The Hydraulic Design of Irrigation Channels for Ishapa, Kwara State, Nigeria

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Abstract
The artificial application of water to land to aid crop production has enabled man to increase his ability to produce food and cash crops. All – the – year round crop production is now possible instead of the previous restriction to rain fed agriculture. However, conserving water and delivery it to the fields in an efficient manner has continued to be a challenge. This work seeks to take advantage of a dam being constructed for water supply purposes at Isapa, Kwara State, Nigeria. The reservoir capacity is far too big for the water demand and therefore a large quantity of water will be available as excess. Incidentally, an expanse of fertile land exists in the immediate downstream of the dam which is suitable for irrigation agriculture.

A detailed topographical survey was carried out among other studies and a layout was prepared for the delivery of water to the fields by the use of irrigation channels. Channel parameters were established through the use various tested formulas found in literature and from experience. It was also concluded that the reservoir capacity is adequate for both water supply and irrigated farm.

Key Words: *Irrigation, Channels, Hydraulic Design*

1.0 Introduction

Irrigation may be defined as the process of artificially supplying water to soil for raising crops. It is a science of planning and designing an efficient, low-cost, economic irrigation system tailored to fit natural conditions. It is the engineering of controlling and harnessing the various natural sources of water, by the construction of dams and reservoirs, canals and headworks and finally distributing the water to the agricultural fields (Punmia and Pande, 2008).

From 50 to 90 percent of the weight of living organisms is water. Hence water is indispensable to the growth of living things. Unfortunately, water is available in varied quantities at different times and season all over the earth. This implies that water may not be available from natural rain except abstracted from other means. The end result of abstraction is its use to irrigate crops.

All the irrigation schemes are so designed that they increase the food production of the country. Apart from the increase in food, there are many indirect benefits or advantages of irrigation, and they are: Increase in Food Production; Protection from Famine; Cultivation of Cash Crops; Addition to the Wealth of the Country; Increase in Prosperity of People; Improvement in the Ground Water Storage; Aid in Civilization; general development of the country; and creation of employment opportunities; etc.

The behavior of weather in Nigeria has been a subject of extensive research. Odekunle (2005) identified that the active lengths of growing season in Ikeja, Ondo, Ilorin, Kaduna and Kano are 5 months, 5 months, 4 months, 4 months and 2 months respectively. He stated that the growing season in these states of Nigeria was directly dependent on the number of months of rainfall in those states. Olaniran (2002) also confirmed the existence of rainfall anomalies in Nigeria. These facts make Nigeria and precisely Isapa an environment prone to unequal distribution of rainfall and the need to depend on irrigation for improved food production. Figure 1 present the weather averages of Nigeria in graphical form.

