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Design of an irrigated perimeter using a Californian network: Hydraulic sizing, calculation methods and water rotation organization

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Abstract

In Niger, thermal pumping systems are widely used by producers with large motor pumps. Water is distributed through earthen pipelines via settling basins. Water distribution efficiency remains very low, below 50%, due to water losses.The cost of pumping alone represents more than half of the total cost of irrigation. The Californian irrigation system is a low-cost irrigation alternative, both in terms of investment and operation, and is very well suited to small producers.This article presents a hydraulic sizing study for a Californian-style irrigation network in a Sahelian region of Niger. Once designed, this network will be supplied by borehole water through eight storage basins. This study outlines calculation methods for several key hydraulic parameters in the design and provides an estimate of crop water requirements using CROPWAT.

Keywords: Californian irrigation system; Hydraulic sizing; Calculation methods; Producers and Niger

1. Introduction

A country's development policy necessarily involves the development of agricultural production, especially irrigated agriculture. Over the past four decades, with climate change jeopardizing rainfed agriculture, Niger has encouraged agricultural activities during the dry season, primarily market gardening and rice cultivation. It is with this same objective that various hydro-agricultural projects have been implemented in the country's regions.

The hydraulic design of irrigation canals or pipes involves determining their geometry (width, depth, slope) and flow rate (Q) to efficiently transport water while maintaining flow velocities (V) that prevent erosion. (Zürcher, 2013)

Flow in open canals is governed by the Manning-Strickler equation.(HIEN.,2012 ; MINISTERE FRANÇAIS DE LA COOPERATION., 1985)

The flow velocity must exceed 0.50 m/s to prevent the formation of deposits in the channels (Boillat.,2019 ; Graf et al.,2000 et MINISTERE FRANÇAIS DE LA COOPERATION., 1974).

The hydraulic parameters to be considered for sizing a surface irrigation network are then calculated using a simple formula, theoretically established over three-quarters of the century.

In agricultural hydraulics, sizing the structures of an irrigation network is a crucial step in designing an efficient and sustainable irrigation system. This sizing must take into account many parameters, such as the flow to be conveyed, the

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water needs of the crops, the fictitious continuous flow, the maximum peak flow, the maintenance dose, the water hand…even the very organization of the water turn at the level of the hydro-agricultural development, the nature of the terrain, the hydraulic constraints and the agronomic requirements (Montazem.,2018; AGUMA., 2020). These calculations are generally performed during the busiest period of the irrigation season, which in Niger is undoubtedly March-April and often May.

The irrigation system we will design is the Californian network. The design of a Californian irrigation network relies on an underground network of rigid PVC pipes that distributes pressurized water from a pump, offering high efficiency, especially for sandy soils or slopes, via regular water intakes and flexible hoses to the crops. Its design incorporates topographic planning and the choice of materials, the main ones being PVC or PEP pipes.

This article will not address the issue of determining the agronomic parameters involved in calculating flow rates.

2. Methodology

To achieve the established objectives, it is essential to adopt an appropriate methodology. The methodology adopted for this study consists of three (3) essential steps: site visit, field data collection, and technical analysis in the office.

2.1. Site Visit

The visit is organized for site reconnaissance and the collection of hydraulic data.

2.2. Field Data Collection

The preliminary field survey consisted of visual observations ;

- Topographic data ;
- Hydraulic data collection ;
- Crop data

2.3. Technical Study in the Office

This is the technical part of the study, and it involves:

- Analysis of hydraulic and agronomic data (calculations of flow rates and quantities of water produced from data collected in the field, crops, etc.)
- Determination of water requirements using CROPWAT software (FAO);
- Determination of continuous flow rate, maximum peak flow rate, irrigation doses, irrigation frequency, water hand, irrigation station duration, and hydraulic zone;
- And organization of the water rotation within the designed perimeter.

3. Results of Technical Work

In general, it should be noted that the site's topography reveals a relatively flat terrain with an average slope of 1.3%. The soil is suitable for market gardening, cereal crops, and forage crops, including orange trees, and is of the clay-loam type.

The cultivated area is laid out to ensure that the plots are of the same size. This will facilitate sizing and allow for a nearly identical choice of equipment.

