Scientific Research Publishing

Open Journal of Modern Hydrology, 2025, 15(2), 33-44
https://www.scirp.org/journal/ojmh
ISSN Online: 2163-0496
ISSN Print: 2163-0461

Hydraulic Sizing of a Solar Pumping Station and Irrigation Pipes for the Development of a Site in Northern Niger

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How to cite this paper: Yerima Bako Djibo, A., Hassane, G. and Imolen, A. (2025) Hydraulic Sizing of a Solar Pumping Station and Irrigation Pipes for the Development of a Site in Northern Niger. *Open Journal of Modern Hydrology*, **15**, 33-44.
https://doi.org/10.4236/ojmh.2025.152003

Received: November 19, 2024
Accepted: February 11, 2025
Published: February 14, 2025

Abstract

Irrigation is considered a means of intensifying agriculture. It helps to increase productivity while securing it against the risks of drought. It is a means of combating poverty and hunger, which are especially endemic in West Africa. The technical study for the development of a site for the creation of an irrigated area is made up of different phases including the plot, the sizing of the irrigation network, the sizing of the pumping station(s), the dimensioning of the drainage network and the circulation and protection networks. The design of the developments takes into account a certain number of essential elements, including the planned crops, the irrigation system, the nature of the soil, the topography of the land, and the availability and quality of water. The objective of this study carried out in the north of Niger (Agadez) is the design of a Californian network where the hydraulic dimensioning of a solar pumping station and irrigation pipes will be carried out. The methodology adopted is first a series of visits for the collection of climatic, agronomic, topographical and technical data, then an exploitation of the data collected and finally, the writing of this article. The study shows that the developed site covers an area of 12 ha, including 48 plots of 0.25 ha. It had a modern layout and a Californian irrigation system. The results of this technical study propose a 270m deep borehole connected to a 54.4 KWC solar pumping system and a 66 KVA emergency generator of the J66 soundproof hooded SDMO brand serving as water supply sources for the developed site. A Grundfos esp 60-17 30 kW pump ensures water extraction. Water is transported to the network via supply pipes with a diameter of 200 mm and distribution pipes whose diameters vary between 160 - 200 mm.

Keywords

Hydraulic Sizing, Solar Pumping Station, Irrigation Pipes, Californian Network and Agadez

1. Introduction

Irrigation with manual drainage or with a motor pump coupled with the manual distribution system (watering can) or by earth canals is the most practiced by most irrigators [1]. However, it is inefficient because it is characterized by water losses, high pumping costs and low yields and income. To make improvements, we must move towards more viable and sustainable irrigated systems [2]. Thus, the sun radiates on the earth a power of 1.6 1018 kWh/m^2/year in all wavelengths of the light spectrum. It is an inexhaustible source of renewable energy on a human scale. Today, this renewable energy is attracting particular attention with regard to energy policy issues [3]. A NASA study conducted between 1983 and 2005 places the Agadem region in the Nigerien Sahara in 2nd position among the sunniest regions on the globe, with an annual average sunshine of 6.92 kWh/m^2/d [4].

Solar-pumped irrigation with distribution by a semi-California network constitutes a more water and energy-efficient solution and makes it possible to extend areas, diversify crops and obtain good yields and higher income. The irrigation solution by "Using solar pumping with distribution by semi-California network" is a widespread technique in the development system in all irrigation zones in Niger. Its implementation is based on technical feasibility studies appropriate to each context, leading to the definition of the necessary equipment and infrastructure [5] [6].

Photovoltaic solar pumping systems are based on the conversion of solar radiation into electricity by solar panels to power a solar pump. The efficiency of solar panels depends on the sunshine and the angle of exposure on the one hand and the temperature of the cells on the other hand. A study is necessary in each case to correctly size the installation.

The aim of this study is to carry out a hydraulic dimensioning of a solar pumping station and the irrigation pipes of a Californian network in the north of Niger.

2. Material and Methods

2.1. Material

The main materials that we frequently use are:

- A probe, a stopwatch;
- A volumetric meter of the drilling;
- A notepad and graph paper.

2.2. Methods

2.2.1. Methodological Approach

In order to properly conduct our research, we adopted the following methodology:

✓ Data collection;

✓ Data processing and drafting of this document;

✓ Regarding the collection of order data:

✓ Climatic: These are the reference rainfall, temperature, and evapotranspiration provided by the nearest station;

✓ Technical: They are concerned with pedology, agronomy, hydrology, and environmental issues, which have been made available to us by the competent services.

