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Determination of design parameters for irrigation water abstraction and supply system: A case study

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ABSTRACT

A selection design process is implemented to determine irrigation water abstraction and supply system for a rice paddy farm. Alternatives are considered based on the result of rigorous engineering survey and analysis on-source of water, the abstraction method, the pump type, model and capacity, plant installation & operation and the supply of water and pipe size. Designing at 85% conveyance efficiency, 10 mm/day plot deep percolation and 12hr per day pumping, for a basin irrigation requiring soil water saturation depth of 11.825 cm and flood water of 10 cm, 185 m^3/hr. pump discharge capacity is obtained. To select a pump model to deliver the required flowrate, pump matching, involving the development of the system characteristics curve equation and its super-imposition on available pump characteristics curve is deployed to choose NCG43 model running at 1450 rpm, a discharge of 185 m^3/hr. and a total dynamic head of 12.5m to meet the irrigation water demand. Further, electric motors and internal combustion engines as well as centrifugal pump and turbine pumps were considered. A multi-power source centrifugal pump that allows the use of electricity, diesel or petrol power unit is recommended. Finally, the minimum diameter of the pipe required to deliver 0.05 m^3/s of water to the largest rotational area of 4.58 ha was determined as 0.21m. A pipe diameter of 25 cm is considered adequate for the water delivery route. The same size is selected for the suction hose to ensure uniformity of installation work as well as reduce operational head losses in the pipe.

Keywords: Conveyance efficiency, pump matching, internal combustion engines, deep percolation.

1. INTRODUCTION

The purpose of the study is to determine irrigation water abstraction and supply system for a rice paddy farm located in the swamp basin of Igwu river in Igbere Abia State Nigeria as a case study for the deployment of irrigation system for rice production. Selecting method of water supply for irrigation must follow detail knowledge of the sources of water in the project area and

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their characteristics to include: the geology of the zone for subsurface water exploitation, the topography of the project site for the supply and distribution of water, the quality and quantity of surface water for useability and adequacy and the rainfall regime for the planning of irrigation water supply. Hence, the selection of method of water abstraction is based on topographic, climatology, geological, hydrological and soil conditions of the field. Such information is required to establish parameters for the selection and design of the irrigation supply network, irrigation distribution and the drainage systems (United State Department of the Interior Bureau of Reclamation, 1978).

The climate of Igbere does not differ from the rest of the rainforest belt of Eastern Nigeria. In other words, Igbere enjoys a warm tropical climate with well-defined wet and dry season. It rains between April and October with a marked break in August and average between 1500 and 2500 mm per annum. The temperature is high throughout the year with monthly mean of 26.6^{0}C. Humidity in the region also follow similar pattern as rainfall and temperature being highest during the high storm months. High relative humidity prevails in the area except for December and January yet the value does not fall below 50% (Ofomata, 1975).

The geology map of the area under study consists of the Nkporo shale, Nanu formation, Ajala sandstone, Nsukka formation, Imo shale and Amaeke formation. The Amaeke formation unconformably overlying the Imo shale, covers most of the study area and forms the main agricultural zone. The formation ranges from clayey through silty, shaly, pebbly, coarse, medium to fine grained sandstone in various localities (Reyment, 1965). The area is contrasted with series of hills that are part of the Okigwe-Awgu escarpment and whose rounded top crest afford an interesting scenery. Ground water exist often in unconfined condition with the water table tending southward to the coast. The depth of water table in the region is about 122 m below the ground surface (Hanson and Nilsson, 1985).

2. METHODOLOGY

This section is concern with the methods for the selection of irrigation water abstraction method, determination of the stream water level for abstraction, selection of pump type, power unit, plant installation and operation.

Study Site

The main source of water supplies for the project water need is the Atayi stream which drains directly into Igwu river and forms part of the Igwu river basin (Figure 1). The Iyioma stream is not considered important in this analysis as it is not perennial. The Atayi stream runs across the field dividing it into two unequal parts with the land rising gently on either side. It covers over 800 m within the project area, takes a land width of about 6.5 m and cuts into the soil to a depth of well over 3.5 m (Document of the International Bank for Reconstruction and Development, 1974).

Atayi Stream Water Quality

Analysis of Atayi stream water was carried out in the water resource laboratory of Department of Civil Engineering University of Nigeria, Nsukka to ascertain the suitability of the Atayi water for irrigation purposes. The chemical characteristics of particular interest if the water is to be used for irrigation include sodium absorption ratio and water conductivity value. The test was carried out according to the procedures outlined in the standard methods for the examination of water (Rice et al., 2017).

Selection of Irrigation Water Abstraction Method

Alternative methods of abstraction considered during the preliminary studies include.

1. Damming the stream.
2. Use of pump

Damming was considered as the most convenient, having low maintenance cost and no-abstraction power input. Site investigation was conducted to determine a suitable site for a dam structure that would raise the water to about 3 m height in order to command most part of the field, a site that would accommodate the resulting throw back without submerging the adjacent fields and a site with such a bank as to reduce cost of embarkment construction. The Atayi stream is situated at altitude of about 115 m above sea level in the village of Amaiyi in Igbere. Minimum and maximum monthly levels of the Atayi stream have been recorded by the Ministry of Agriculture and Natural Resources, Owerri over a period of seven years (1975 - 1982) (Document of the International Bank for Reconstruction and Development, 1974). The annual extreme values were therefore plotted using the information to establish design level for siting the pumping house. For the design of pump station, it was decided to select a design level which had a return period in excess of 30 year. From a frequency distribution of monthly peak values, the 30-year return period at Atayi was calculated.

