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Feasibility of Transferring Drinking Water from the Senegal River in the East (Backel) to the West Center (Fatick) in Senegal

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Abstract

Every year, 24 billion m^3 of fresh water are thrown into the sea by the Senegal River, while most of the country's populations do not have permanent access to drinking water. Also, agricultural land, which extends as far as the eye can see, is only used during winter periods, thus slowing down the development of agriculture. It is in this context that this article studies the feasibility of transferring drinking water from the Senegal River in the east of the country to the center-west through a transfer canal to meet the drinking water needs of the populations. In addition, we intend to flood the fossil valleys from this canal and recharge the aquifers. The watershed resulting from the juxtaposition of the two watersheds which dominate central Senegal has a slightly descending profile from Bakel to Fatick. This promotes gravity flow of water over 542 km. This analysis is carried out by the Global Mapper software and SRTM1 images. We report that all water needs have been estimated at approximately 70 m^3/s based on the ANDS census in 2023, the distribution of arable land and groundwater recharge areas in the country. The waters flowing in the canal have depths (draft) not reaching 4.6 m. These results are obtained by applying the Manning Strickler equation, on a channel with a straight cross-section in the shape of a trapezoid and lined with sand concrete. The canal thus designed will bring water to populations and arid zones in the central and central-western regions of the country where problems persist. However, it will be necessary to overcome a difference in altitude of 96 m over 30 km to raise the water from the river to the threshold of the canal in order to ensure the flow in the latter. We have retained two calculation variants (Canal + Pumping or Single Pumping) whose pumping stations will be powered by solar fields. Due to the heavy investments, the installations upstream of the canal will be modular over time. Consequently, the central canal project will be constructed in six (6) phases of ten (10) years.

Keywords

Fresh Water, Canal, Fossil Valleys, Aquifers, The Dividing Line, Watersheds, Gravity Flow, Sand Concrete, Height Difference, Modular, Solar Fields

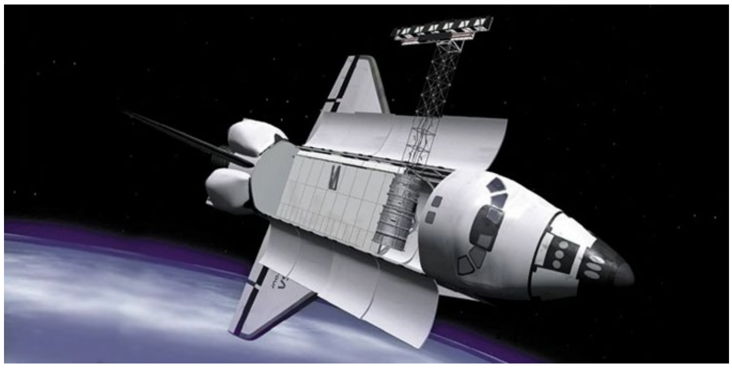
1. Introduction

Senegal has a problem related to the availability of water quantity and quality. And yet, every year, 24 billion m^3 of fresh water from the Senegal River escapes through the gates of the Diama dam and flows into the sea. It is in the analysis of these two antagonistic situations that we judge the problem of a paradox. The latter is the key to the motivation of this article in the field of water management. The unavailability of this precious liquid is aggravated by the overexploitation of the aquifers and the scarcity of rainfall. It should be noted that the boreholes, the KMS of Lake Guiers, the udder desalination plant are means provided by governments to stem the drinking water shortages that plague our populations. But all these efforts only temporarily alleviate the problems in question. We are signaling that the ideas of building projects such as the Cayor Canal, the Baol Canal and the water highways would be sustainable solutions to these problems. This is how we came up with the idea of a water transfer canal (the Canal du Centre) [1]. Its objective is to recover as much as possible from the 24 billion cubic meters of water lost to the sea downstream of the Senegal River and redirect it to the country's arid areas to boost agriculture, on which 65% of the population depends [2]. It is an open-air canal lined with sand concrete and capable of carrying up to 70 m^3/s of water by 2075, or 2.3 billion cubic metres per year. The volume recovered should be able to make available several tens of thousands of hectares of food and fodder crops. In addition, fossil valleys will need to be rebuilt, groundwater tables will need to be recharged, and millions of populations will be supplied with drinking water [3].