Site Visit

The visit is organized to reconnaissance the site and collect data for the design of an irrigation system and the choice of crops on the perimeter.

Field Work

- The summary field survey which consisted of making visual observations;
- Collection of data on the perimeter (soil type, temperature, wind speed, rainfall, etc.);
- Data on drilling;
- Topographic data.

Technical Works

This is the technical part of the study. It involves:

✓ Calculation of irrigation parameters (basic data, choice of crops, water requirement of the crop, water distribution, water flow);

✓ Determination of water needs using CROPWAT FAO software;

✓ Design and sizing of irrigation equipment;

✓ Sizing of energy source equipment.

Data processing consisted of exploiting the data collected. This data is processed with appropriate software.

2.2.2. Field Data Collection

➢ **Topographic data**

There already exists a topo survey of the perimeter carried out by the Irhazer-Tamesna project [7] and which we have used.

➢ **Collection of data on the perimeter** (soil type, temperature, wind speed, rainfall, etc.).

➢ **Soil type**

The site is characterized by clay-loamy-sandy soil, which presents cracks with a fine texture.

➢ **Temperature**

The study area has a semi-desert climate, and the recorded temperatures are characterized by very strong annual and daily variations. Two (2) periods of maximum temperatures were observed: one from April to June and the other from September to October. The average minimum temperature is recorded in December and January, and the monthly average temperature ranges from 17˚C to 37˚C. (Table 1)

Table 1. Monthly distribution of sunshine duration, Agadez station.

Month	Jan	Feb.	March	April	May	June	July	August	Sep.	Oct.	Nov.	Dec.
Sunshine (h)	8.9	9.63	9.02	8.93	8.27	7.31	7.31	8.09	8.61	9.38	9.61	8.64

- **Wind speed**

The average daily wind speed in the area is around 3 m/s. Higher speeds are reached in January-February and December but never reach 4 m/s. It is in September that the weakest winds are observed, with an average of 2.4 m/s throughout the portion that has been monitored.

The monthly averages of the daily speed of the Agadez stations are presented in Table 2.

Table 2. Monthly distribution of average wind speeds, Agadez station.

Month	Jan	Feb.	March	April	May	June	July	August	Sep.	Oct.	Nov.	Dec.
Wind (m/s)	3.6	3.6	3.3	3.1	2.9	2.7	2.8	2.6	2.4	2.9	3.3	3.5

- **Rainfall**

Located in the desert part of Niger, the Agadez region, more particularly the study area, records fairly low precipitation, very poorly distributed in time and space. (Figure 1)

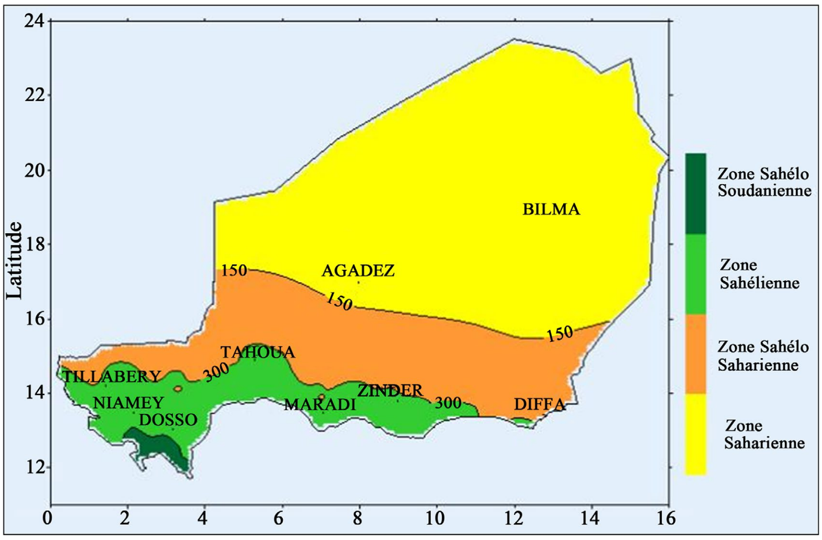

Figure 1. Map of isohyet curves of Niger.

The first very light precipitation appears in April in our study area.