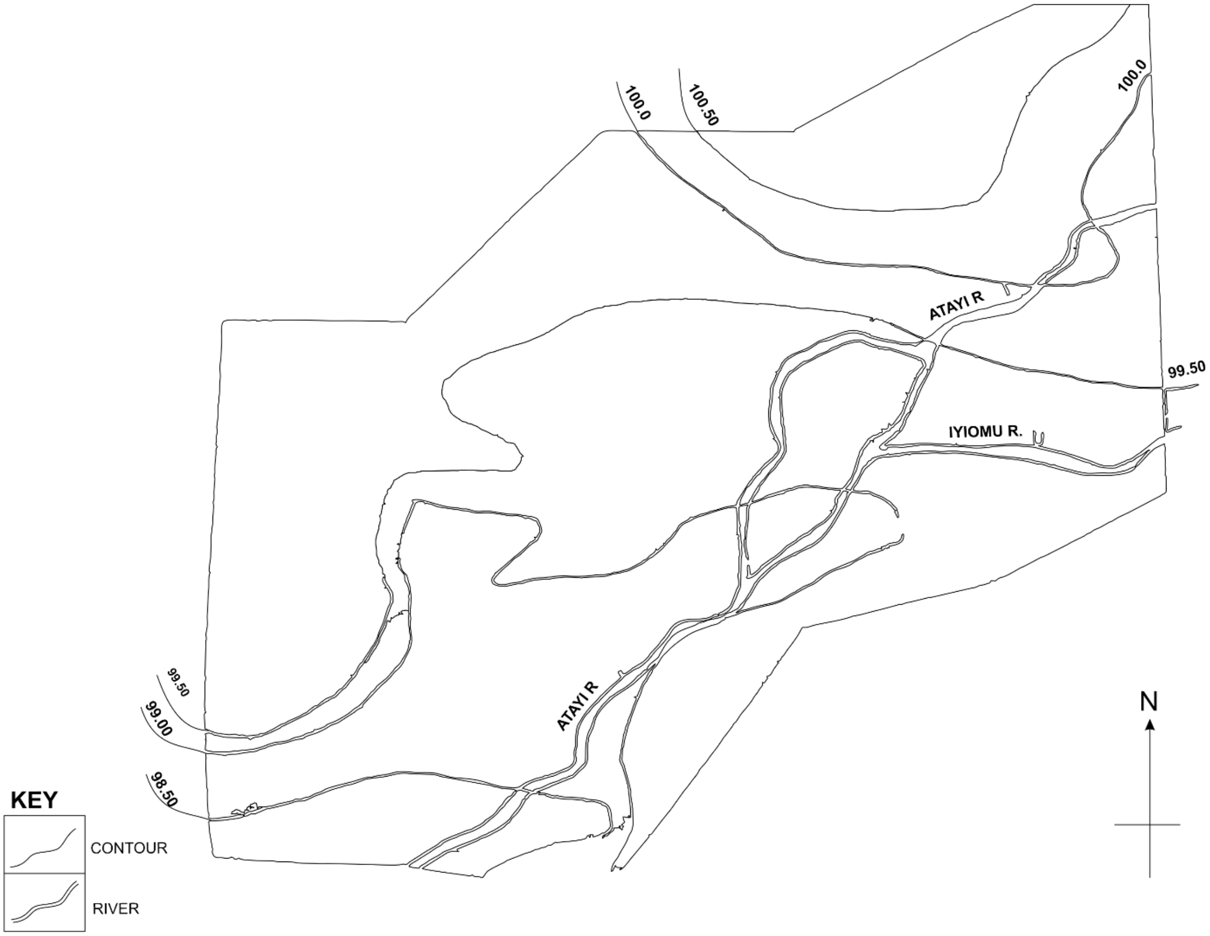

Figure 1 Topographic map of study site

Determination of Pump Discharge Capacity, Type & Model

In the selection of pump to supply the irrigation water requirement, the system head and desired discharged were first determined (Douglas et al., 1979). The pump manufacturers catalogue with pumps characteristic curves were then used to select the pump model that will operate efficiently near or at the design discharged and head. The discharge capacity of pump was based on project irrigation water requirement (the water use concept) and of such magnitude as to meet the peak water demand occurring during the spikelet initiation period in the peak flooding water requirement. Further, the field is divided into four areas of 4.58 ha, 3.67 ha, 3.60 m and 3.20 ha depending on the topography of the field. This is to ensure considerably reduction in the size of pump, cost of delivery system, efficiency of water control and to reduce fluctuation in labour need. In the selection of type of pump, the following factors were considered

1. Characteristics of water
2. Amount of water to be lifted.
3. Depth of pumping level
4. Type and amount of power available
5. Economic status of the farmer
6. Type of pump available.

To select a pump model to operate in conjunction with the system. (i.e., the water supply layout) and to deliver the required flowrate, pump matching involving the development of the system characteristics curve equation and its super-imposition on available pump characteristics curve is deployed. The intersection of the two curves gave the operating point (Figure 2). The system characteristics curve is given by equation 1.

$$E = H + KQ^2 \quad (1)$$

Where

E = Total dynamic head (m)

H = Static lift (m)

K = Factor incorporating friction losses.
Q = discharge (liters/s)