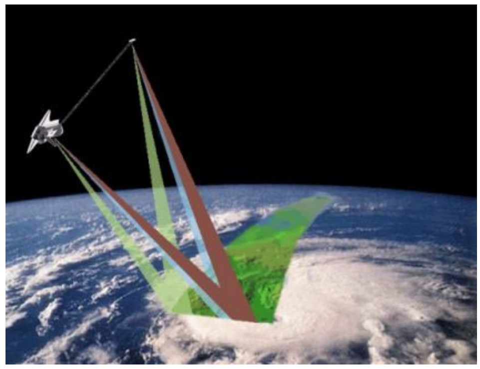
2. Materials and Methods

2.1. Data Acquisition

The topography of the environment is the most essential part of a hydraulic project because it defines the type of flow to be adopted. We will use the SRTM1 images to determine the topography of the terrain that we will encounter along our channel. The SRTM (Shuttle Radar Topography Mission) refers to topographic raster and vector files provided by two American agencies including NASA and NGA (formerly NIMA). These altimetry data were collected during an eleven-day mission in February 2000 by the Space Shuttle Endeavour (STS-99) at an altitude of 233 km using radar interferometry (**Figure 1(a)** and **Figure 1(b)**) [4].



(a)



(a)

Figure 1. (a) Space Shuttle Endeavour (nasa.gov); (b) Mast into Earth orbit for SRTM radar mapping of the Earth's topography (https://www.nasa.gov/).

This observation campaign made it possible to establish digital terrain models (DTMs) for nearly 80% of the land area extending from 56˚ South latitude to 60˚ North latitude. Other data are also available to the public: raw radar data and data generated from MNT [5]. Among the MNT, there are three types of files:

- SRTM1: resolution of one arcsecond (31 m at the equator), covering only the United States of America and its dependencies;
- SRTM3: three-arcsecond resolution (93 m at the equator), worldwide coverage;
- SRTM30: 30-arcsecond resolution (926 m at the equator), worldwide coverage, a kind of update of the GTOPO30 format (**Figure 2**). In this article, we will use SRTM1 files (**Figure 3**) in order to minimize uncertainties in the fields to be studied.

The accuracy of topographic surveys is highly dependent on acquisition methods and the resulting artifacts. In the case of radar interferometry, shoreline areas along the coast are very misinterpreted due to waves, and the shuttle must make several passes over the desired area to minimize this defect as well as to eliminate areas hidden from the radar radius by the surrounding terrain [6].

The software converts, edits, publishes, prints, manages GPS, creates mosaics, tiles and allows users to perform advanced spatial analysis, including vegetation indices, watershed analysis, volume calculation, etc.

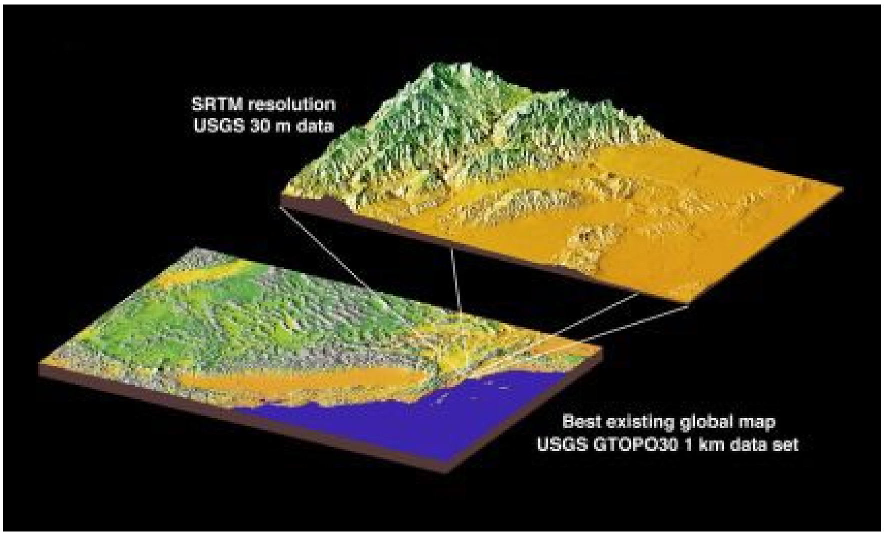


Figure 2. Comparison of SRTM1 and SRTM30 images (https://www.nasa.gov/).