The rainy season mainly occurs between June and August, and the majority of rains are recorded during these three (3) month periods.

2.3. Sizing of the Pumping Station and Energy Source

The site pumping station is a mini borehole with a very powerful Grundfos pump of model esp 60 - 17 of 30 kW, ensuring water drainage connected to a solar pumping system of 54.4 KWC and a 66 KVA emergency generator set, J66 model.

2.3.1. Determination of Solar Pumping System Parameters

We are sizing the solar-powered photovoltaic pumping system for water supply for irrigation of the future irrigated area.

The following data characterizes the system:

- Water requirements: 1400 m3/day, which was taken for the design;
- Site characteristics (Irradiation): Daily irradiation: 5.8 kWh/m^2/day (see Figure 2 below).

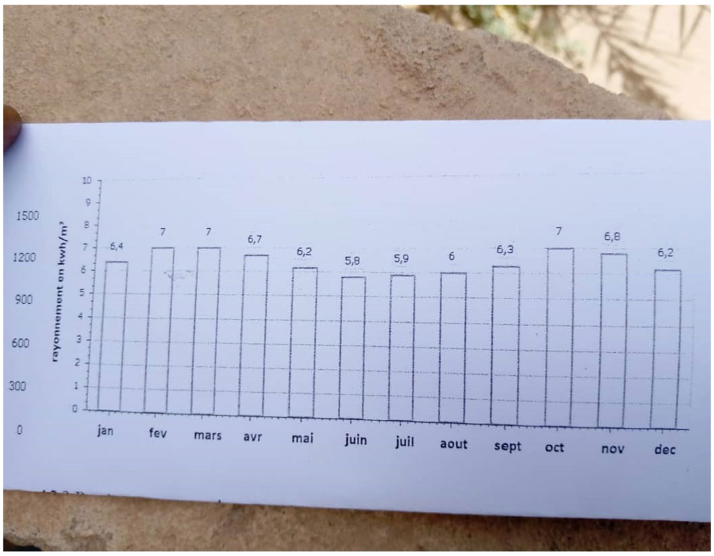

Figure 2. Solar radiation on the Tiguirwit 2 site (source Tiguirwit 2 solar pumping system study_ BENALYA Group 2022).

- Characteristics of the Total Head (*HMT*) from the borehole to be pumped by the solar device (Figure 3).

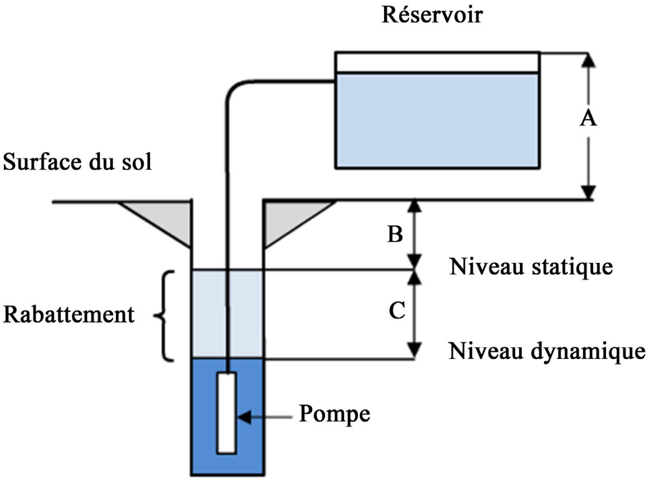

Figure 3. Diagram of the photovoltaic pumping device over the sun.

The total head (HMT) of a pump is the pressure difference in the water column meters between the suction and discharge ports. It is given by:

$$HMT = Hg + Pc$$

Hg: geometric height between the pumped water table (dynamic level) and the use plan (see **Figure 3**).

For its determination, we used the following formula:

$$Hg = A + B + C$$

Topographic studies made it possible to determine A, B, and thus, we have: $A = 3.20$ m; $B = 11.4$ m and $C = 5.60$ m.

The diameter of the suction pipe must be calculated so that the pressure losses correspond to a maximum of 10% of the total geometric height.

$$HMT = A + B + C + Pc = 3.20\text{ m} + 11.4\text{ m} + 5.60\text{ m} + 2\text{ m} = 22.20\text{ m}$$

- Characteristics of the chosen photovoltaic module:

✓ Poly-crystalline IBC Solo Sol;

✓ Rated power: 320 Watt;

✓ Nominal voltage: 37.61 Volt.

