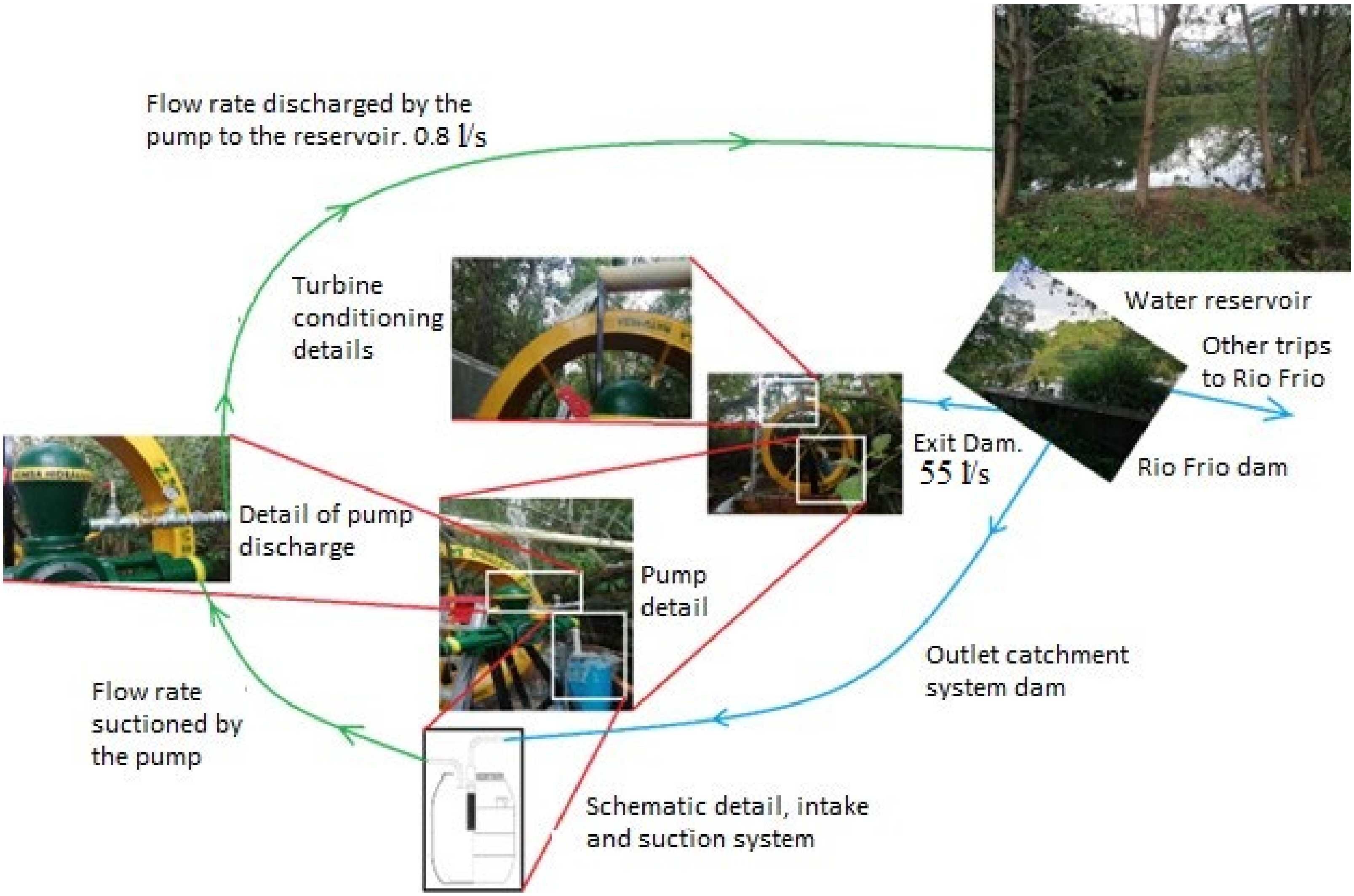

Figure 2. Overall project outline.

Materials and methods

Problem specification

The farm "La Esperanza" is located in the village of Río Frío approximately ten minutes from the city of Neiva, belonging to the municipality of Rivera, in the sub-basin of Río Frío, which covers an area of approximately 62 km^2, representing 16.7 % of the area of the municipality of Rivera. Figure

3 shows the location of the municipality. Among the main rivers are: Río Negro, Río Blanco and La Dinda, which supply the aqueducts of the urban area of Rivera and the villages of Salado, Alto Guadual and Llanitos, and also supply the rural area of the villages of Termopilas, Alto Pedregal and part of Bajo Pedregal. According to the CAM (Corporación Autónoma Regional Del Alto Magdalena), the biggest existing demand is for crops, but for the periods of June, July and August there is no water available to meet the demand.

Tecnología y Ciencias del Agua

OPEN ACCESS

Check for updates

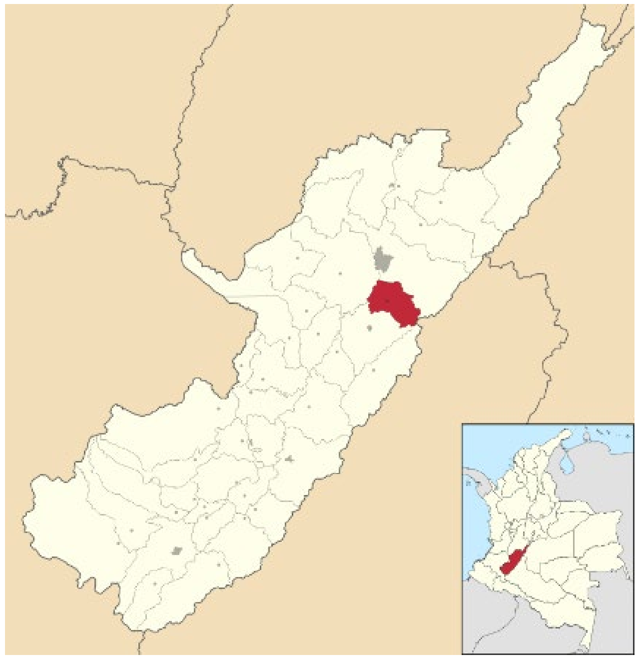

Figure 3. Location of the municipality of Rivera (above); farm La Esperanza, and project location (below).

Initially, the site was surveyed in order to get an idea of its location, size and distribution. The property is used for different farm activities, such as cattle raising, horse breeding and maize cultivation. The farm also has large wooded areas and the Río Frío River flows through it, supplying water for the various agricultural activities in the area. Using Google Earth software and the indications given by the owners of the property, we were able to obtain the exact location of the area, as well as its limitations, in order to subsequently carry out the topographic survey.