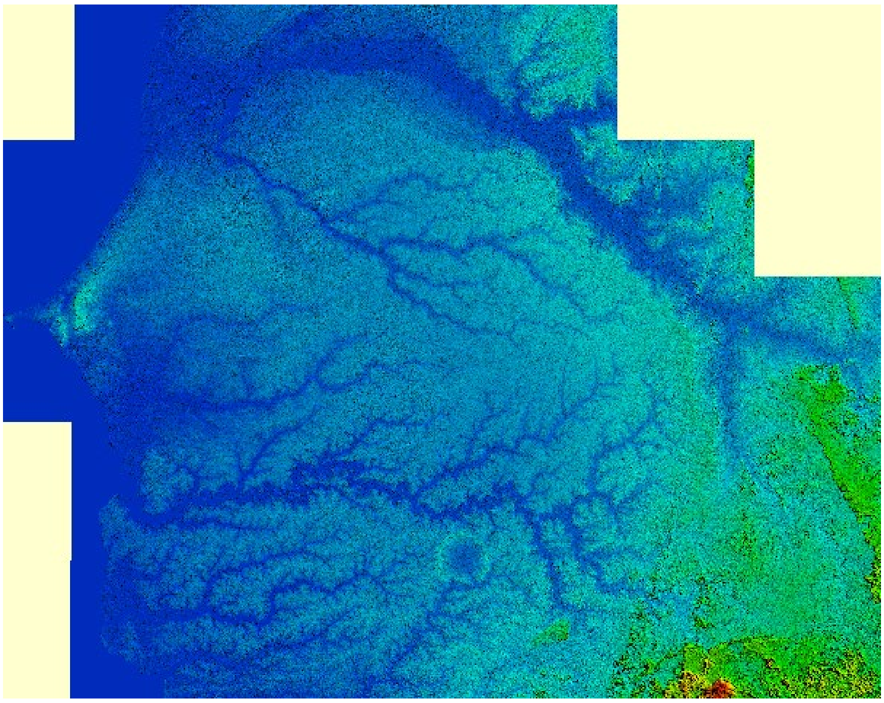


Figure 3. Map of Senegal according to SRTM1.

Data files can be loaded as layers, so a digital elevation model (DTM) can be loaded with a topographic map to create a 3D view of the map. A digital aerial photograph can be draped alongside vector data to create an information-rich map. The result can be printed, or the workspace can be exported as a high-resolution raster image for use in a presentation or report (**Figure 4** and **Figure 5**) [7].

2.2. Data Processing and Analysis (Numerical Statistics)

The sizing of the channel depends exclusively on the flow rate to be transferred. This takes into account the population to be supplied, the industries to be served, the animals to be watered, the land to be irrigated, the valleys to be replenished and the aquifers to be recharged. This is why, as with any design process, we will also determine in this part of this thesis the losses related to the operation of the canal, evaporation and possible infiltrations [8]. The population is estimated on the basis of the lifespan of such a project. That is to say, throughout the expected lifespan of fifty (50) years, the structure must be able to provide the flows necessary to supply water to the populations and the land [9].

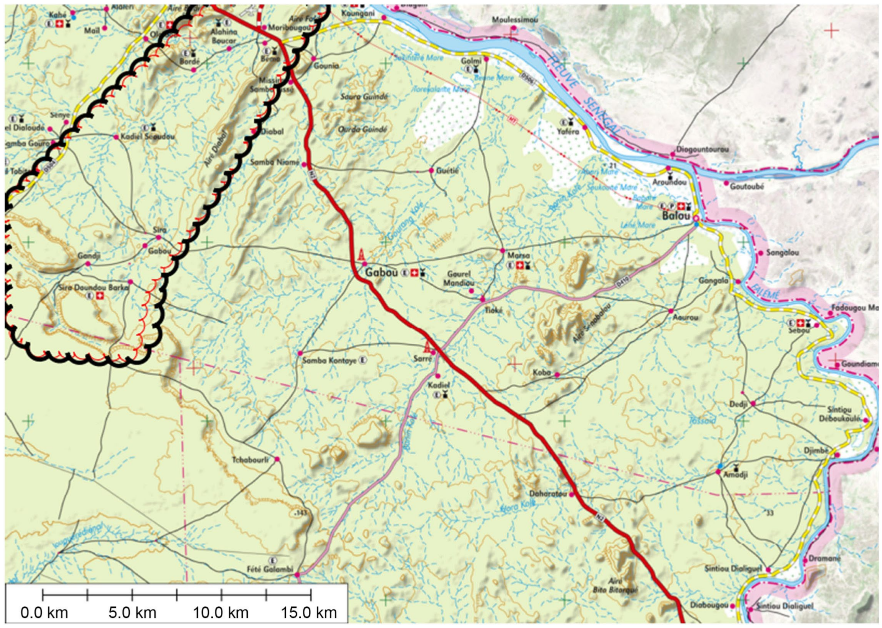


Figure 4. Printing of topographic image of the upstream part of the canal.