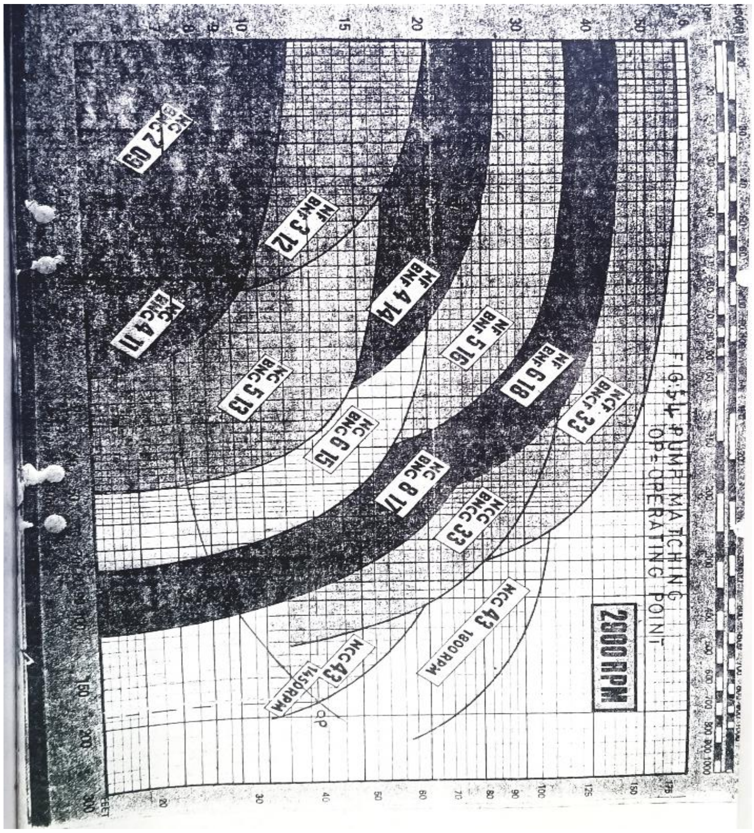

Figure 2 Pump Matching

Determination of Pump Power Requirement

The efficiency of a selected pump is a paramount factor both in its selection and subsequent power need (Isrealsen & Hansen, 1962). The efficiency of the selected pump is determined from the equation 2.

$$N = \frac{QTDH/C}{BP} \qquad (2)$$

Where
N = Efficiency
BP = Actual brake power (kw)
TDH = Total differential head (systematical)
C = Co-efficient of conversion
Q = Discharge (liters/s)

Determination of the Net Positive Suction Head

Important to overall plant performance is the plant operation & installation efficiency as determine by the net positive suction head available (NPSHA). The combination of air release and vaporization is known as cavitation. It occurs when the absolute pressure of the liquid is at a given temperature. The effect of cavitation includes noise, erosion of metal surfaces and vibration of the system leading to performance failure. To avoid this situation arising from the proposed pump installation an analysis is made to determine the net positive suction head available (Linsley and Franzini, 1979).

Main Pump Station

The pump is required to raise the water from the stream level and to deliver it into the head of the main canal. The main canal conveys the water to all parts of the project field and delivers it into the various branch canals for distribution throughout the project area. Site survey was carried out at the location for the main pump station. The site envisaged is a relatively flat open area centrally located and sandy. A sheer strength test of the station site revealed a high-pressure bearing capacity.

Pipe Sizing

The selection of pipe sizes for the irrigation water supply network was based on such considerations as initial cost, economy of use and effect on pump size as well as technical limitations of velocity of suction and delivery of water (Randall and Whiteside's, 2012).

Supply Line

Underground delivery system was adopted to have the shortest length of pipe without winding the pipeline. By burying at about 0.75m (rooting depth 0.4m) cultivation can be carried on above the pipe and land area is not affected. Moreover, the undulating nature of the field surface favour underground pipe. Furthermore, no interference is posed to the movement of farm machinery by the buried pipelines. The aesthetic appeal of buried pipeline cannot be ignored.

3. RESULT & DISCUSSION

RESULTS

Atayi Stream Water Quality

Table 1 is the result of the physical examination of Atayi water. The physical properties are compared with international standard for drinking water in the absence of equivalent irrigation standard (WHO, 1971).

Table 1 Physical Test of Atayi Raw Water

Characteristics	International Standard for drinking water recommended limits	Atayi Streams Raw water
Taste	Unobjectionable	Unobjectionable
Colour	"	-
Temperature	$25^{o}c$	$23.5^{o}c$
Odour	Unobjectionable	Unobjectionable
Suspended Solid at $105^{0}c$	Less than 50% mg/1	0.05 g/1

The water sample was dried at $105^{o}C$ and the residues weighed (Randall and Whiteside's, 2012). From Table 1, the raw water of Atayi stream has objectionable taste, colour and odour. The dissolved solid is within limit for drinking purpose let alone irrigation. Table 2 presents the result of the chemical analysis.

Table 2 Chemical Properties of Raw Water Obtained from Atayi Stream

Characteristics	Milligram Per Liter (mg/l)
pH	6.0
Conductivity (μmhos/cm)	0.15
Dissolved Cations	
Calcium Ca^{++}	1.6
Magnesium Mg^{++}	0.3
Sodium Na^{+}	0.6
Potassium K^{+}	0.7
Dissolved Anions	
Carbonate CO_3^{--}	6.4
Bicarbonate HCO_3^{--}	24.1
Sulfate $S0_4^{- -}$	-
Chloride $C1^{-}$	28.0
Sodium Absorption Ratio SAR	0.62
Sodium Hazard Class	S1
Maximum Allowed Salt Level	0.52 (μmhos/cm)

The sodium absorption (SAR) which is a measure of the sodium concentration in the water (Isrealsen & Hansen, 1962) and an indicator of potential alkali hazard was obtained from the equation,

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \qquad (3)$$

Where Na^{+}, Ca^{++} and Mg^{++} represent the concentration in mg/1 of the respective ions.

Water must move through the soil to transport excessive soluble salts out of the root zone. The fraction of the applied water entering the soil for this purpose is the leaching requirement (Pearson and Bernstein, 1959) summarized the maximum allowable salinity levels during the three stages of rice growth as

Early tillering C	3μmhos/cm
Late tillering	4μmhos/cm
Heading	58μmhos/cm

They noted that the soil salinity should be limited to 4μmhos/cm during transplanting (Rice et al., 2017). Assuming a deep percolation loss of 0.72 mm/dy (i.e., 15% ET) at a crop consumptive use of 4.77 mm/dy, the fraction of applied water required to maintain the soil salinity level in the roof zone at 4μmhos/cm is given by

$$Lr = \frac{Dd}{Et\ \ Dd} \times 100 \qquad (4)$$

Where

Lr = Leaching requirement (%)

Dd = minimum value for the drainage water from the root zone (mm/dy)

Et = evapotranspiration (mm/dy)

$$LR = \frac{0.72 \times 100}{4.77 + 0.72} = 13\%$$

The estimated deep percolation loss of 15% will therefore be sufficient to ensure no general buildup of salinity – level. The maximum amount of salt allowed in the irrigation water (Isrealsen & Hansen, 1962) for the project rice at 4 μmhos/cm crop tolerance level and 13% leaching water was obtained from

$$Ecm = EC_{L} \times LR \qquad (5)$$

Where

Ecm = Maximum amount of salt allowed in the water (μmhos/cm)

EC_{L} = Limitating root zone salinity level (μmhos/cm)

LR = Leaching requirement.