Figure 3 demarcates the boundaries of the farm and locates, at the point denoted as "Bomba Pelton", the location of the outlet of the dam that provides a flow rate of 55 l/s that will drive the water wheel to pump the water resource to the "Reservorio" which is fed by tributaries and fishponds that are very close to the property, but which in the dry season does not maintain the adequate level for irrigation in the area. Figure 3(b) shows the layout of the water conduction line from the lower dam to the reservoir. The topography of the terrain was taken with the help of an EVO II Pro 6K drone supplied by the GEOMAAC S.A.S. company, a high-resolution map was created with the cartographic details and with this the information provided was corroborated, the map produced can be seen in Figure 4. The areas for maize cultivation, wooded areas, pastures, the reservoir, the dam, the location of the farm and even the access roads were accurately identified. The most relevant information is reported in Table 1. Once all the field information was obtained from the survey, we proceeded with the digitisation and data processing. With the support of ArcGIS® software, planimetry maps, contour lines, a digital elevation model and an orthomosaic of the property were created.

Figure 4. Detailed map farms La Esperanza.

Table 1. Relevant topographical and cartographical data farm La Esperanza.

Coordinates		Maximum building height	Minimum site height
86.3503, 75 E	80.2051, 30 N	611 masl*	468 masl

*Metres above sea level.

ZM hydraulic pump

The work done by the ZM hydraulic pump uses the kinetic and potential energy of a flow of water that moves a turbine (wheel) to harness that energy, see Figure 5. The motion or energy is transferred to a shaft, which rotates a pump, which sucks in the water and then drives it. It does not require conventional energy such as electricity or petroleum derivatives (Guaña-Quilumba & Quishpe-Sacancela, 2018).

Figure 5. ZM Maxxi Bomb. Source: ZM Bombas (2020).

Tecnología y Ciencias del Agua
OPEN ACCESS
Check for updates

The ZM Maxxi pump is a double-acting reciprocating pump that harnesses the hydraulic energy produced by the momentum of the water in the pockets of a metal wheel, this weight of water causes the wheel to rotate and by using an eccentric point (3) (Figure 6), on a metal disc (1), the movement of two pistons (4) is produced, which in practical terms work like syringes, sucking and propelling the water through the check valves (7 and 8) which allow the water to pass into the air capsule (9) and from there into the pumping pipes.

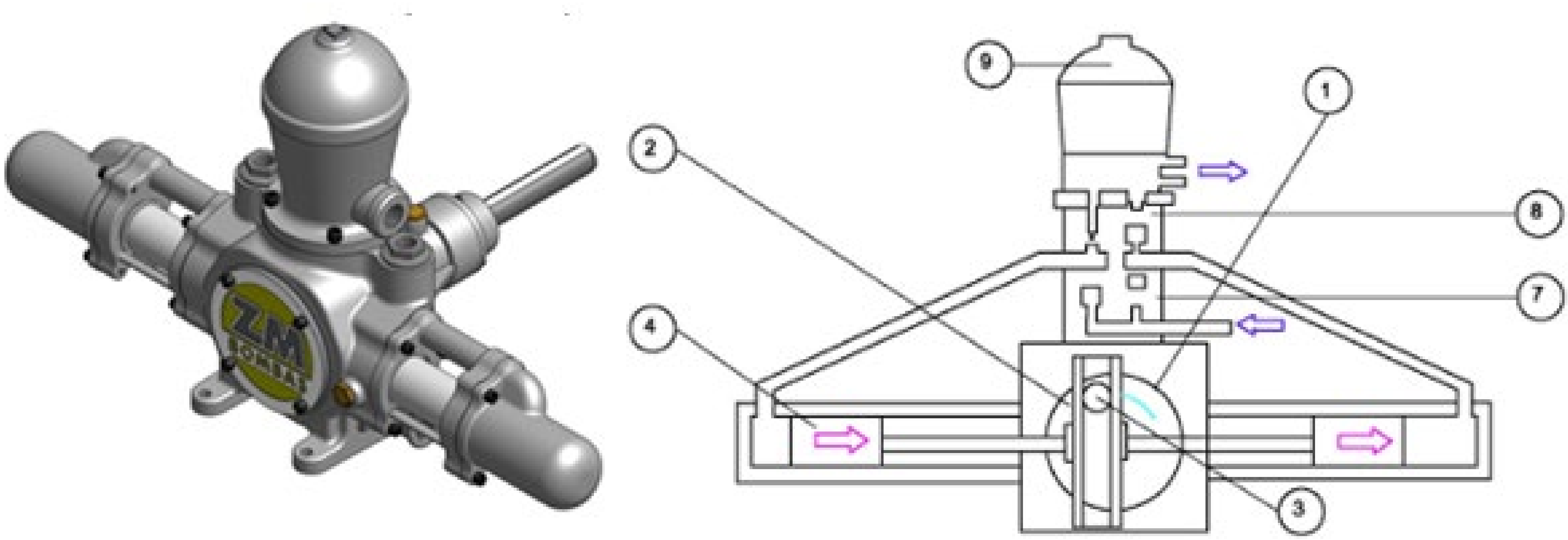

Figure 6. Cross section ZM Maxxi pump. Source: ZM Bombas (2020).

Electric pump with peripheral impeller

The peripheral pump (Figure 7) is now presented as the alternative to be considered in this project, as one of the goals is to demonstrate the feasibility and suitability of using the pump with a hydraulic power source; peripheral impeller pumps are similar to centrifugal pumps, with the difference that in this type of pump the liquid does not enter the casing axially but peripherally as the discharge (1), and in the casing it is driven from the inlet (suction) to the outlet (discharge) by means of the impeller blades (2) at very high speeds, inside the annular channel (3) where it rotates after making a path of almost 360°. The pump body is coupled axially to the electric motor, but the coupling (4) houses a seal (5) that prevents the passage of fluid to the motor, thus avoiding short circuits. The impeller receives mechanical power from the rotor of the electric motor through the shaft (6) which rotates freely enough supported by deep groove ball bearings (7) which are sealed and lubricated with grease inside. The squirrel cage rotor and its laminates rotate by electromagnetic induction following the rotating magnetic field caused in the stator winding (8) by the electric current that is fed by the terminals at the top of the motor of the electric pump and that is consumed and determines the operating cost that will be analysed later to make the techno-economic comparison between the two technologies in this study.