3.1. Crop Water Requirements Calculations

Crop water requirements were determined using CROPWAT software. This irrigation management software, developed by the FAO (Food and Agriculture Organization of the United Nations), calculates water requirements and the quantities of irrigation water needed for future crops in the study area. The results are shown in the tables below.

In our study, the irrigation network to be designed is of the Californian type, and its sizing was based on the most demanding crop (alfalfa) with an efficiency (E) of 85%. This crop requires the largest volumes of water.

The different crops to be grown on this perimeter once designed are: alfalfa (3ha); onion (8ha); wheat (3ha); squash (0.5ha); melon (0.5ha) and watermelon (1ha).

Given that the gross water requirements are per hectare, the gross water requirements for the entire area (3 ha) are shown in Table 1.

Table 1 Water requirements of crops during the highest month in the study area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NN mm	176.1	187.4	231.0	230.9	**242.3**	189.9	69.4	0.0	14.7	65.8	73.3	88.2
GN m3/h	1761	1874	2310	2309	**2423**	1899	694	0	147	658	733	882
EF Californian	0.85	0.85	0.85	0.85	**0.85**	0.85	0.85	0.85	0.85	0.85	0.85	0.85
GN Californian	2138,35	2275,57	2805	2803,78	**2942,21**	2305,92	842,71	0	178,5	799	890,071	1071

NN = Net Need; GN = Gross Need; EF= Efficiency

To determine net and gross needs, we used the formulas below:

Net Need (BN) = ETM - Effective Rainfall

Gross Need (GN) = Net Need / Efficiency

- The highest gross water requirements were recorded in May at 2942.21 m^3/ha for the Californian network.
- Daily gross water requirements = 110 m^3/ha/day for the Californian network using the same CROPWAT software.

It should be noted that the hydraulic parameters below were determined using data from the most restrictive month (May).

3.2. Continuous fictitious flow (CFF)

This is the unit flow rate that the network would have to transport if it operated 24/7 or at the time interval considered, and which would allow the water needs of a unit area to be met.

CFF = GN Period *1000/ND*86400

With the Californian network, the CFF throughput will be: 2942,21*1000/31*86400= 1,098 l/s/ha

ND (number of days in the period considered)

GN periods (m3/ha)

1m^3=1000liters

1Day = 86400 seconds

3.3. Peak Maximum Flow Rate (PMF)

The maximum peak flow rate is the actual flow rate that must be introduced into the network to compensate for the water deficit. This is the actual flow rate on which the network will be calibrated.

The daily irrigation duration for the area will be assumed to be 9 hours per day.

For the Californian network, **PMF = GNperiod x1000(l/s/ha)/JxNh x3.600**

Ou bien on peut déterminer DMP avec la formule suivante :

PMF= DFCx24 /alpha Nh l/s/ha

Alpha = 1 when all days of the period are irrigation days.

Nh = Number of hours

$$PMF = CFF\ x24\ /\ Nh\ (l/s/ha).$$

$$PMF = 2942{,}21*1000/\ 10*31*3600 = 2{,}63 l/s/ha$$

Experience shows that the flow rate at which the producer operates under real irrigation conditions with the Californian system powered by a low-power motor pump (<5hp) is generally less than 6l/s. We will take 3l/s/ha even in the case where producers allow themselves to do several crops at the same time.

3.4. Irrigation doses

Three different doses are distinguished:

3.4.1. Humidification Dose (HD)

This is the amount of water that needs to be applied at the beginning of the irrigation season to bring the dried-out soil up to its retention capacity(Hcr).

$$\mathbf{HD= 0{,}45xdaxH_{e}xZ}$$

$$HD= 0{,}45*1{,}20 *0{,}16 *1000= 86{,}4mm= 864\ m^{3}/ha$$

He = humidity Weight

Z= depth to moisten
Da = soil dry Apparent density

In our study area, we have clay-loam soil.

We chose alfalfa as our reference crop because it has the highest water requirement in May in the study area (Agadès).