The water conductivity value of 150 μmhos/cm and SAR value of 0.62 imply that the Atayi stream water can be classed in terms of irrigation suitability as $C_1\,S_1$ water which means that the water is low in salinity and can be used on all soils without developing harmful level of exchangeable sodium (Albaji, 2022).

Determination of Irrigation Water Abstraction Method

The investigation for abstraction method reveals that possible dam sites satisfying the condition earlier enumerated are well away upstream of the Project field. The use of these possible dam sites called for a very complex procedure of ascertaining all who have rights to the surrounding fields and obtaining the agreement of all, to the release of any fraction of such land for purposes of constructing embarkments, spillways and pipeline as well as possible land submergence. There was also the problem of obtaining the agreement of the traditional Heads before assuming the control over the use of the community water supply source. Constrained both by topographic limitations and tenurial practices pumping within the project boundary was considered a feasible abstraction alternative (at least for now), with pipe running into the stream and the pump house located on the shore above the maximum recorded water level.

The irrigation water source is surface stream which contain certain percentage of sediment, the quantity varying over the seasons. While centrifugal pump has a potential to handle reasonable quantity of sediment, turbine pumps on the other hand are known to be highly susceptible to sediment content of pumping water (Rice et al., 2017). For surface irrigation, the irrigation water requirement is usually high while head requirements are generally low compared with sprinkler or drip. Centrifugal pumps fit better for low head and high discharge, easier to operate, lower initial cost, fewer wearing parts and uniform discharge than turbine pumps. With self-priming device attached to modern centrifugal pump the need for priming is eliminated. With portable pump unit, water can be lifted from any section of the stream to any part of field, thereby reducing maximum head need and levelling cost.

However, to reduce operation cost and management problem it was recommended that a main abstraction point, that commands at least 90% (ninety per cent) of the irrigated area be established. Hence a stream bed at the confluence of Atayi & Iyioma of 95.75 m was adopted for the main abstraction point. The shortest line between the distribution points and the existing shore as well as the deepest part of the stream was chosen as the main intake. A 60 cm minimum water depth during pumping period was considered adequate for the purpose of submerging the strainer to ensure that the pump is continuously supplied with water. A detailed analysis of high and low stream levels of the Atayi Stream was carried out using 7-year data generated by Ministry of Agriculture Owerri between 1976 and 1982 (Table 3). The volume of water retain in the stream varies between 29 m^3 and 18 m^3 with a depth that fluctuate between 2.72 m and 0.58 m over the year. It follows from the analysis that the intake works must operate with a stream level varying between 96.23 m and 99.35 m above sea level.

Table 3 Atayi High Levels and Plotting Position (Annual Series)

Year	Annual Peak Monthly Level (m)	Annual Series	Return Period
1976	2.65	2.72	8
1977	2.16	2.65	4
1978	2.15	2.50	2.67
1979	2.30	2.30	2
1980	2.72	2.16	1.6
1981	2.50	2.15	1.33
1982	1.82	1.82	1.14

For the design of pump station, it was decided to select a design level which had a return period in excess of 30 year. From a frequency distribution of monthly peak values, the 30-year return period at Atayi was calculated. The design stream level of 3.6 m for a 30-year return period was obtained as shown in figure 3.

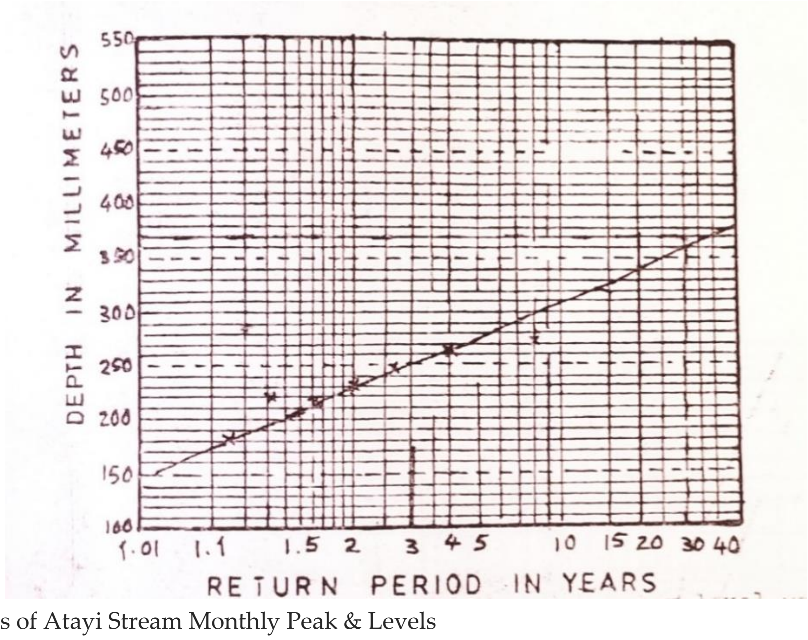

Figure 3 Frequency Analysis of Atayi Stream Monthly Peak & Levels

With a bed level of 95.25 m the high-water level would then be 99.35 m. This level is about 0.88 m above the highest recorded during the data period. It was therefore considered that a design level of 99.40 m is satisfactory for sitting the pumping house. The mean low levels recorded in the Atayi stream are shown in Table 4 and the frequency plot of monthly return annual low values presented in figure 4. A straight line was visually fitted to the annual series of the low levels to obtain the 30 years stream level of 0.475m. This gave a stream level of 96.23. This value is about 0.11m below the minimum water depth recorded during the 8-year study period.