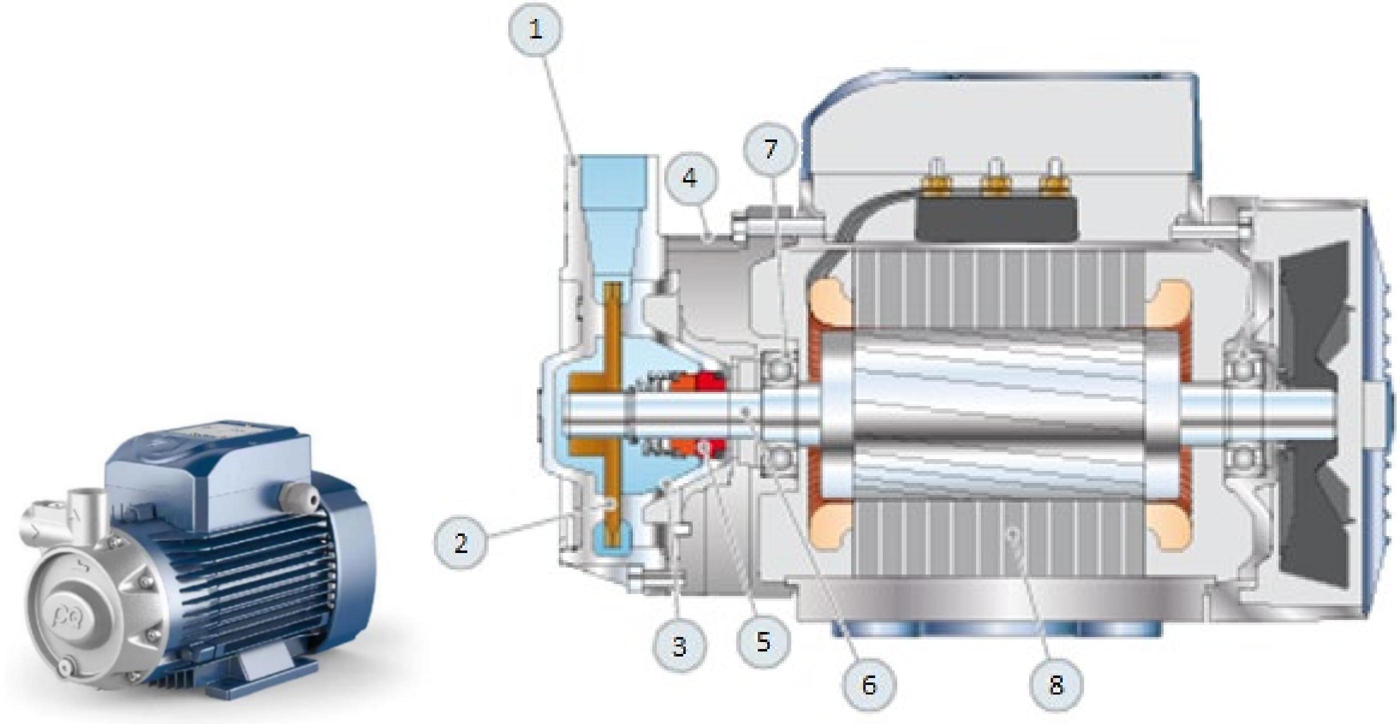

Figure 7. Peripheral electric pump Pedrollo® with cross-section.
Source: Pedrollo (2023).

ZM Pump selection

For the calculation and selection of the ZM pump, it was first necessary to establish what the needs are, since the pipe diameter, losses and maximum discharge head are sized on the basis of these needs. The difference in height of 22 m and the distance to which the water must be taken of 688 m, which were defined by means of the topographic survey, in addition to the flow rate, which is 70 m^3/day, were also considered. Once the above was defined, the manufacturer's technical manual suggested by the company was consulted. The pump model is defined on the basis of the assessment of the head and flow rate in the manufacturer's catalogue, which meet the established conditions.

Accordingly, once the pump model to be used has been chosen, the regulation mode that best suits the conditions of the supply system is established, i.e. the setpoint curve shown in Figure 8. Once the pump to be used is clear, the diameter and width table of the wheel that will be responsible for driving the entire system is used.

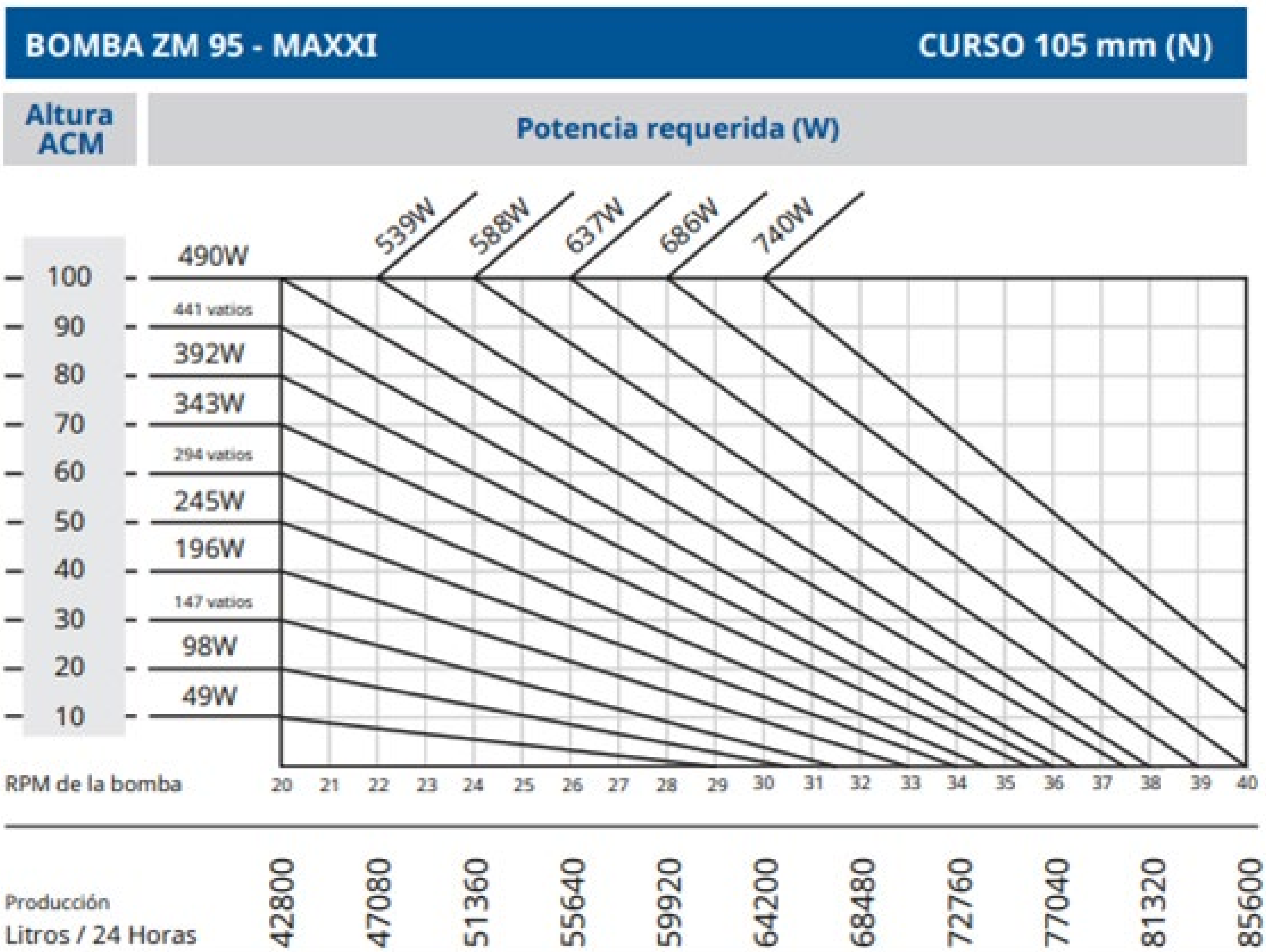

Figure 8. Pump setpoint curve ZM 95 MAXXI. Source: ZM Bombas (2020).

Subsequently, with the help of ArcGIS® software, we proceeded with the preparation of the layout plan of the discharge pipe (conduction line), in order to know where the conduction line will go and its exact length, which will be important to have clear at the time of making the calculations, the installation and the preparation of the budget. Finally, the budget was divided into six chapters: aerial photogrammetric survey, land suitability, concrete slab, hydraulic network, pumping system and indirect costs.