- Calculation of the energy required for the submersible pump It is determined by the following formula:

$$Ec = CH \times Q \times HMT / Rp$$

where Ec (electrical energy) is usually expressed in kWh.

Q: Flow [m^3/day].

HMT is the total head.

CH is the hydraulic constant depending on terrestrial gravity and water density:

$CH = g \cdot \delta = 9.81.103/3600 = 2.725$ ($\text{Kg} \cdot \text{s} \cdot \text{h/m}^2$) and Rp the efficiency of the pump set (generally from 30% to 45%).

Pumping group efficiency: Motor efficiency x pump efficiency.

Engine efficiency from 75% to 85%, we will take the average which is 80%.

Pump efficiency from 45% to 65%, here too we will take the average of 55%.

Either $Rp = 0.8 \times 0.55 = 0.44$ or 44%

$$Ec = CH \times Q \times HMT / Rp = 2.725 \times 1400 \times 22.20 / 0.44 = 192484\text{ Wh/j}$$

where Ec or $Eelec$ (electrical energy).

2.3.2. Sizing of Solar Panels: Calculation of Peak Power *Pc*

The energy supplied by the solar panels in one day must be equal to the daily energy consumed by the pump

$$\underset{\text{Wh/j}}{Eelec} = \underset{\text{W}}{Pc} \times \underset{\text{h/j}}{EI} \times K$$

EI: Irradiation here equal to 5.8.

K: Efficiency of the power system (solar panels, heat, dust, line voltage drop, etc.) from 0.7 to 0.9.

We will take $K = 0.8$.

$$Pc = Eelec/EI \times K = 192484/5.8 \times 0.8 = 41482\ \text{W}$$

41482/320 = 129.63, so the need will be 130 panels.

Pump choice

We choose the pump according to the flow rate and the total head, and we calculate the hourly flow rate using the following formula: $Qh = Q\ \text{m}^3/\text{h}$.

With: h: number of hours of maximum sunshine (Approximately 7 hours). Q: desired flow rate (1400 m^3/day). This gives an hourly flow of approximately 140 m^3/h. Knowing that the total head is 22.20 m, then we chose the 30 kW submersible pump (Table 3).

Table 3. Pump characteristics.

Model	Brand	Motor Power	Tension	Diameter
SP 60-17	GRUNDFOS	30 kW	400 V	Chips

2.3.3. Choice of Drive

For pumps with direct current motors, the electronic converter makes it possible to constantly obtain the best operating point of the pump (maximum flow rate) despite variations in sunlight. In most cases, it also makes it possible to manage the pump's operation in the event of a lack of water in the borehole or well and maximize the filling of the water retention tank. The characteristics of the latter are summarized in Table 4.

Table 4. Drive specifications.

Model	Brand	Motor Power	Tension
ESP30/40	ATERSA	30 kW	400 V

2.3.4. Generator

The pump requires at least twice its power to start. For 30 kW, the power required for the generator will be 60 kW. The 66 kW generator which is on the perimeter is well indicated (Table 5).

Table 5. Characteristics of the chosen generator.

Model	J66 soundproof hood
Brand	SDMO
Power	66 kW

2.3.5. Drilling Flow

We carried out flow measurements in the field at the borehole meter.

The measurements are obtained as follows:

On seven occasions (dry season and rainy season), readings were taken at the meter for an hour.

Measurements taken during the dry season

- The flow rate of 04/2/203 at the drilling level was 1060 m^3;
- On 04/09/2023 we have a flow rate of 1070 m^3;
- On 04/16/2023 we have a flow rate of 1080 m^3;
- On 04/23/2023 we have a flow rate of 100 m^3.

Measurements carried out during the rainy season

- On 06/20/2023 we have a flow of 970 m^3;
- On 06/27/2023 we have a flow rate of 965 m^3;
- On 07/04/2023 we have a flow rate of 925 m^3.

From the measurements taken, we note a very large drop in flow which explains that during the rainy season.

The meteorological data recorded at the study site makes it possible to set the daily flow at 1070 m^3/h. Thus, we obtain the flow rate of the borehole by taking the ratio of the daily flow rate to the maximum number of hours of irrigation per day 1070/10 = 107 m^3/h rounded to 110 m^3/h.

In conclusion, from the different results obtained and retained, the characteristics of the drilling are summarized in Table 6.