Table 4 Atayi Stream Low Levels and Plotting Position

Year	Annual Minimum (m)	Annual Series (m)	Return Period Year
1976	0.63	0.58	8
1977	0.62	0.62	4
1978	0.58	0.63	2.67
1979	0.67	0.67	2
1980	0.86	0.77	1.6
1981	0.77	0.86	1.33
1982	0.95	0.95	1.14

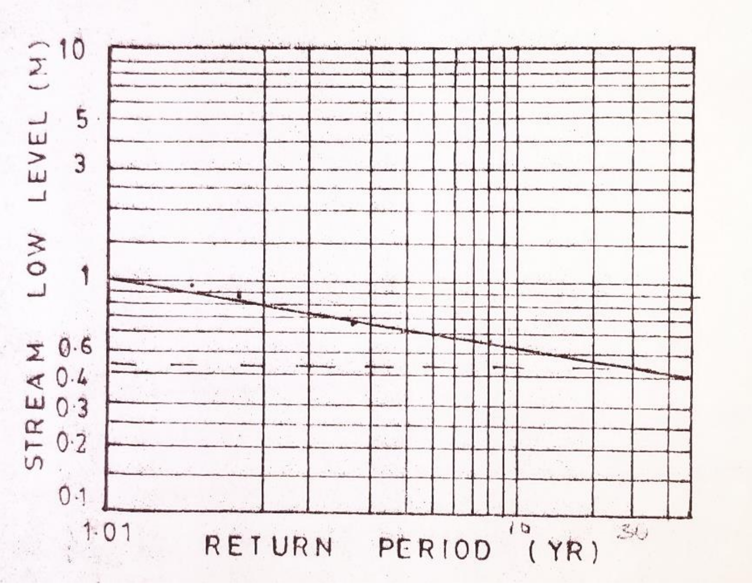

Figure 4 Frequency Analysis of Atayi Stream Monthly low levels

In this analysis the return periods quoted for the design levels of the pumping station and the abstraction level are considered conservative. This is however justified on the ground that the record chosen in the analysis were limited to actual recorded data and too short to be relied upon. Further the recurrence interval computed by the equation.

$$T = \frac{n+1}{m} \tag{6}$$

are estimated average return periods and there is no implication that such floods will occur at even reasonably constant intervals (v, 2022). Table 4 shows the theoretical distribution of the return periods. From the Figure 4 a 30-year return period with 50% assurance level would yield 21-year interval. At a maximum operating water level of 95.63 m (Randall and Whiteside's, 2012) an excavation of about 1.15 m deep and two-meter (2 m) square must be made on the stream bed to obtain this level and ensure that pump does not choke up debris and mud from the streambed and bank during period of low water level.

Determination of Pump Discharge Capacity, Type & Model

The rate of pumping was based on the maximum design rotational area of 4.58 ha and obtained from equation 6 (Hunter, 2021).

$$G = \frac{27.78 \quad AY}{RTE} \tag{7}$$

Where:

G = Rate of discharge of pump (l/s)
A = Area of land (ha)
Y = Wet depth of water required (cm)
R = Rotational period
T = Duration of pumping
E = Project efficiency

Designing at 85% (eighty-five per cent) conveyance efficiency, 10 mm/day plot deep percolation and 12hr per day pumping, for a basin irrigation requiring soil water saturation depth of 11.825 cm and flood water of 10 cm, the pump discharge capacity was obtained as

$$G = \frac{27.78 \times 4.58 \times 28.825}{7 \times 12 \times .85}$$

$$= 51.371/s$$

$$= 185 m^3/hr.$$

This is about 0.0112 m^3 /s / ha, more than enough to serve the proposed basin and contour level flooding water requirements. The static suction lift i.e., the vertical distance between the center line of pump and pumping water level was obtained by assuming a maximum pump height of 3 m to give a design suction lift of 4 m. The static discharge head which is a measure of elevation differences between the center line of the pump and the point of use was taken as 2.5 m. Hence a total static head of 6.5 m (7 m) was used. The dynamic factor KQ^2 was determined from equation 8.

$$KQ^2 = \frac{n}{Z}\left(\frac{Crv2}{2g} + \frac{flQ^2}{3d^{\ \ 5}}\right) \qquad (8)$$

Where $\frac{n}{2}\frac{CrV^2}{2g}$ = losses in fitting.

$\frac{flQ^2}{3d^{\ \ 5}}$ = Frictional losses along the pipe length

Cr are resistance coefficients for the various fittings and f the friction factor.

$$\text{If} \qquad V = \frac{Q}{A} = Q/(\pi/4)\ d^2 \qquad (9)$$

Then

$$KQ^2 = \frac{n}{2}Cr\frac{0.0826}{d4}Q^2 \qquad + \frac{flQ^2}{3d5}$$

$$KQ^r = \frac{n}{2}\frac{0.0826}{d4}Cr \quad + \quad \frac{fl}{3d5}Q^2$$

Where,

On the suction side losses would be due to

1. Friction along the pipe
2. Long radius flanged elbow.
3. Strainer – basket type for friction loss in steel pipe n=0.016

$$\because \qquad f = \frac{185 \quad n^2}{d113} \qquad (10)$$

$$= \frac{185 \times (0.016)2}{(.25) \quad 113}$$

$$= 0.075$$

At 30-meter distance from the point of abstraction

$$Kfd = \frac{f\,1}{3d5} = \frac{0.075 \times 30}{3 \times (.25)5}$$

$$= 769.84$$

For fitting (Linsley and Franzini, 1979)

Elbow Ce = 0.14

Strainer Cs = 0.67

$$\because \qquad kft = \frac{0.026 \times .14}{(.25)4} + \frac{0.0826 \times .67}{(0.25)4}$$

$$= 2.96 + 14.167$$

$$= 17.128$$

The friction factors down the suction side of the network are taken as

$$= 769.84 + 17.13$$

$$= 786.97$$

On the delivery side losses would be due to Friction along the pipe length, Head loss in gate value and Head loss in reflux value.