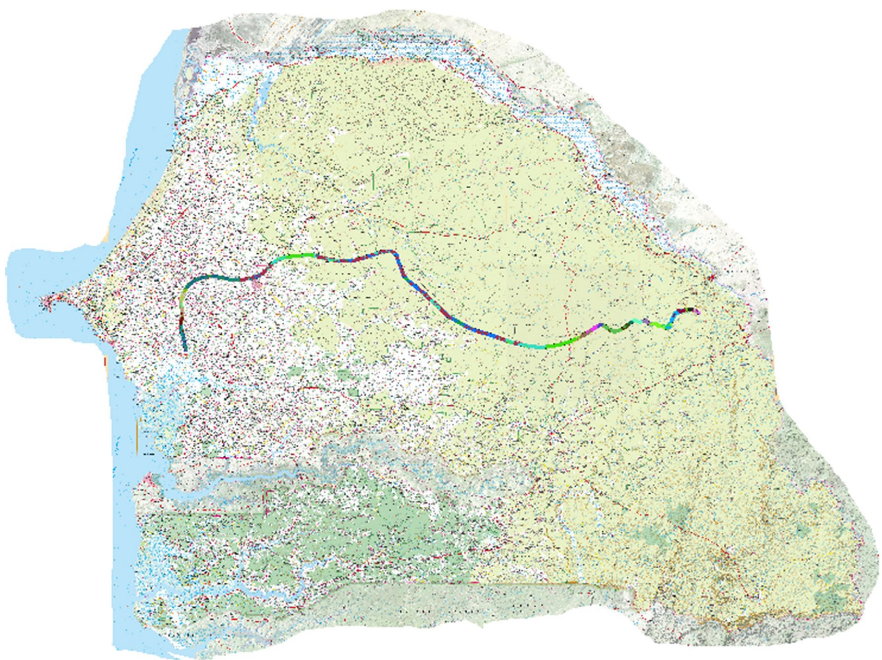


Figure 5. Overlay of the canal route with a topographic map of the country.

Through the ANSD (National Agency for Statistics and Demography), Senegal carried out a general census of its population in 2013, and then a projection for 2025 was carried out.

The canal route (**Figure 5**) defines the regions to be served along the route of the water. It is on this basis and the distribution of populations in the country (ands.sn) and over time (**Table 1**) [10].

Table 1. Distribution of the population according to nodes and years.

Knots	Populations of the year							Population growth rate	Growing cumulative workforce
	2013	2025	2035	2045	2055	2065	2075		
Fatick	1,464,366	2,152,371	2,623,728	3,198,310	3,898,722	4,752,521	5,793,296		5,793,296
Bambey	794,177	1,832,625	2,233,960	2,723,184	3,319,547	4,046,509	4,932,672		10,725,968
Touba	1,012,638	1,468,646	1,790,271	2,182,331	2,660,249	3,242,829	3,952,990	**2%**	14,678,958
Kaffrine	566,992	869,348	1,059,730	1,291,805	1,574,704	1,919,555	2,339,927		17,018,884
Matam	289,918	453,901	553,303	674,473	822,179	1,002,231	1,221,714		18,240,599

Depending on the standard of living, the need for drinking water varies. The impacts of this large-scale project will raise the standard of living of most Senegalese people. For this purpose, we will consider an annual increase in these needs of 2% from the year 2025 until the project horizon in 2075 (**Table 2**) [11].

Table 2. Individual drinking water needs as a function of time.

Years	2003	2025	2035	2045	2055	2065	2075
Needs in (l/d)	54	75	91	111	136	166	202
Needs in (m^3/d)	0.054	0.075	0.091	0.111	0.136	0.166	0.202

3. Results

The Following Formula (1) Makes It Possible to Estimate the Drinking Water Needs over the Project Horizon.

$$C = C_0 * (1 + a)p \tag{1}$$

C: The average consumption of the project year here 2075;

C_0: The average consumption of the year the canal was put into service;

A: The increase in average consumption during the life of the project;

P: The number of years which separate the horizon and the date of commissioning of the project.