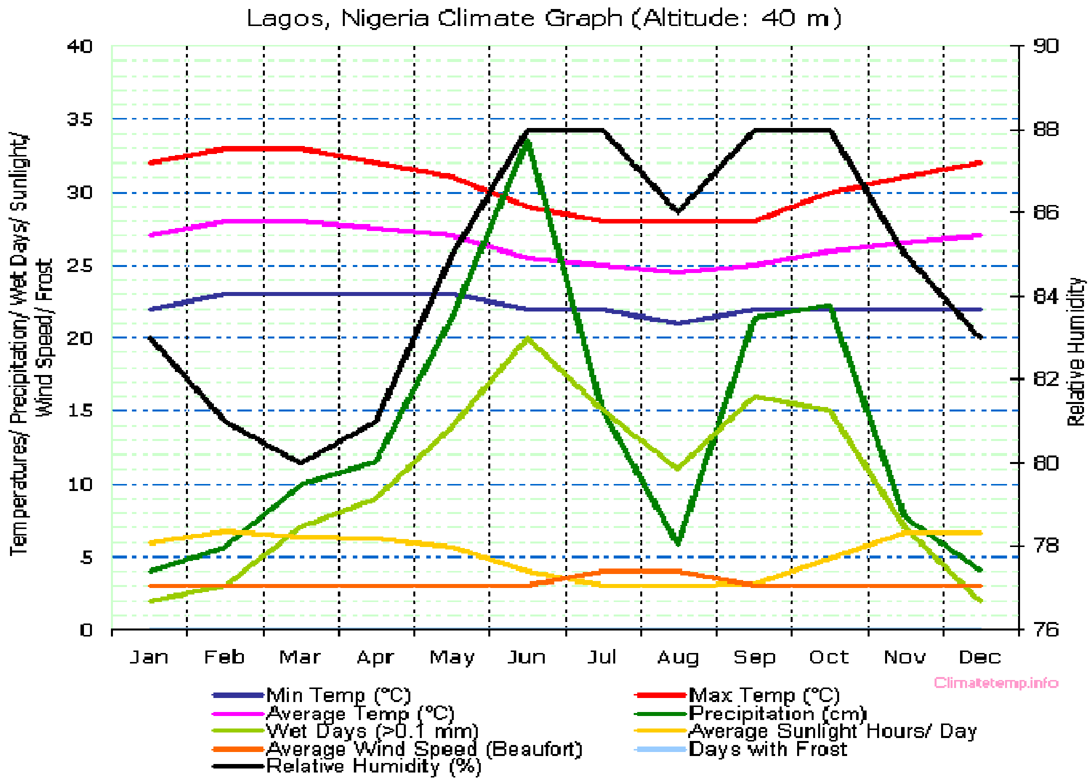

Figure 1: Nigeria Climate Graph in metric [Source: www.climatetemp.info/Nigeria]

2.0 Study Area

Isapa, a town in Ekiti Local Government Area of Kwara State, Nigeria, is located on latitude $8^{O}07'30''$ and longitude $5^{O}20'00''$ as shown in Figure 2. Isapa is about 115 km from Ilorin the state capital just off Ilorin – Lokoja highway. Predominantly farming is the major source of livelihood of the inhabitants with livestock rearing and Fishing done on small scale. The community is blessed with natural flowing water which is being dammed for domestic water supply. With a dam reservoir Capacity established at 12.5 Mm^3 and the domestic water demand of the community of 0.5 Mm^3, the dam storage will be grossly underutilized. The inclusion of an irrigation facility will ensure a more judicious use of the excess water to be stored in the dam reservoir. Irrigated land represents about 18 percent of all land under cultivation but often produces over twice the yield of non-irrigated fields. Hence the main objective of this work is to provide a design proposal for irrigation purposes for the achievement of a sustained production of Crops throughout the year for the farmers in Isapa Community.

Figure 1: Google Map of Isapa Community in Kwara State

3.0 Literature Reviews

3.1 Methods of Irrigation

There are four main methods water application to fields. These are furrow, sprinkler, basin and drip, (trickle) irrigation (Sharma, 2007). For adoption of any irrigation of the irrigation methods, the following requirements are essential:

- Application is within desirable limits. Stream flow is adequate so that the depth of wetting and hence the stand of crop is approximately uniform. The irrigator achieves high productivity so that during a day's work he can irrigate a large hectare.
- Afford a uniform water distribution in root zone of a crop with as small as 6cm applications for light irrigation
- Allow heavy uniform application of 15 to 20cm of water depth and under some conditions as much as 25cm per irrigation for salt leaching where such a problem exists
- Allow use of large concentrated water flows for reduction of conveyance losses, field channel network and labour cost,
- Suitable for use with economical conveyance structure
- Facilitate mechanized farming
- Occupy minimum land under bunds
- Inexpensive and economically justifiable
- High efficiency of water application i.e. the ratio of water stored in the root zone to that delivered to the field should be maximum
- Minimum wastage of water either through surface runoff or through deep percolation below the root zone of a crop.

Irrigation canals which are constructed without artificial lining on their water carrying surface are called artificial channels. Designing unlined channels depend on the conditions, particularly the soil formations, sediment transport characteristics, operational needs and desired standards of maintenance.

For erodible channels flow velocities are kept low so that the channel bottom and sides are not eroded. The minimum flow velocity in flows carrying a large amount, of sediment should be such that the material being transported is not deposited in the channel.

❖ Non-Erodible (Lined) Channels

In the design of a rigid-boundary channel, the channel cross section and size are selected such that the required discharge is carried through the channel for the available head with a suitable amount of freeboard.

Freeboard is provided to allow for unaccounted factors in design, uncertainty in the selection of different parameters, and disturbances on the water surface, etc.

The channel alignment is selected so that the channel length is as short, as possible and at the same time meets other site restrictions and requirements, such as accessibility, right of way, and balancing, of cut and fill amounts. The bottom slope is usually dictated by the site topography whereas the selection of channel shape and dimensions take into consideration the amount of flow to be carried, the ease and economy of construction and the hydraulic efficiency of the cross section.

A triangular channel is used for small rates of discharge, and a trapezoidal cross section is generally used for large flows.

For structural reasons, channels excavated through mountains or built underground usually have a circular or horseshoe shape.

Normally, the Froude number is kept low (approximately up to 0.3) so that the flow surface does not become rough, especially downstream of obstructions and bends. Similarly, the flow velocity is selected such that the lining is not eroded and any sediment carried in the flow is not deposited.