For ACP n = 0.09

$$\therefore \quad f = \frac{185 \times (009)x^2}{(.25)\ 113}$$

$$= 0.024$$

For a total length of 160m

$$Kfd = \frac{0.024 \times 160}{3 \times (0.25)5}$$

$$= 1310.72$$

For the fitting

Gate value Cg = 0.06

Reflux value Cv = 0.06

$$Kftd = \frac{0.0826 \times .06}{(.25)4} \times 2$$

$$= 1.27$$

A friction factor of 1310.72 + 1.27= 1311.99 for the delivery water conduit was used to obtain a total friction factor of K = 1311.99 + 786.97 = 2098.96 equivalent to

$$K = 2100$$

Hence the system characteristics curve was obtained from equation 10 below.

$$E = 7 + 2100Q^2 \qquad (11)$$

The plot of this equation on Figure 2 indicates that NCG43 running at 1450 rpm and a discharge of 185 m^3/hr. and commending a total dynamic head of 12.5 m can adequately cater for the irrigation water demand.

Determination of Pump Power Requirement

Since the characteristics curve of the pump selected does not include the efficiency curves the pump efficiency was estimated inductively. The specific speed which is the speed of a geometrically similar pump when delivering one cubic metre per second of water against a total head of one metre is computed from equation 12

$$Ns = \frac{nQ^{1/2}}{H3/4} \qquad (12)$$

Where

Ns = Specific speed (rpm)

N = pump speed (rpm)

Q = pump discharge (US gal/m)

H = total dynamic head (ft)

From figure 2

N = 1450 rpm

Q = 185m^3/hr.

$$= \frac{185}{} \times \frac{1.58503}{3600} \times \frac{104}{}$$

$$= 814.53 \text{ gal/min}$$

$$\text{Hence } Ns = \frac{1450 \times (814.53)^{1/2}}{\left(\frac{12.5}{.3048}\right)3/4}$$

$$= 2553.58 \text{ rpm}$$

$$= 2554 \text{ rpm}$$

Figure 5 below, indicates a peak efficiency of 0.85% for pump of similar geometric construction with specific speed ranging from 2000 to 3000 and discharging at about 815 gal/min (0.0513m^3/s). However, a pump efficiency of 80% (eighty percent) was adopted.

Using this in equation 2, the power required to provide the desired head and the discharge BP is obtained from.

$$N = \frac{QTDH/C}{BP}$$

$$BP = \frac{51.39 \times 12.5}{102 \times .80}$$

$$= 7.87 \text{ kw}$$

$$= \frac{51.39 \times .12.5}{76 \times .80}$$

$$= 10.57 \text{ hp}$$

8 kw power producing engine is considered adequate for the pump.

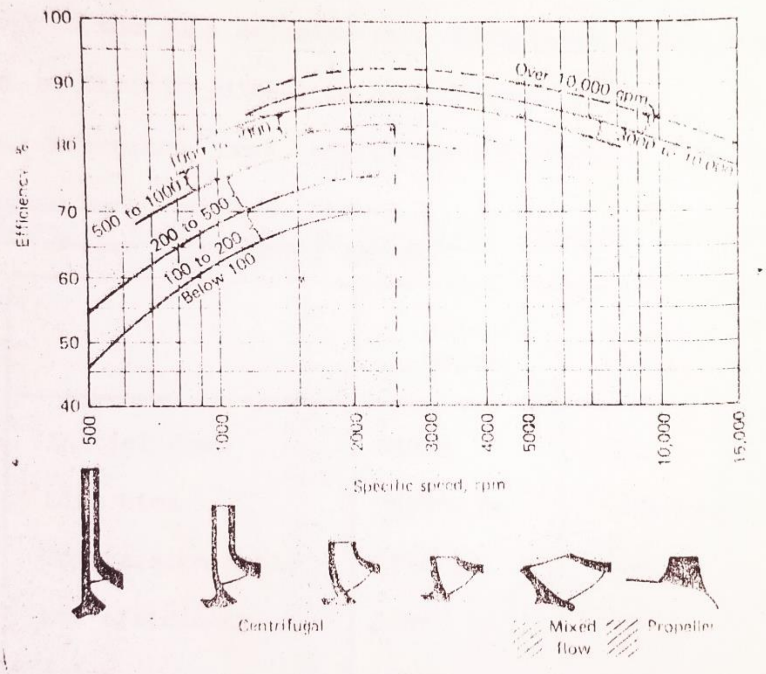

Figure The relation of specific speed to the shape of the impeller, the discharge, and the efficiency of the pump. (Courtesy of Worthington Pump, Inc.)

Figure 5 Pump Efficiency Estimate

Selection of Energy Source

Following the determination of pump efficiency and power requirement is the selection of energy source. Electric motors and internal combustion engines were considered. Electric motor was ruled out since on grid line does not extend into the project area. However, the pump selected is a hybrid energy type allowing the use of electricity, diesel or petrol power unit. The performance, cost, efficiency and expected life of diesel and petrol engine were compared Table 5.

Table 5 Diesel & Petrol Engine Compared.