Maintenance dose (MD)

Once the moistening dose has been applied and the soil has reached its retention capacity, it is sufficient to add, at regular intervals, an equivalent quantity of water of 1/2 to 2/3 of the Humidification Dose.

$$\mathbf{MD = 0{,}5*HD}$$

$$HD= 0{,}5*86{,}4 =43{,}2\ mm= 432m^{3}/ha$$

3.5. Irrigation frequency (N)

This is the number of times irrigation is required per month or over a period of time to maintain soil moisture within acceptable limits:

For the Californian system, N is determined by the formula below:

$$\mathbf{N = GN\ period/Dr}$$

N = 2942,21/518.4 = 5.67 rounded to 6 irrigations per week.

Real Dose (Dr)

For convenience, the number of applications is generally arranged to correspond, as far as possible, to a whole number of actual irrigation days. The actual dose should always be less than or equal to the calculated dose (MD).

$$\mathbf{Dr = GN\ period/N(mm)},$$

$$Dr = 2942{,}21//6 = 490.37\ m^3/ha \text{ rounded to } 490\ m^3/ha$$

Dr is in mm if GN is in mm
Dr is in m^3/ha if GN est m^3
N is the frequency of irrigation or watering

3.6. Water hand(m) or module, or intensity

This is the flow rate supplied by the last-order intakes of the networks ; the water hand is not calculated and varies from 10 to 50 l/s. Choosing a water hand is very important because it determines the calibration of the canals. In irrigation, the following consequences are observed in relation to the flow rate :

Low flow loss time

Strong flow water loss

The flow rate provided must be easily controlled by the irrigator.

The meteorological data collected on the perimeter gives a daily flow rate of 1070 m^3/h. Divided by the number of irrigation hours per day, 1070 m^3/h / 10 = 107 m^3/h, rounded to 110 m^3/h.

Daily GN = 110 m3/ha/day

hence : 110/3= 36,666 m^3/h et on fait 36,666 m^3/h*1000/3600=10l/s

We recommend a water module or hand flow of 12 l/s

3.7. Duration of the irrigation station (T)

This is the time taken at each rotation to deliver the actual dose to the same plot from a known flow rate such as the water hand.

Either per hectare

For the Californian network **T= Dr/m**

T : en seconds D= m3/ha m : m3/s

$$T = 420/0{,}01019\ ;\ T= 41216\ s = 11h25$$

11h25/4 = 2,85h As a safety precaution, we will take 3 hours

To irrigate 0.25 ha, we will therefore take 3 hours.

We take m = 12 l/s hence the Dr becomes: 3 *4*3600*0,012= 518,4 m3/ha

3.8. Hydraulic district (W)

The hydraulic district in gravity irrigation is the surface area of all the plots that can be irrigated from the same water source.

$$\mathbf{W\ (ha) = m\ (l/s)/PMF(l/s/ha)}$$

W= 10/3= 4ha for a hydraulic district

Because the total area reserved for setting up the future perimeter is 19ha, we will limit the number of hydraulic districts to 4. And each district will have 12 plots of 0.33ha.

3.9. Sizing of the motor pump

In Niger, experience with irrigation projects, especially small-scale irrigation, shows that 2-5 HP motor pumps, generally sold in all regions of the country, respond well to the extreme conditions of pumping surface and groundwater.

Therefore, the choice of motor pump does not require rigorous sizing calculations. The chosen motor pump is the SEH50/GX120 (HONDA) with 2.9 HP and a 20m total head.

3.10. Distribution Network Sizing

Due to management and operating conditions of pressurized PVC pipes, diameters of 50 mm or 63 mm to 75 mm will be limited.

Considering a flow rate of 3 l/s, all three diameters (50, 63, and 75 mm) are suitable for the 150 m network length, as they all correspond to total dynamic head (TDH) values below the 20 m threshold. Under these conditions, it is more sensible to choose 50mm diameter pipe for the network, as it would be less expensive than 63mm and 75mm diameter pipes.

Since the plots have an area of 0.33 hectares, with sandy-clay soil, the total length of the network will be 150 meters.

The irrigation network will be buried at a depth of 40 cm to prevent damage from external factors, including solar radiation and trampling by people or animals. This depth will also keep the network out of reach of soil cultivation equipment.