Design, selection and assembly of the assembly with accessories

To start with the installation of the system, a place was selected that was easy to access, easy to catch water on the wheel and easy to suction water to be pumped, the land was adapted, cleaning the site, removing all types of vegetation and debris that could interfere with the installation and operation of the system. Subsequently, it was necessary to build a concrete slab to support the entire assembly. The ACI Standard ACI351.3R-04 "Foundations for Dynamic Equipment", establishes types of foundations for machinery. In the case of the current application, the most suitable type of structure is the block foundation (Arias, Olaya, & Ardila, 2021). The criterion used for the sizing of the concrete slab is the mass ratio, which indicates that a foundation whose weight is 3 to 5 times the weight of the machinery is proposed (Chávez-Schaw, 2014). The slab was made according to the dimensions and weight of the pump, which is about 300 kg, for our case the slab is 3 m x 3 m with a thickness of 10 cm, which would be equivalent to a volume of 0.9 m^3 of concrete and would have an approximate weight of 2 100 kg. Once the concrete had cured, the trestle was fixed on the masonry base, the pump on the trestle and finally the wheel on the pump axle (Figure 9).

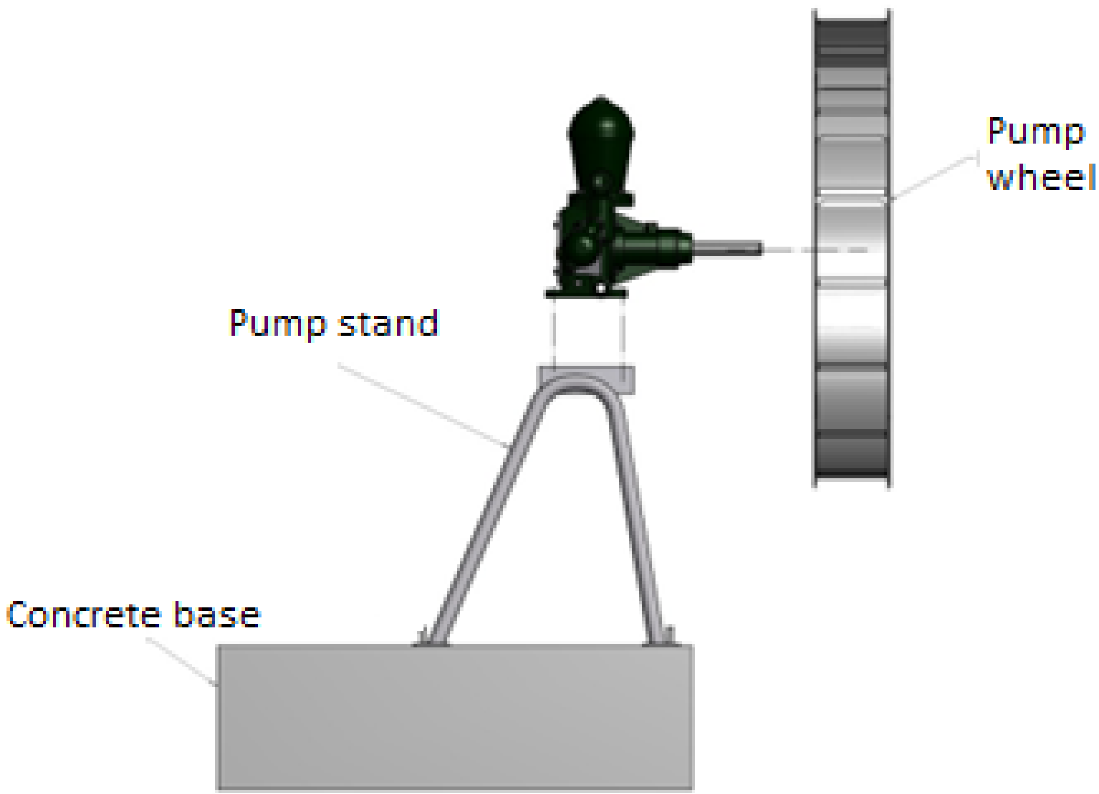

Figure 9. Basic recommendations for the assembly of the ZM® hydraulic pump assembly. Source: ZM Bombas (2020).

Water catchment and suction system

For the catchment system, a hose was laid to carry the water from the dam by gravity to a reservoir, in this case a plastic drum with a volume of 200 l, as this is the minimum quantity required for proper suction operation. As the water to be collected is above the level of the pump, the plastic drum was installed approximately 50 cm below the level of the pump. One of the considerations taken into account at this point was the installation of a screen at the inlet of the intake hose and the pipe that discharges the water for the wheel drive, due to the fact that the dam has a high content of algae and other suspended materials. This, in order to provide better water quality to the system and avoid clogging that could damage the operation and useful life of the system.

Wheel drive system

In order to obtain a greater hydraulic potential, it was necessary to make the wheel supply system observing some fundamental points recommended by ZM Bombas (2020), as can be seen in Figure 10: (1) that the water supply or discharge pipe be located approximately 10 cm above the wheel and (2) the positioning of the pipe up to approximately the centre of the wheel, (3) with an approximate inclination of 3 to 5 % of the length, (4) and that the distance from the wheel to the concrete plate be approximately 10 cm.

Tecnología y Ciencias del Agua
OPEN ACCESS
Check for updates

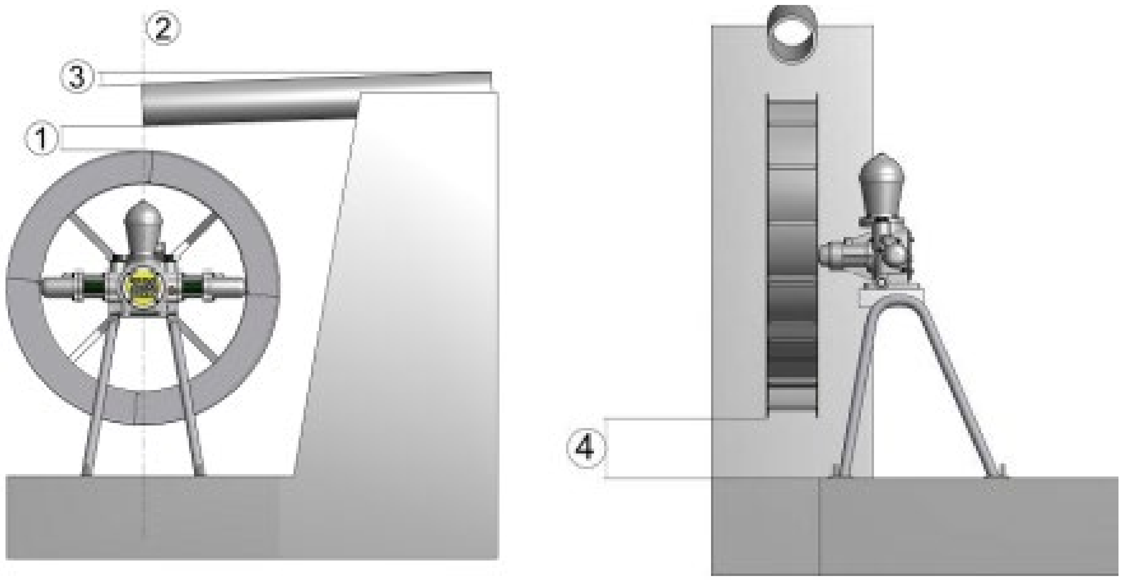

Figure 10. ZM pump drive system. Source: ZM Bombas (2020).