	Petrol Engine	Diesel Engine
Initial cost	₦105000	₦250000
Lifetime	16500 hr	27500 hr
Compression ratio	7½: 1	16.1
Max efficiency	20%	23%
Speed	3500	2900
BHP	22.00	22.00

Source: MMT CTD, Kano*EY - 20D ROBIN ENGINE

Determination of Pump Plant Performance

Following the selection of pump and energy source the overall pumping plant performance is evaluated by determining the overall efficiency (Equation 13). This was obtained by dividing the energy imparted to the water by the pump by the input energy to the engine such that

$$\text{Overall} = \text{pump} + \text{engine}$$

$$= \frac{CQTDH}{IE} \qquad (13)$$

Where

IE = Energy in fuel consumed by engine kj./h

C= Conversion factor

= 35.50 kj/h

Q = discharge flow rate (1/s) low
Energy content of diesel fuel
= 39020 kj/1 [15]

From the studied performance data sheet, the specific fuel consumption for speed and brake power required was 298/kwh for a diesel fuel having 0.84 specific density. Hence about

$$\frac{298}{0.84 \times 100} = 0.355 \text{ litre /kwh}$$

Would be required to operate the engine

$$\therefore \quad IE = 39020 \times 0.355 \times 8.05$$
$$= 111509.41 \text{ kj/hr.}$$
$$\text{Overall} = \frac{51.39 \times 12.5 \times 35.50}{111509.41}$$
$$= 20\%$$

This is about two per cent greater than the recommended acceptable overall efficiency for similar engine (Table 6).

Table 6 Overall pumping plant performance for selected engine types

Power source	Maximum Theoretical	Recommended as Acceptable	Average value from field test
Electric	72 - 77	65	45 – 55
Diesel	20 - 25	18	13 - 15
Natural gas	18 - 24	15 - 18	9 - 13
Butene, Prepare	18 - 24	15 - 18	9 - 13
Gasoline	18 - 23	14 - 16	9 – 12

Table 6 depicts typical values of overall efficiency for representative pumping plants expressed as percentage (Savva and Frenken, 2001)

$$Q = \frac{0.54 \times .1084}{12.9}$$
$$= 0.45 \text{ gal/hr.}$$
$$= 0.45 \text{x} 3.78541$$
$$= 1.70 \text{ litre/hr.}$$

Pipe Sizing

From the continuity equation for water flow through pipes- equation 14 (Michael, 1978)

$$Q = AV = \frac{nd^{-2}}{4} V \tag{14}$$

Where
Q = discharge (m^3/s)
A = area of pipe (m)
V = Velocity of pipe flow (m/s)
d = minimum pipe meter

At a maximum suction velocity of 3 m/s (Albaji, 2022)

$$\text{and} \quad Q = 0.051 \ m^3/s$$
$$d = \frac{4Q}{VA} = \frac{4 \times 0.051}{3 \times ñ}$$
$$= 0.15\text{m}$$

At a maximum velocity of water delivery through pipe of 1.5 m/s (Marvin, 1980). The minimum diameter of the pipe required to deliver 0.05 m^3/s of water to the largest rotational area of 4.58 ha was determined as

$$d = \frac{4Q}{Vñ} \tag{15}$$
$$= \frac{4 \times 0.051}{1.5 \times ñ}$$
$$= 0.21\text{m}$$

Asbestos cement pipe (ACP) was recommended for the delivery conduit considering the ease with which it can be installed and its adaptability. Steel pipe would be used for the suction to obtain a continuous length with or without stiffeners.

Plant Installation & Operation

The combination of air release and vaporization is known as cavitation. This is computed from equation 13

$$\text{NPSHA} = \text{Ha} - \text{Ms} - \text{Hf} - \text{es} - \text{fs} \qquad (16)$$

Where

Ha = atmospheric pressure at the water surface (for a water of specific gravity equal to 1 m

As = Static Suction lift (m)

Hf = Friction loss in suction pipe (m)

es = Saturated vapour pressure of water at the operating temperature

fs = Safety factor

Now

$$\text{Ha} = 10.33 - 0.00108\text{E}$$

Where

E = elevation (m) = 150 (m)

$$\therefore \quad \text{Ha} = 10.33 - 0.00108 \times 150$$

$$= 10.168\text{m}$$

$$\text{Hs} = 4\text{m}$$

H_f the friction loss in the suction lose was determined from the Scobey for steel pipes.

$$S = \frac{CV^{1.9}}{10^3 D1.1} \qquad (17)$$

Where

S = friction slope (m/m)

C = 5162kg

Ks = Scobey resistance coefficient

(0.40)

D = Diameter (mm)

V = Velocity m/s

$$V = \frac{Q}{A} = \frac{185 \times 4}{3600 - (.25)^2}$$

$$= 1.047 \text{ m/s}$$

For a pipe length of 30m

$$S = \frac{5162 \times .40 \times (1.047)1.9 \times 30}{10^3 \times (250)\ 1.1}$$

$$= 0.16\text{m}$$

Other losses were those due to fitting and bend. A self-priming pump was proposed hence no provision was made for foot value.

$$\text{Hf} = \frac{Cs \quad V^2}{2g} + \text{Ce} \quad \frac{V^2}{2g} \qquad (18)$$

$$= \frac{0.14 \times (1.05)^2}{2 \times 9.81} + \frac{0.67 \times (1.05)^2}{2 \times 9.81}$$

$$0.0079 + 0.038$$

$$= 0.0455\text{r } 0.05\text{m}$$

$$\therefore \quad \text{Hf} = 0.16 + 0.05 = 0.21\text{m}$$

$$\text{es at } 23.5^{o}\text{C} = 0.296$$

$$0.30 \text{ m} \quad \text{from table}$$

$$\text{fs} = 0.6$$

$$\therefore \quad \text{NPSHA} = 10.168 - 40.21 - 0.30 - 0.5$$

$$= 5.058$$

$$= 5.1 \text{ m}$$

Supply Line

Using total velocity of 0.6 m/s (Rice et al., 2017) the pump stand diameter was obtained as

$$\text{d3} = \frac{4Q}{V\tilde{n}} \qquad (19)$$

$$= \frac{4 \times .051}{0.6 \times \tilde{n}}$$

$$= 0.33\text{m}$$

Height of pump stand was obtained from equation 15.

$$H = 2/3\ (D1 + Do) + 8b + Ph + fs) \qquad (20)$$

Where
H = pump stand height (cm)
Di = inlet pipe size (cm)
= outlet pipe size (cm)
Fb = free board (cm)
Ph = allowance above bottom of the standpipe (c)
(fs) = safety factor (0.1m)
Using the maximum pump size of line on serving field (Wang & Hagan, 1981)
D_o = 25cm
D_L = 25cm
f_b = 30cm
Ph = 10cm
Then

$$H = 3/2 \times 50 + 30 + 10 + 10$$

$$= 125\text{cm}$$

Discussion

It is recommended that volute type centrifugal pump with open impeller (in case of sediment problem) be used to lift water in the project. A mobile unit mounted on trolleys with rubber tyred wheels is proposed to permit water lifting to any area above the main station command to be supplied from the nearby canal or stream. This is especially necessary for application where leveling is not feasible due to shallow topsoil. It also further eliminates the need for booster pumps. Moreover, the arrangement of semi–permanent pumping system would drastically cut down the problem of labour management as in the case of purely portable setting.