Normally, these channels are designed based on the assumption of uniform flow, although in some situations gradually varied flow calculations may be needed to assess the suitability of selected channel size for extreme events.

Selection of type of Irrigation Channels and Suitable type of lining

The essential requirements of a satisfactory type of Channel and Channel lining are;

i) low cost,
ii) impermeability,
iii) hydraulic efficiency (i.e., reduction in rugosity coefficient)
iv) durability,
v) resistance to erosion,
vi) repair ability, and
vii) Structural stability.

3.2 Channel Design Parameters

The design of a channel involves the selection of channel alignment, shapes, size, and bottom slope and whether the channel should be lined to reduce seepage and/or to prevent, the erosion of channel sides and bottom. Since a lined channel offers less resistance to flow than an unlined channel.

Procedures are not presently available for selecting optimum channel parameters directly. Typically, the design of a channel is done by trial and error.

Channel parameters are selected and an analysis is done to verify that the operational requirements are met with these parameters. A number of alternatives are considered, and their costs are compared. Then, the most economical alternative that gives satisfactory performance is selected.

3.3 Most Efficient Hydraulic Section

Theoretically speaking, the most efficient hydraulic section yields the most economical channel. However, it must be kept in mind that the above formulation is oversimplified. For example, it did not take into consideration the possibility of scour and erosion which may impose restrictions on the maximum flow velocity.

The conveyance or carrying capacity of a given channel section increase directly with the hydraulic radius (R). This means it increases with decreases in the wetted perimeter (P).

The best hydraulic section is one that has the least wetted perimeter for the same area (A). The channels in this work will be designed for the best hydraulic efficiency practicable. The best hydraulic section may not necessarily be the most practicable. Hence the most economical slope for a channel must simulate the following conditions.

1. Maximum discharge for a given cross sectional area
2. Minimum excavation and lining i.e least expenditure for the design amount of discharge
3. Least wetted perimeter or its equivalent so that there is minimum resistance of flow and consequently there is optimum discharge.

The Table below gives the geometric attributes of three best hydraulic sections.

Table1: Best Hydraulic Sections

Cross – sectional Shape	Area A	Wetted Perimeter P	Hydraulic Radius R	Top Width W	Hydraulic Depth D
Trapezoid – half of a Hexagon	$\sqrt{3y^2}$	$2\sqrt{3y}$	$\frac{1}{2}y$	$\frac{4}{3}\sqrt{3y}$	$\frac{3}{4}y$
Rectangle – half of a Square	$2y^2$	$4y$	$\frac{1}{2}y$	$2y$	y
Triangle – half of a Square	y^2	$2\sqrt{2y}$	$\frac{1}{4}\sqrt{2y}$	$2y$	$\frac{1}{2}y$

[Source: Mays, 2005]

Where y is the depth of the channel, R is the hydraulic depth, S is the slope of channel and n is manning's coefficient for the channel lining. For a concrete lined channel n = 0.015. For a rectangular channel, designing for the best hydraulic section we have: B = 2d; P = 4d; and A = $2d^2$. Where B, d, P, A are the bottom width, depth, wetted perimeter and Area of channel respectively. Also for n = 0.015 we use equation 3.6 and 3.9 to find the width, perimeter and area. Allowance of about 40% of depth of flow will be made for free board.

Where a trapezoid channel is used the best hydraulic section will have side slope of √3/3 horizontal to 1 vertical. For a Trapezoidal channel, designing for the best hydraulic section we have: $B = \frac{2d}{\sqrt{3}}$; $P = 2\sqrt{3d}$; and $A = \sqrt{3d^2}$

3.4 Flow Computation

For steady uniform flow the depth and velocity is constant hence no acceleration.

Hence $$V = C\sqrt{RS} \qquad 1$$

Where $$C = \left(\frac{\rho g}{k}\right)^{\frac{1}{2}} \qquad 2$$

This equation is called Chezy's equation and it has a unit of $M^{1/2}S^{-1}$ and C = Chezy's coefficient, others study or work of channel flow are Mannings.

$$C = \frac{R^{\frac{1}{6}}}{n} \text{ in S.I unit} \qquad 3$$

$$V = \frac{R^{\frac{1}{6}} R^{\frac{1}{2}} S^{\frac{1}{2}}}{n} \qquad 4$$

But $$Q = VA \qquad 5$$

This gives Manning's formula for uniform flow calculations as:

$$Q = \frac{AR^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \qquad 6$$

where, Q = flow in m^3/sec; A = Area of flow section in m^2; R = Hydraulic Radius in m; S = Slope of channels in m/m; and n = Manning's roughness coefficient. Recommended values for different types of channels are given in Table 2.