Unloading system

For the installation of the discharge pipe, the pump was fixed with the outlet towards where the pipe was placed, a pressure gauge, a ball valve and a check valve were also installed at the beginning of the discharge pipe, the purpose of this last accessory being to retain the water that is in the pipe to avoid a reverse rotation of the propellers when it is not working or when some type of maintenance is required.

As it was determined that the discharge line is made of polyethylene hose, a larger diameter was used than the one shown in the calculations (see results section) at the beginning of the pipe, depending on the internal amendments of the hose, which are smaller in diameter.

Once the hose had been laid to the reservoir, it was verified by means of gauging that the flow to be pumped would reach its destination. Once this had been verified, the system was stopped to finalise the installation process, burying the conduction hose at a depth of approximately 30 cm, so that it would not interfere with the agricultural work.

Commissioning

Prior to the fine tuning of the system, the pump was primed by introducing water through the bleed valve in order to remove the air inside the pump and the suction line for better efficiency when pumping water and to avoid cavitation. Next, it was verified that the intake line was not clogged due to suspended materials and algae present in the dam and that the water tank (plastic drum) was at the required level for optimum suction operation.

Once this had been done, the system was started up by letting water fall through the discharge pipe responsible for driving the pump wheel, checking that the flow rate it handled was the one specified in the manual of 55 l/s by means of gauging, Subsequently, it was confirmed that the wheel would rotate at 33 revolutions per minute (rpm) and the flow rate delivered to the reservoir through the pipeline was checked, being 0.81 l/s found by means of volumetric gauging, which is necessary to meet the requirements made by the owner of 70 m^3/day.

System installation costs

Table 2 shows the model of the ZM Maxxi hydraulic pump that was selected for this project, as will be shown below, with its characterisation.

Table 2. Features ZM 95Maxxi hydraulic pump.

Model	Manometric height max.	Flow max. head	Min. manometric height	Flow min. head	Temperature	Useful life
ZM 95 Maxxi	130 m	85 600 l/día	10 m	42 800 l/día	0-60 °C	30 years

Source: ZM Bombas (2020).

Table 3 shows the alternative model chosen for the techno-economic comparison: the Pedrollo electric pump.

Table 3. Characteristics Pedrollo PQ3000 electric pump.

Model	Power	Tension	Consumption	Frequency	Manometric height max.	Flow max. head	Min. manometric height	Flow min. head	Temperature	Useful life
PQ3000	3 Hp	220 V	14.2 Amp	60 Hz	180 m	7 200 l/day	0-50 m	72 000 l/day	0-90°C	20 years

Source: Pedrollo (2023).

A cost evaluation was carried out between the two possible pumping alternatives to be implemented, the ZM 95 Maxxi pump and the Pedrollo PQ3000 electric pump, taking into account the installation of the hydraulic network, construction of the foundations and labour; for the Pedrollo pump, the sum of the cost of carrying the energy to the dam was necessary, where the assembly of posts, braiding (wiring), hardware and meter (meter) was taken into account.

In addition to the costs of the entire installation of each pump, the depreciation of each pump on an annual basis was taken into account in the selection. For the annual depreciation, the linear depreciation Equation (1) was used:

$$Da = Vi/Vu \tag{1}$$

Da = annual depreciation

Vi = initial value of the equipment

Vu = useful life in years

For the maintenance costs of the pumps, the basic tasks of cleaning, lubrication, adjustments and visual inspection were considered in order to avoid or mitigate the consequences of equipment failures, thus preventing incidents before they occur. In the case of the ZM pump, preventive maintenance costs correspond to oil change, gasket replacement, bearing lubrication and valve cleaning. For the Pedrollo pump, the maintenance cost refers to the replacement and lubrication of gaskets or mechanical seals, lubrication of bearings and labour. According to recommendations given by the distributors, it is necessary to perform maintenance every 6 months for each of the pumps in order to maintain the conservation of the equipment, guaranteeing good operation and reliability, as well as avoiding the costs of corrective actions.

Results

Pump selection calculations

Definition of the need. As described in the previous section, it was determined that a water flow of 70 000 l/day was required, from the dam to the reservoir with a vertical head difference of 22 m and a length of the penstock estimated at 688 m. On the basis of the above data, the following are dimensioned: the diameter of the pipe, the losses and the maximum discharge head.

Selection of pipe diameter

The desired flow rate was considered as follows:

$$70\,000\ {}^{l}/_{day} = 2\,916.6\ {}^{l}/_{time} = 2.916\ {}^{m^3}/_{time}$$

From Table 4 of load losses, it is established that, for a minimum flow rate of 2.916 m^3/h, approximately 3 m^3/h, it is appropriate to select a pipe diameter of 1 ½", given that the losses can be equivalent to 1.5 % of the length of plastic pipe through which the fluid is conveyed, which was considered pertinent.

Table 4. Table of head losses in 100 m of pipe. Source: ZM Bombas (2020).

Flow (m^3/h)	Diameter (in)		
	1.1/4”	**1.1/2”**	**2”**
2.0	2.10	0.7	0.25
2.5	3.10	1.10	0.37
3.0	4.20	1.50	0.5
3.5	5.50	1.95	0.68
4.0	7.00	2.50	0.85

Calculation of lifting height

The height loss was considered as follows:

$$\frac{688\,m(1.5)}{100} = 10.32\,m$$

Then, the total height in metres of water column (MCA) is calculated as the sum of the vertical drop height plus the lost height, thus:

$$22\,m + 10.32\,m = 32.32\,m$$

Pump model selection

The characteristic curve data was checked in the catalogue and, as mentioned in the previous section (Figure 8), the ZM95 (N) pump configured with a 105 mm stroke for an MCA (metres water column) head of 32.32 m and an output of 70 000 l/day was considered suitable, which, as can be seen in Figure 11, will require an approximate power of between 539 to 588W from its drive wheel, rotating at about 33 rpm.