From pumping raw water into the Senegal River to redistributing drinking water to households and industries, the canal will experience various water losses. This article is limited to losses linked to evaporation, infiltration, and the purification of raw water [12].

Apart from losses due to the purification of this water, all other losses will be calculated on the basis of raw water (water in the canal) [2].

Therefore, the flow rates calculated in Table 3 must be multiplied by Kp = 1.2 to include the losses through purification.

Table 3. Partial and cumulative weighted requirements as a function of time and nodes.

knots	raw water needs of the populations of the year (m^3/s)							coefficient k_1 of loss by drinking water	growing cumulative needs
	2013	2025	2035	2045	2055	2065	2075		
Fatick	1.095	2.242	3.332	4.951	7.356	10.931	16.243		16.243
Bambey	0.594	1.909	2.837	4.215	6.263	9.307	13.830		30.073
Touba	0.757	1.530	2.273	3.378	5.019	11.083	11.083	1.2	41.156
Kaffrine	0.424	0.906	1.346	2.000	2.971	4.415	6.561		47.716
Matam	0.217	0.473	0.703	1.044	1.551	2.305	3.425		51.142

Other needs include water for crops, for animals, for recharging aquifers and revitalizing fossil valleys. In order to assess these needs, we are going to take a flat-rate approach for animals and crops, granting each hectare of defined surface area a certain volume of raw water. Taking into account the types of crops planned, the volume retained is 50 m^3/ha/day [13] [14].

In reality, the total area planned for crops is colossal, 30,000 hectares of crops spread across the arid zones of the country. Its development will take place gradually over time (Table 4) and its raw water requirements will follow the same trend (Table 5).

Table 4. Evolution of agricultural developments according to nodes and time.

Knots	Surfaces to be developed (en ha)	Percentage of agricultural developments of the year					
		2025	2035	2045	2055	2065	2075
Fatick	9000	5	30	60	80	100	100
Bambey	7500	10	50	90	100	100	100
Touba	3500	50	100	100	100	100	100
Kaffrine	5000	40	100	100	100	100	100
Matam	500	40	100	100	100	100	100

Table 5. Areas and cumulative needs depending on the nodes.

Knots	Surfaces to be developed (en ha)	Agricultural needs of the year (m^3/s)						Raw water requirements (m^3/ha/day)	Growing cumulative needs
		2025	2035	2045	2055	2065	2075		
Fatick	9000	0.260	1.563	3.125	4.167	5.208	5.208		5.208
Bambey	7500	0.434	2.170	3.906	4.340	4.340	4.340		9.549
Touba	3500	1.013	2.025	2.025	2.025	2.025	2.025	50	11.574
Kaffrine	5000	1.157	2.894	2.894	2.894	2.894	2.894		14.468
Matam	5000	1.157	2.894	2.894	2.894	2.894	2.894		17.361

Table 5 shows that demands for drinking and agricultural water will be minimal during the first years of the center canal (in 2025) and maximum over the project horizon (in 2075). And on the other hand, the demand for charging will evolve inversely. Therefore, it is appropriate to optimize the calculation flow of the canal section to minimize development costs. Using Figure 6, let us closely analyze the changes in needs over time [15] [16].