This network sizing only concerned the diameters of the pipes chosen previously and was done mainly based on the geometric height of the pumping (10m), maximum flow rate of water application to the plot (12l/s) and the total head losses (ΔJt) = ($\Delta Jl+\Delta Js$)

3.11. Water rotation organization

Based on the hydraulic design and sizing work described above, and in agreement with the technicians of the relevant departments and the producers, the organization of the water rotation at the level of the new designed development is summarized in the following tables.

The designed perimeter was divided into 48 small plots of 40m3 each and irrigated by 8 water storage basins.

Table 1 Water rotation for the first day at the perimeter designed

Time		**Basins that must operate simultaneously**	**Plots per basin**		**Irrigated Area (ha)**
			N° basin	**N° Plot**	
Beginning	**End**				
08h	11h	4	1; 3; 5; 7	13; 15; 14;16; 17; 18; 19; 20; 21; 22; 23; 24	
11h	14h				
14h	17h				
Total area irrigated per day	**4**				

Table 2 Water rotation for the 2nd day at the perimeter designed

Time		Basins that must operate simultaneously	Plots per basin		Irrigated Area (ha)
			N° basin	N° Plot	
Beginning	End				
08h	11h	4	2; 4; 6; 8	1; 3; 2; 4; 5; 7; 6; 8; 9; 10; 11; 12	
11h	14h				
14h	17h				
Total area irrigated per day	**4**				

Table 3 Water rotation for the 3rd day at the perimeter designed

Time		Basins that must operate simultaneously	Plots per basin		Irrigated Area (ha)
			N° basin	N° Plot	
Beginning	**End**				
08h	11h	4	1 ; 3 ; 5 ; 7	37 ;38 ;39 ;40 ;41 ;42 ;43 ;44 ;45 ;46 ;47 ;48	
11h	14h				
14h	17h				
Total area irrigated per day	**4**				

Table 4 Water rotation for the 4th day at the perimeter designed

Time		Basins that must operate simultaneously	Plots per basin		Irrigated Area (ha)
			N° basin	N° Plot	
Beginning	**End**				
08h	11h	4	2; 4; 6; 8	25; 27; 26; 28; 29; 30; 31; 32; 33; 34; 35; 36	
11h	14h				
14h	17h				
Total area irrigated per day	**4**				

Table 5 Water rotation for the 5th day at the perimeter designed

Time		Basins that must operate simultaneously	Plots per basin		Irrigated Area (ha)
			N° basin	N° Plot	
Beginning	End				
08h	11h	4	1; 3; 5; 7	61; 62; 63; 64; 65; 66; 67; 68; 69; 70; 71; 72	
11h	14h				
14h	17h				
Total area irrigated per day	**4**				

Table 6 Water rotation for the 6th day at the perimeter designed

Time		Basins that must operate simultaneously	Plots per basin		Irrigated Area (ha)
			N° basin	N° Plot	
Beginning	End				
08h	11h	4	2 ; 4 ; 6 ; 8	49 ;50 ;51 ;52 ;53 ;54 ;55 ;56 ;57 ;58 ;59 ;60	
11h	14h				
14h	17h				
Total area irrigated per day		**4**			

The basins are rectangular in shape. They are sized according to the daily needs of the crops. Irrigation water is stored in these basins during pumping. From there, the water flows directly to the perimeter by gravity. In this case, the basin serves both as a storage and distribution point for the water into the pipes.

4. Conclusion

In this study, the structures were sized using a calculation software called CROPWAT. This software is adapted for hydraulic calculations in irrigation projects. Irrigation design studies aim to develop and improve agricultural production.

In this work, we have attempted to analyze the problems posed by the implementation of an irrigation project for a newly developed area.

Based on water needs and taking advantage of the soil characteristics and the nature of the area, we chose the Californian irrigation system technique due to its compatibility with the project requirements.

which is the set of the number of doses, frequencies and dates of watering that must be applied to cultivated plants throughout their entire growing season, in order to compensate for the water deficit in the active layer of the soil with the best watering technique that is adapted according to the data that characterize our plot.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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