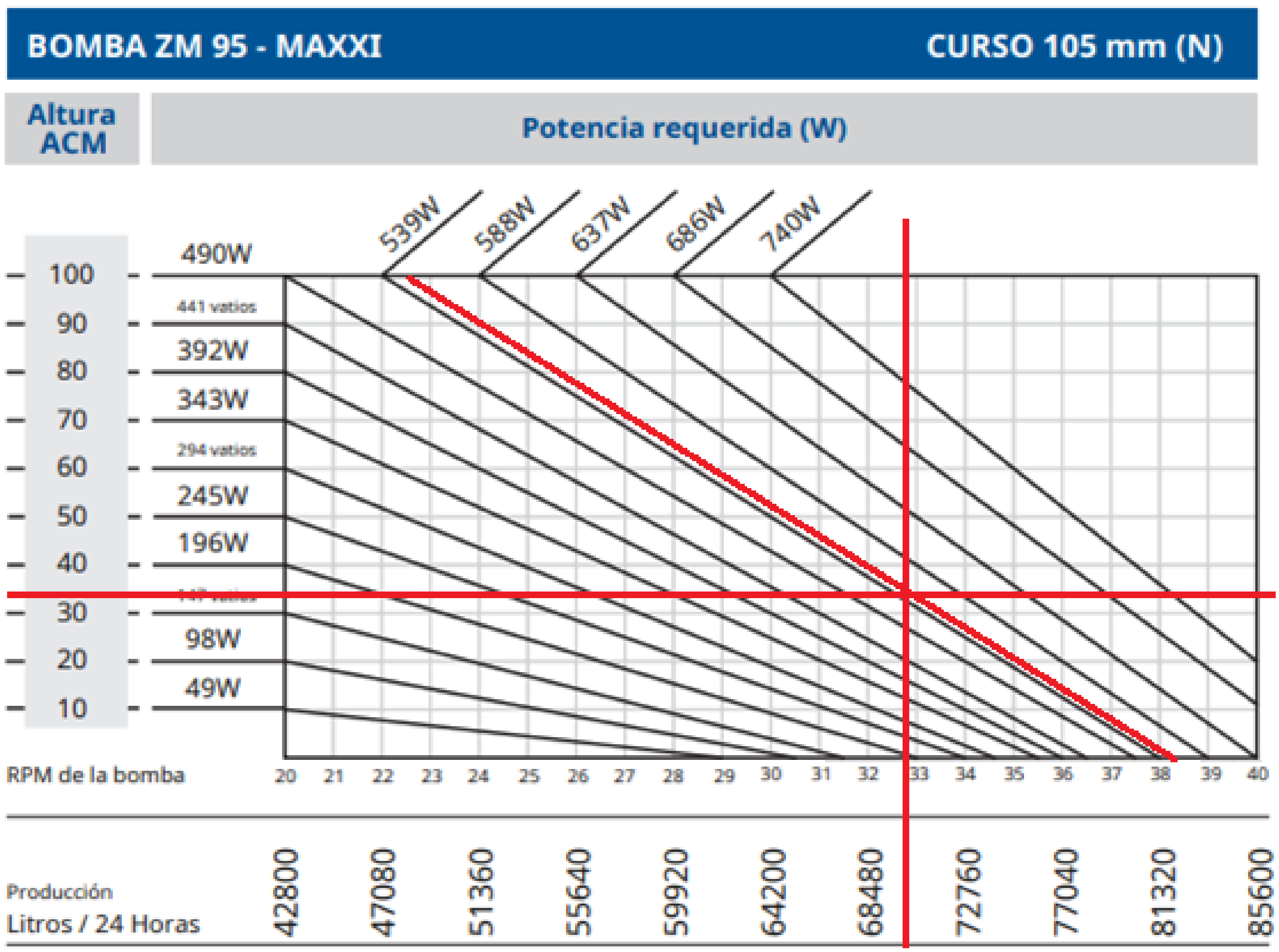

Figure 11. Pump characteristic curve ZM 95 MAXXI. Source: ZM Bombas (2020).

Drive wheel selection

The model of the wheel was determined by the maximum power requirement of 588 W. This in turn will depend on the water flow available to the wheel which, as described in the previous section by volumetric gauging, is 55 l/s. In this case, with a 2 m diameter wheel with a width of 0.35 m, a useful power of 593 W would be available with the flow available at the outlet of the dam, as can be seen in Table 5.

Table 5. Wheel diameter selection.

Flow (l/s)	Diameter wheel diameter (m)			Width of the wheel width (cm)
	2	1.8	1.5	
	Usable power (W)			
60	647	588	500	35
57.5	620	564	480	
55	593	539	458	
52.5	566	515	435	
50	539	490	415	

Tecnología y Ciencias del Agua

OPEN ACCESS

Check for updates

Comparison of alternatives for design validation

To choose the best pumping system by comparing the hydraulic pump and an electric pump as the conventional alternative with the lowest initial investment cost, a cost evaluation was carried out. Table 6 shows the costs of the two possible pumping alternatives to be implemented, the ZM 95 Maxxi pump and the Pedrollo PQ3000 electric pump. The initial investment is specified in the following section of this article, the installation cost of the ZM 95 Maxxi alternative corresponds to chapters Introduction, Materials and Methods, Results, Discussion of the budget, while the cost of the equipment and accessories that need to be purchased for its start-up are detailed in Conclusions. It is important to clarify that these values also consider the indirect costs that amount to 20 % of each investment, this is also detailed in the following section.

Table 6. Economic comparison of pumping systems.

Pumping alternative	Initial investment		Cost of operation		
	Cost of equipment + accessories (Ch. 5)	**Installation cost (Ch. 1-4)**	**Annual electricity consumption cost**	**Preventive Maintenance yearly**	**Annual depreciation**
Pump ZM 95 Maxxi	USD 7 155	USD 2 105	USD 0	USD 105	USD 192
Pedrollo PQ3000 electric pump	USD 706	USD 4 994	USD 2 959	USD 73	USD 35

It should be noted that, although the costs of the ZM 95 Maxxi pump are very high in the short term compared to the other pumping method, in the long term this would be compensated by the low labour required for its operation, and by the fact that it does not use any energy or fuel for its operation, due to the fact that it takes advantage of the renewable energy available on site. And that the initial investment cost of the Pedrollo PQ3000 pump is significantly increased if the power supply from the local grid to the dam site is considered as part of the installation cost, as explained in the methodology section of the comparison of alternatives.

Both investments would be recovered as a result of increased livestock production in the upper part of the farm, but it is worth noting from the data reported in Table 6 that, if only the savings in the cost of electricity consumption were to be considered as income, the payback time for the ZM 95 Maxxi pump would be 3 years and 3 months, which is considered a short payback time.

Estimate for installation of ZM hydraulic pump

The budget is divided into five chapters, which correspond to each of the activities to be carried out in their respective order, and in order to estimate the cost of the entire assembly, the costs of the equipment, materials and labour that would be required to carry out each of them were taken into account.

- **Chapter 1, Introduction**: Refers to the aerial photogrammetric survey, a topographic study to be carried out by means of a drone, with the aim of obtaining all the information on the terrain in terms of its characterisation; boundaries, enclosures, distribution, access roads, areas, contour lines, etc. With a value of 865 USD.

- **Chapter 2, Materials and methods**: The land will be cleaned and levelled, where all vegetation and debris around the pump installation area will be removed, and the soil will be levelled due to the irregularities it presented. With a value of 21 USD.

- **Chapter 3, Results**: Concrete slab, is broken down with the use of sand, cement and crushed concrete, plus labour, calculated for the casting of a slab with dimensions of 3x3 metres with a thickness of 10 cm. With a value of 149 USD.

- **Chapter 4, Discussion**: Hydraulic network, rolls of 1½" polyethylene hose with a length of 90 metres were used. For this chapter, a labour item was considered that refers to the excavation and manual installation of the hose over a 20 cm wide by 50 cm deep indentation, with a length of 688 M. With a value of 719 USD.