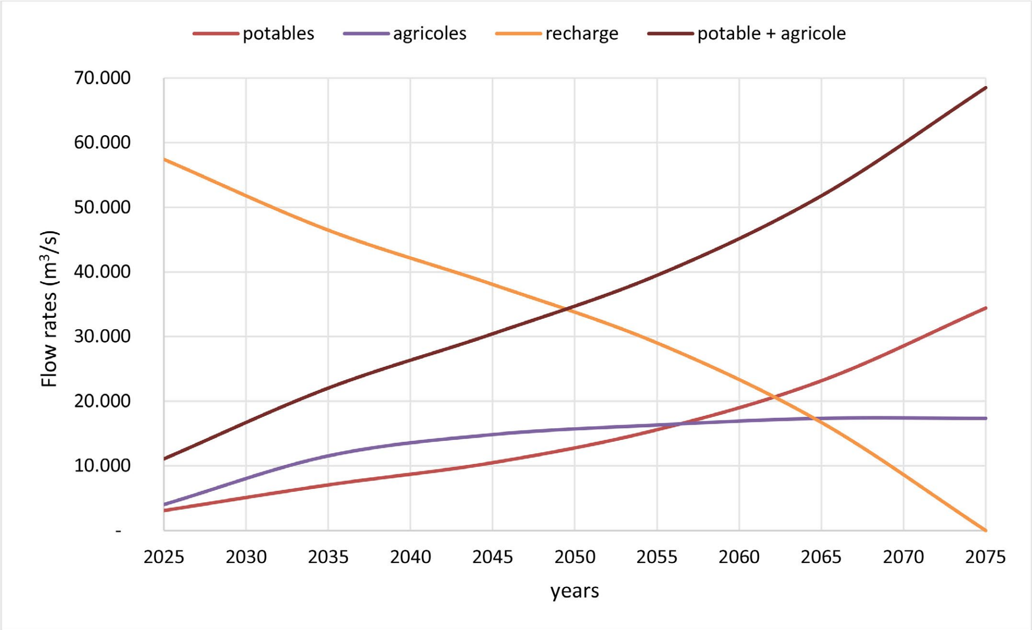


Figure 6. Changes in needs over time.

The agricultural and drinking curves represent changes in water demands over time.

The drinking + agricultural curve represents the sum of water needs for cultivation, households and industries.

The recharge curve estimates the flow of water that the canal will be able to transfer in addition to its design flow until 2075.

This graph (Figure 6) shows that if the canal is sized for agricultural and drinking needs only, the recharge flow rates could be supported by the same section of canal until 2075. Table 6 gives the flow rates sizing [17] [18].

Table 6. Channel route throughputs based on nodes.

Knots	Water needs for the year 2075 (en m³/s)				Increasing cumulative calculation rates (m³/s)
	Potable	Agricultural	Recharge	Calculation flow	
Fatick	16.243	5.208	47.052	21.451	21.451
Bambey	13.830	4.340	50.333	18.170	39.621
Touba	11.083	2.025	55.394	13.109	52.730
Kaffrine	6.561	2.894	59.049	9.454	62.184
Matam	3.425	2.894	62.184	6.319	68.503

Considering all these analyzes and calculations, an instantaneous flow rate of 68.503 m^3/s is planned for the dimensioning of the center canal.

4. Conclusion

Water transfer projects have always been highlighted when proposing sustainable solutions regarding water supply in Senegal. The Cayor Canal should provide drinking water for the Thiès-Dakar conurbation and water for crops in Cape Verde and the Thiès region. The Baol canal with its four calculation variants should ensure the AEP of the Touba—Mbacké agglomeration, livestock and agriculture en route. The water highways are the result of the operation of three projects: the two previous ones and the fossil valley revitalization project. The latter is largely made up of penstocks [19]. The more sustainable and ambitious central canal is added to the list. It is because the relief allows it that it crosses the interior of the country from Bakel to Fatick, supplying all the regions it crosses. This article makes it possible to justify the feasibility of a water transfer channel capable of transporting several million cubic meters of water per day for decades [20]. These volumes will of course make it possible to supply the populations with drinking water and the land with water for crops, for the revitalization of dead valleys and for the recharge of aquifers. This project will mobilize more than 2.2 billion cubic meters of water each year from the Senegal River. All quantities of raw water will make available, among other things, 30,000 ha of arable land and 3.7 million cubic meters of drinking water every day. During periods of river flooding, many recharge areas may be flooded to recharge the water tables and many fossil valleys will be refilled. The route of this present canal showed a profile making gravity flow possible. However, its analysis was done according to the SRTM1 points file. This is raw data from topographic surveys. However, their accuracy is strongly dependent on the acquisition methods and the resulting artifacts [21] [22]. Therefore, we recommend a more elaborate survey campaign in order to acquire more precise point files. In addition, determining the minimum irradiation of the area where the installation of solar fields is planned could optimize the number of solar panels necessary for the construction of the photovoltaic power plant. This article defines technical parameters justifying the possibilities of constructing the canal and its impoundment. Therefore, other studies will be necessary for developments downstream of the center canal. These constructions include water treatment plants, hydro-agricultural developments, dams and sanitation for the discharge of wastewater, among others.

Conflicts of Interest

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

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