Table 6. Characteristics of the drilling after completion.

Forage	Total depth (m)	Max flow (m^3/h)	Current flow (m^3/h)	Static level (m)
IRH100393	270	120	110	11.40

The fact that solar energy is available right at the point of use frees the farmer from the problems of fuel supply, or the existence of easily accessible electricity transmission lines. Currently, the main obstacles hindering the use of solar pumps on a larger scale are their high cost and the too recent nature of this technology. The development of a sufficiently reliable and reasonably expensive solar pump—which would be very likely within a few years—could give a boost to agriculture in the Third World. Solar pumping systems allow water to be supplied from a source at any location, even if no energy source is present on site. The source can be a pond, a well, a borehole, a river, a stream, etc.

In my country, the solar pumping system is actually calculated at 44% and is very close to modern standards. The ineffectiveness of this system is observed during the rainy season when there is very little sunshine. The solutions envisaged are of two (2) types: we have a 5 m^3 pool to store and use on days of low radiation. A thermal device is also used during low sunlight.

2.4. Hydraulic Sizing of Irrigation Network Pipes

The sizing will be done from the irrigation terminals to the supply pipe.

2.4.1. Irrigation Terminals

The irrigation terminals or supply terminals are sized so as to deliver the flow rates they need to the plots. These are the main PVC pipes attached to the secondary pipes. Each irrigation terminal supplies two (2) plots. In this case, the design flow rate of a supply terminal is double a hand of water (10 l/s).

The pipe diameter is therefore obtained using the following formula:

$$D(\mathrm{m}) = 2\sqrt{Q/\pi \times V}$$

$$V = (4 \times Q)/(D \times D \times \pi)$$

D: pipe diameter;

Q: flow rate in m^3/s;

V: flow speed in the pipe in m/s Speed condition: $1\ \mathrm{m/s} \leq V \leq 3\ \mathrm{m/s}$.

The speed in all tubes must be such that:

- For plastic tubes $V \leq 1.7$ m/s;
- For others (steel, aluminum, cast iron, etc.) V tubes ≤ 2 m/s.

2.4.2. Secondary, Primary and Supply Pipes

The secondary pipes are sized in the same way as the irrigation terminals. However, a secondary pipe simultaneously supplies six (06) irrigation terminals. Thus, the design flow of a secondary pipe is double that of an irrigation terminal, that is to say, 30 l/s.

As for the main pipe, it supplies the secondary pipes in turn. Since the flow rate passed through the main pipe is the same as that at the secondary pipe, the dimensions of these two pipes remain identical. The same goes for the supply pipes which feed the main pipe.

In conclusion, the secondary, main, and supply pipes are sized at the same flow rate. Therefore, their diameters are the same, but their speeds and diameters are different (Table 7).

Table 7. Characteristics of irrigation pipes.

Pipelines	Sizing flow rates (m^3/s)	Flow velocity (m/s)	Diameter (mm)
Power terminal	0.010185185	1.07	110
Secondary Pipes	0.030555556	1.52	160
Primary Pipes	0.030555556	1	200
Feed pipes	0.030555556	1	200

2.4.3. Evaluation of Pressure Losses in Network Pipes

To evaluate the pressure losses in the pipes, it is technically accepted to consider the hydraulically most unfavorable pipes. However, in our case, the supply terminals, the secondary pipes, the primary pipes and the supply pipes have the same respective lengths; we will be interested in the longest circuit of the network to evaluate the load losses

The linear pressure losses inside the pipes are calculated by the following Colbrook, Calmon and Lechap formula:

$$\Delta H_{rampe} = \frac{aQ^n L}{D^m} \times F$$

Q: flow rate in m3/s is the flow rate of the ramp considered;

D: cataloged internal diameter of the ramp (m);

L: length of the pipe in m;

a, n and m are the coefficients according to Calmont-Lechapt.

$a = 0.916 * 10^{-3}$, $m = 1.78$ and $n = 4.78$ for PVC $50 \leq D\,(\text{mm}) \leq 200$.

F: reduction coefficient due to the distribution of water along the pipe F is a function of the number of distributors or outlets on the pipe (N).

if $N = 0$, $F = 1$, $N = 2$, $F = 0.639$ and if $N > 100$, $F = 0.35$.

This formula, which takes into account the number of openings, tends to reduce loss loads when the number of openings is large.