- **Chapter 5, Conclusions**: Pumping system, this section took into account all the accessories that derive from the pump to the suction and conduction pipe (pressure gauge, stopcock, foot valve, clamps, quick coupling, 1½" PVC male, 1½" elbow, 1½" pipe, 1½" galvanised tee, galvanised reducer bushing, galvanised stopcock, check valve, 10" sewage pipe), also taking into account the prices of the pump, wheel and plastic drum. With a value of 5 960 USD for a direct subtotal value of 7 714 USD.

To this, a section dedicated to indirect costs was also added, corresponding to administrative (5 %), contingency (5 %) and utility (10 %) costs, resulting in a total cost of USD 9 257 for the implementation of the entire project.

Tecnología y Ciencias del Agua

OPEN ACCESS

Check for updates

Installation of the hydraulic pumping system

Assembly of the assembly

For the installation of the pump, several aspects were taken into account for a trouble-free operation. A place was chosen near the dam that was easily accessible, where the vegetation would allow the operation of the equipment and where it would be easier to collect the water that drives the system, as can be seen in Figure 12. Once the pump, wheel and trestle were assembled on the masonry base shown, it was necessary to install welded angle steel bars on the trestle to support the 10" pipe that drives the system, see Figure 12(b), because the pipe could not be kept suspended in equilibrium due to its own weight and the water it needs to transport. This pipe was located approximately 10 cm from the wheel and on its axis with a slight slope, in accordance with the recommendations presented in Figure 9, thus allowing the water to fall by gravity and guaranteeing the greatest hydraulic potential.

Figure 12. Assembly of the ZM 95 MAXXI Pump Assembly (left); system drive piping (right).

Water catchment and suction system

The system intake is made up of: (1) 200-litre plastic drum; (2 and 3) threaded foot valve with filter, which allows water to pass in one direction, preventing the pump from unpriming; this valve is made of bronze, guaranteeing greater resistance to corrosion and a longer useful life; and (4) water supply pipe. Figure 13 shows the assembly of the water suction of the pumping system. At this point it was necessary to make use of a mesh that goes over the plastic drum, in order to prevent leaves and branches from falling directly into the captured water and damaging the quality of the flow to be suctioned. Thanks to the level of the dam which is approximately 2 metres above the pump body, the filling of the plastic drum fed by a pipe by means of gravity is guaranteed. Once the drum is full, the water overflows and returns to its course and its level is guaranteed.

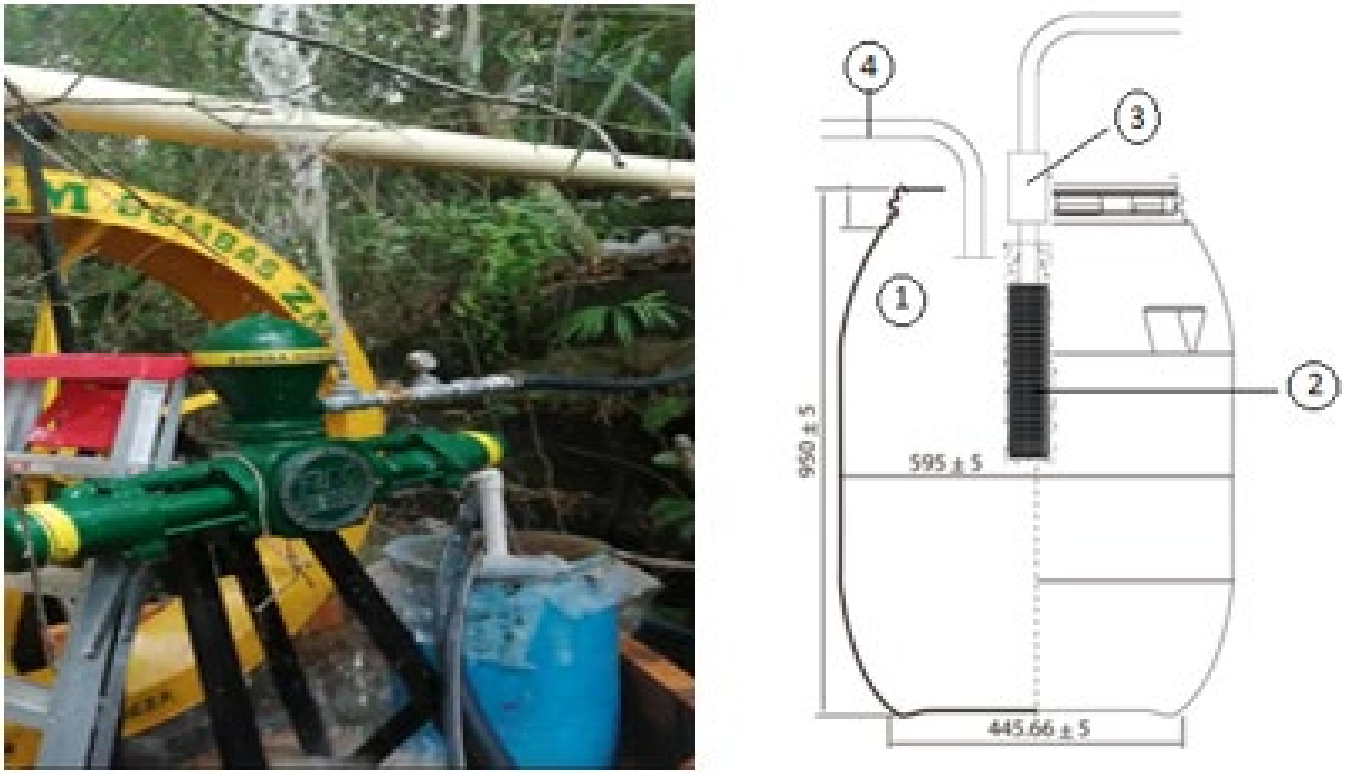

Figure 13. Composition of the intake and suction system.

Unloading system

To begin with the installation of the discharge pipe or line, the following fittings were taken, a 1½" brass ball valve, a 1½" brass curtain check valve and a 1½" horizontal 240 psi pressure gauge, Teflon tape was added around the nipple of each one, to achieve a better joint and avoid water leaks, this assembly is shown in Figure 14. Subsequently, once the fittings leaving the ram were in place, a polyethylene hose was used with a larger diameter than that obtained in the design calculations, this being a diameter of 2", based on the internal amendments of the brine, which is smaller in diameter and did not allow the connection with the fittings, this hose was only installed at the beginning in a section of 10 m, where later, by means of a pipe union, the diameter of the hose was reduced to that previously selected in the design of 1½".

Figure 14. Fitting of discharge pipe fittings.

Commissioning

Once the entire installation process had been completed, it was checked that the theoretical data obtained by means of the calculations performed bore a relationship with the data obtained when the pump was started up. For the above, the volumetric gauging method was used, a procedure that was carried out at the outlet of the discharge pipe (conduction line), and in which conventional measuring tools were used, such as: a bucket of known volume (10 l) and a stopwatch. Table 7 shows the results of the gauging carried out.

OPEN ACCESS
Check for updates

Table 7. Average volumetric gauging time.