Table 2: Recommended Values for Manning's ''n''

Type of Channel and Description	n
Concrete Lined	0.015
Stone masonry (smooth finishing)	0.020
Unlined /formed	0.025-0.050
Natural Streams	0.040-0.050

[Source: Mays, 2005]

4.0 Materials And Methods

4.1 Raw Water Requirement

Estimated water demand for Isapa is about 1,000m^3/day. However an allocation of 500,000m^3 is to be reserved for water supply to cater for future requirements. A topographical survey of the immediate downstream was carried out which was used to prepare a layout of canals as shown in Figure 2. Gross area to be brought under irrigation is 100 ha as per the survey. Assuming the cultivation of three types of crops, the crop water requirement is estimated to be 10.96 Mm^3/year. Total water requirement per year for water supply and irrigation is thus about 12.5 Mm^3 which is about the reservoir capacity of the Isapa dam.

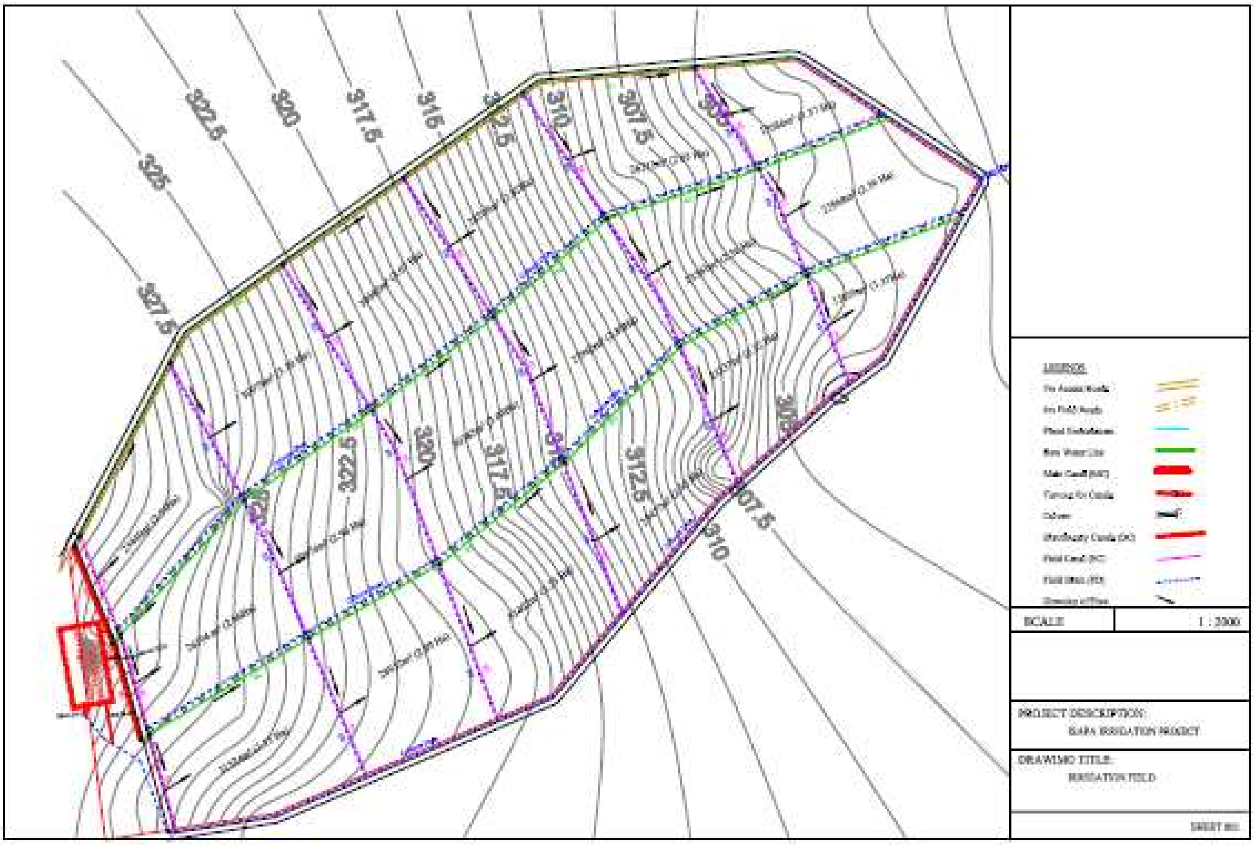

Figure 2: Field Layout of Canals for Isapa Irrigation Scheme

5.0 Hydraulic Designs of Concrete Lined Channel

For the purpose of this work, it is reasonable to assume irrigation duration of 6 hrs. Based on the crop water requirement and an area of 100 ha:

- Maximum Monthly Irrigation =36,500m^3/Ha/Month
- Maximum Daily Irrigation = 1,216.67m^3/day
- Maximum Discharge/ Ha = 0.056m^3/Ha/Sec
- Maximum Area Covered by Field Cana l = 3.35Ha
- Maximum Capacity of Field Canal (Q) = 0.19m^3/s

The topography of the area is such that the bottom slope S_o, is about 0.0004

For lined Concrete Flow Surface n = 0.015 (Table 2)
Applying Manning equation (equation 6) yields

$$AR^{\frac{2}{3}} = \frac{nQ}{S_o^{0.5}} = \frac{0.015 \times 0.19}{0.0004^{0.5}} = 0.1425$$

$$AR^{\frac{2}{3}} = (\sqrt{3}y^2)(0.5y)^{2/3} = 1.0911y^{2.67}$$

Solving for y we get:

$\frac{0.1425}{1.0911} = y^{2.67}$. Then y =0.47m for the field canals (i.e. full supply depth)

The Table 3 below shows computations of y for all channels as laid out in Figure 2.

Table 3: Table of Design Parameters for Isapa Irrigation Project

TYPE	Channel Description	Design Parameters					
		Channel Section Type	**Catchment area (Ha)**	**n**	**Maximum Slope S**	**Hydraulic Capacity Q (m^3/s)**	**Channel depth y (m)**
A	Main Canal	Trapezoidal	51.4	0.015	0.0002	2.88	1.47
B	Distributaries	Trapezoidal	16.25	0.015	0.0004	0.91	0.68
C	Field Canal	Triangular	3.35	0.015	0.0004	0.19	0.47

For the distributaries Channels, the best hydraulic section will have a side slope of $\sqrt{3}/3$ horizontal to 1 vertical. For a trapezoidal section, designing

Bed width, $B = \frac{2y}{\sqrt{3}} = \frac{2 X 0.68}{\sqrt{3}} \quad = 0.78m$

From

$$P = 2\sqrt{3}y \qquad = 2\sqrt{3} X 0.68 = 2.85m$$

Also from

$$A = \sqrt{3y^2} = \sqrt{3 X 0.68^2} = 1.175\text{m}^2$$

Applying a free board of 40% , d = y X 1.4

d = 0.47 X 1.4 = 0.95m

Maximum Velocity is calculated from Q = VA

$$V = \frac{Q}{A} = \frac{0.91}{1.175} = 0.7744m/s$$

Table 4 below also gives the channel dimensions calculated from the obtained channel depths in Table 3.

Table 4: Computation Model for Isapa Irrigation Project

TYPE	Channel Description	Channel Dimension					
		Channel Area A (m^2)	**Wetted Perimeter P (m)**	**Depth d (m)**	**Bottom Width B (m)**	**Top Width T (m)**	**Maximum Velocity V (m/s)**
A	Main Canal (Trapezoidal)	2.549	4.20	2.06	1.70	4.76	1.1299
B	Distributaries (Trapezoidal)	1.175	2.85	0.95	0.78	2.19	0.7744
C	Field Canal (Triangular)	0.221	1.939	0.658		0.94	0.8597

3.0 Conclusions

The major concern of an irrigation engineer is to sustain the provision of water to plant any time of the year to guarantee food production all year round. This is basically done by impounding water during excess period and then releasing and distribution through Canals during drought.

This work is necessitated by the fact that a dam is already being constructed in Isapa. The dam is proposed to be used for domestic water supply. With a dam reservoir Capacity of 12.5Mm^3 and a domestic water required for the community being 0.5Mm^3, the dam storage will be grossly underutilized. The inclusion of an irrigation area will make judicious use of the excess water stored in the Dam.

The methodology of this work includes acquiring of relevant Hydro-metrological data; the identification of crops grown in the area; computation of domestic water use and the hydraulic design of the Channels for irrigation.

The design of channels with rigid boundaries which do not erode or scour was discussed. Then, equations were derived for the most efficient hydraulic section that conveys the maximum discharge for a specified cross sectional area for different cross sectional shapes.

There were three categories of channels designed. They are the Main Channels, Distributaries and Field Channels. The adoption of this project as a basis for further studies on irrigation systems will guarantee the economic growing of plants suited for Isapa environment without jeopardizing the domestic water supply need of the populace. The cultivation of 100 ha of land in such a community for all the year farming will greatly reduce unemployment and improve the lot of the people.

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