Here, we have 6 outlets, so $F = 0.435$ for the secondary pipes

The pressure losses at the pipe singularities are estimated at 10% of their linear pressure losses. The total loss is the sum of linear pressure losses and singular pressure losses (**Table 8**).

Table 8. Load losses.

	AH simple (m)	AH linear (m)	AH singular (m)	AH total (m)
BA	0.0000000000140	0.000000000084	0.0000000000084	0.0000000000924
CS	0.0000000005967	0.000000078769	0.0000000078769	0.0000000866461
CP	0.0000000004482	0.000000094113	0.0000000094113	0.0000001035241
CA	0.0000000009221	0.000000117111	0.0000000117111	0.0000001288219

BA: Power terminal; CS: Secondary pipes; CP: Primary pipes; CA: Feed pipes.

The Californian network minimizes water losses, and there are no measurements or calculations to support this assertion in the study. We could not include data quantifying the reduction in evaporation and infiltration because these data are very negligible.

2.4.4. Cost of Development of 12 ha in Californian Network with Solar Pumping Station

Table 9 shows us the cost of development of 12ha in Californian network with solar pumping station

171,568,473FCFA = 272,794 USD

If we take a gravity irrigation system, the development of 12 ha with electricity supply, its cost is 12,000,000FCFA/haX12ha = 144,000,000 FCFA. So less expensive than the Californian system with power supply.

For the first system, apart from maintenance, there are maintenance costs, electricity and fuel costs for the pumping station. Meanwhile, for the device, maintenance costs are minimal.

Table 9. Cost of development of 12 ha in Californian network with solar pumping station.

Designation	Unity	Quantity	unit price	Amount FCFA
Installation of the solar pumping system				
Supply of the solar field	u	1	27,487,874	27,487,874
Set of aluminum panel supports with concrete anchoring, fixing and orientation	u	1	5,376,182	5,376,182
Three-phase dimmer output 400 V/50 Hz + Pumping system + Panel line connection system + lightning arrester	u	1	8,374,550	8,374,550
Supply and installation of a three-phase pump under 400 V including accessories, delivery pipes and accessories, safety cable and low level detector	u	1	10,854,200	10,854,200
Electrical wiring assembly for the pump and various pump accessories	u	1	875,432	875,432
Electrical wiring assembly for panels and various pump accessories	u	1	1,150,000	1,150,000
Mesh fence of the 1.8m solar field with door	u	1	1,100,000	1,100,000
Group shelters in permanent materials	u	1	750,000	750,000
Others (lighting, after-sales service, etc.)	ff	1	7,400,000	7,400,000
Generator	u	1	8,125,360	8,125,360
Retention basin	u	1	39,824,875	39,824,875
Californian network implementation	ml	997	60,431	60,250,000
Total				**171,568,473**

3. Conclusions

The choice of the design of a Californian network is more judicious in terms of irrigation with a view to minimizing water losses, where water resources are increasingly decreasing or even becoming scarce.

The main aim of this study was to carry out a hydraulic dimensioning of a solar pumping station and irrigation pipes.

The study shows that the site is characterized by clayey-loamy-sandy soil, which presents cracks with a fine texture.

The average minimum temperature is recorded in December-January, and the monthly average temperature varies from 17˚C to 37˚C. The average daily wind speed in the area is around 3 m/s. The first very light precipitation appears in April in our study area. The rainy season mainly occurs between June and August, and the majority of rains are recorded during these three (3) month periods.

Our developed site will be supplied by a 270 m deep borehole, a maximum flow rate of 120 m^3/h and a minimum flow rate of 110 m^3/h. The supply terminals and the pipes (input, secondary and primary) have respectively 36.66 m^3/h and 110 m^3/h.

From the objective analysis of the results from the calculations, it emerges that:

- the development work on the site through the installation of a Californian irrigation system will make it possible to secure the regular water supply;

- the energy necessary for pumping is generated by the installation of 170 plates of 320wc with a 30 kW electric pump;

- the completion of the perimeter development project required an investment of 171,568,473 CFA francs;

- the profitability of the project is acceptable.

This study can constitute a basic document for a natural or legal person responsible for the possible development of a California-type irrigation network and a means of showing farmers that it is possible to avoid losses by infiltration. and by evaporation during transport and distribution of water with the Californian network.

Authors' Contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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