Volume (l)	Time (s)
10	12
10	13
10	13
10	12
10	14
10	12
10	12
10	13
10	12
10	13
Average	**12.6**

Knowing the volume and filling time of the bucket, the flow rate was calculated using Equation (2):

$$Q = V/t \tag{2}$$

Where:

Q = flow (l/s; m^3/h; m^3/day)

V = volume (l; m^3)

T = time (s; h; day)

$$Q = \frac{10\ L}{12.6\ s} = 0.7936\ l/s$$

$$0.7936\ \frac{l}{s} = 2\,857.14\ \frac{l}{h} = 2.857\frac{m^3}{h} = 68.57\ \frac{m^3}{day}$$

This results in an average flow of 0.7936 l/s, equivalent to 68.57 m^3/day, which is slightly less than the owner's demand of 70 m^3/day, but within the acceptable range to meet the needs of filling the reservoir for subsequent use in irrigation for livestock fodder production.

Discussion

The pumping system implemented with the ZM Maxxi pump proved to be an efficient and sustainable solution to meet the water needs of the La Esperanza farm during times of drought. This system, based on the use of hydraulic energy, met the objective of pumping an average flow of 68.57 m^3/day to a reservoir located 22 m above sea level and 688 m away, without incurring electricity consumption costs. Compared to the Pedrollo PQ3000 electric pump, although the initial investment of the ZM Maxxi system is higher, its operating cost is practically zero due to the elimination of electricity consumption. This results in a payback time of only 3 years and 3 months, which validates its economic viability in agricultural scenarios with limited access to the electricity grid.

The results obtained are in line with previous studies on pumping systems using renewable energy. For example, Guaña-Quilumba and Quishpe-Sacancela (2018) reported the implementation of a similar system that pumped water 700 metres away using a hydraulic pump, also highlighting a significant reduction in operating costs and an extended lifetime. However, the present study introduces a further optimisation by reducing head losses through proper selection of pipe diameter and specific design of the catchment system, which ensures a stable flow rate even under peak conditions.

In contrast, the conventional electric pump analysed in this study has advantages in initial costs (Pedrollo, 2023). However, its dependence on electricity and the costs associated with its operation, which amount to USD 2 958 per year, limit its competitiveness in the long term. In addition, the useful life of this alternative, estimated at 20 years, is significantly lower than that of the ZM Maxxi pump, which reaches 30 years, according to the manufacturer's data and previous experience (ZM Bombas, 2020).

The ZM Maxxi system represents not only an economically but also an environmentally sustainable solution by using a renewable energy source. Studies such as those by Arias *et al*. (2021) highlight the importance of implementing hydro technologies in rural areas to reduce carbon emissions associated with the use of fossil fuels and improve the energy autonomy of communities. In this context, this project contributes significantly to the sustainable development of the agricultural sector, showing that investment in hydropower technology can be a catalyst for rural productivity and resilience to climate change.

Conclusions

The implementation of the ZM Maxxi pumping system fulfilled the objectives of having water in a reservoir in the upper part of the farm for fodder production by means of a pumping system without electricity consumption, being more economical and sustainable over time.

The ZM Maxxi hydraulic pump proved to be an effective solution for transporting almost 70 m³ of water per day to a reservoir located 22 metres above sea level and 688 metres away, without incurring electrical energy costs. This system contributed significantly to improving the water supply of the upper part of the La Esperanza farm during times of drought.

Compared to a conventional electric pump, the ZM Maxxi pumping system offers annual savings of USD 2 958 by not requiring electricity for its operation, resulting in a return on investment in the medium term.

Although the initial installation cost of the system with the ZM Maxxi pump was higher than that of an electric pump (USD 9 255 versus USD 5 699), the operating costs of the ZM Maxxi system are significantly lower, eliminating energy consumption and reducing maintenance costs, making it the more viable option in the long term.

The implemented system has a delivery flow of 68 570 l/day of water, which meets the irrigation needs for the production of fodder for the livestock on the farm, improving the sustainability of livestock activities in the area.

The ZM Maxxi pump has an estimated service life of 30 years, outperforming the electric pump, which has a service life of 20 years, further highlighting the long-term cost-effectiveness of the selected pumping system.

Acknowledgements

Thanks to the Universidad Surcolombiana and the Centro Tecnológico de Ingeniería GEOMAAC for their invaluable collaboration in this project. Their support and resources have been fundamental for the realisation of this research.

References

Arias, L., Olaya, F., & Ardila, J. G. (2021). Caracterización y redimensionamiento de sistema de bombeo de agua para cultivos acuícolas en finca el Rubí en Aipe-Huila. *Revista Ingeniería y Región*, 25, 72. DOI: 10.25054/22161325.2780

Bermeo-Mayancela, E. E. (2022). *Estrategias de mercado para pequeños productores agrícolas de las comunidades indígenas de la organización Tukayta del cantón Cañar* (Bachelor's thesis). Universidad Politécnica Salesiana, Ecuador.

Chávez-Schaw, J. M. (2014). *Análisis y diseño de cimentaciones para turbinas hidráulicas en hidroeléctricas medianas* (Doctoral dissertation). Universidad de San Carlos de Guatemala, Guatemala.

Díaz-Rodríguez, N., & Pérez-Guerrero, J. N. (2007). Metodología para evaluar el impacto de la maquinaria agrícola sobre los recursos naturales del medio ambiente. *Ciencias Holguín*, 13(2), 1-12.

Gras, C., & Hernández, V. (2016). Modelos de desarrollo e innovación tecnológica: una revolución conservadora. *Mundo Agrario*, 17(36), 1-37.

Guaña-Quilumba, F. R., & Quishpe-Sacancela, E. V. (2018). *Diseño e implementación de un sistema para impulsar agua desde una vertiente hasta un tanque de distribución a 700 m de distancia mediante un sistema de bombeo (*Master's thesis*).* Universidad Politécnica Salesiana, Ecuador.

Leibovich, J., & Estrada, L. (2008). *Competitividad del sector agropecuario colombiano basado en el estudio: diagnóstico y recomendaciones de política para mejorar la competitividad del sector agropecuario colombiano*. Bogotá, Colombia: Consejo Privado de Competitividad.

Palacio-Castañeda, N. (2010). *Propuesta de un sistema de aprovechamiento de agua lluvia, como alternativa para el ahorro de agua potable, en la institución educativa María Auxiliadora de Caldas, Antioquia* (Bachelor's thesis). Universidad de Antioquia, Colombia.

Pedrollo. (2023). *Pedrollo, Catálogo general.* Recuperado de https://www.pedrollo.com.co/public/allegati/PK_ES_60Hz.pdf

Polanco-Puerta, M. F. (2007). *Maquinaria y mecanización agrícola*. Bogotá, Colombia: Universidad Abierta y a Distancia.

Santos, L. K. C. (2018). El uso de la tecnología en la agricultura. *Pro Sciences: Revista de Producción, Ciencias e Investigación*, 2(14), 25-32. DOI: 10.29018/issn.2588-1000vol2iss14.2018pp25-32

UPRA, Unidad de Planificación Rural Agropecuaria. (2024). *Población ocupada del sector agropecuario aumentó 147.685 personas durante diciembre de 2024*. Recuperado de https://www.agronet.gov.co/Noticias/Paginas/

ZM Bombas. (2020). *Hidrometalurgia ZM limitado*. Recuperado de www.zmombas.com.br