A plot of the system characteristics curve equation on Figure 2 indicates that NCG43 pump model running at 1450 rpm, a discharge of 185 m^3/hr. and commending a total dynamic head of 12.5 m can adequately cater for the irrigation water demand. Since the characteristics curve of the pump selected does not include the efficiency curves the pump efficiency was estimated inductively to determine the pump power requirement. Figure 5 indicates a peak efficiency of 0.85% for pump of similar geometric construction with specific speed ranging from 2000 to 3000 and discharging at about 815 gal/min (0.0513 m^3/s). However, a pump efficiency of 80% (eighty percent) was adopted. 8 kw power producing engine is considered adequate for the pump. The pump selected is a hybrid energy type allowing the use of electricity, diesel or petrol power unit after due consideration of performance, cost, efficiency and expected life of diesel and petrol engine as depicted in Table 5.

The result indicated that petrol engines are cheap - one thousand seven hundred and fifty naira (₦105,000), have short lifespan (9years), low compression ratio (8:1) and hence low efficiency (18 – 23%). The table also shows that diesel engines have high initial costs (₦250,0000), high compression ratio (17:1), hence high burning efficiency of the fuel, slower rotating speed and long-life life span. Finally, the study revealed that diesel engines require frequent overhaul while petrol engine were rather scrapped instead of overhauled. On the strength of the above observation direct couple diesel engine powered centrifugal pump is recommended. From both the light and heavy-duty engines available, a consideration of efficiency of selected pump, required brake horsepower and pump speed fitted the choice in favour of heavy-duty engines, with high compression ratio, longer lifetime and higher efficiency in spite of its high initial cost.

The performance curve of Better Diesels “DIW 6270A” was studied to enable certain practical design parameters to be determined. The investigation indicated that for this model, running at continuous rated fixed speed of 1450 rpm and producing 8.05 kw, about 298 g/kwh diesel of 0.84 specific gravity is required. Other operation condition of temperature (9 m blend up to 30^0C), altitude (up to 150m), relative humidity (70%) and cooking air requirement (of about 86 litres/s) were also met by the site condition cubic capacity (304 cm^3), compression ratio (17:1), dry weight of engine (47 kg), etc. Following the selection of pump and energy source the overall pumping plant performance is evaluated by determining the overall efficiency to obtain 20%. This is about two percent greater than the recommended acceptable overall efficiency for similar engine. This amounts to 1.7 litre/hr. The result of the Net positive suction head available (NPSHA) is 5.1 m. The NPSHA must exceed the net positive suction head required (NPSHR) to move the water into the eye of the impeller to avoid cavitation. Since information on the NPSHR is not available for the pump selected, the pump location at installation would be adjusted accordingly to meet the above condition. Detail of the irrigable area served by the pump, discharge capacity, static lift and proposed pumping installation are given Table 7.

Table 7 Pump Size and Pump House Location

Return Period (Yr.)	Water Level (m)	Pump House Ground Level	Length of Intake (m)	Max Lift (m)	Discharge (m^3/s)	Area Served (ha)	Power Required (Kw)
30	99.35	99.40	30	12.5	0.051	4.58	8.05

A 30yr return period depth would be approximately 3.6 m. The pump would be driven by a diesel engine of 8.06 kw using refined diesel of 0.84 specific gravity. The pump spindle is closed coupled to the drive and discharges through 25 cm delivery pipes to the various canal heads. The unit is mobile but would operate mainly from the proposed site to reduce labour need. It is also recommended that the pump and power unit be housed in a sufficiently protective building as a measure against harsh weather (harmattan and Rain), guide against thievery and to facilitate maintenance work. The station is planned for continuous operation during periods of peak demand and space provided for the installation of a further unit. This is to provide flexibility in the pumped supply and additional supplies in case of increased cropping intensity. Provision is also made for fuel storage, access for inspection and cleaning as well as other necessary ancillary equipment. Suction pipe diameter of 15 cm was considered while a pipe diameter of 25 cm was considered adequate for the delivery hose based on the analysis.

The same size was selected for the suction hose to ensure uniformity of installation work as well as reduce operational head losses in the pipe. Asbestos cement pipe type A50 was proposed. This as indicated by “A50” allows 1.5 m cover and 15.25 m hydrostatic head. To ensure good watertight joint coupling sleeves with rubber gaskets is recommended. Using total velocity of 0.6 m/s the pump stand diameter was obtained to transfer water from the pump to the underground delivery pipes. A 35 cm pump stand diameter is proposed. A gate opening was provided on either side of the stand to permit entry of water to the desired line - A or B. A 1.5 high pump stand of diameter 35 cm made of precast steel with two outlets was proposed. Height of pump stand is also determined to be 125 cm.

4. CONCLUSION

The paper set out to determine the parameters for the choice of a water abstraction and supply system for a rice paddy endowed with a surface water source – Atayi stream. Based on feasibility, a pump system is adopted as against damming the stream. Using agronomic data on water requirement of rice at various stages of maturity, the percolation characteristic of the soil and losses along the supply line, the pump discharge capacity and efficiency requirement that meet the need were established to guide the selection of pump type. For purposes of plant installation & operation the total overall plant performance efficiency as determine by the net positive suction head available (NPSHA) is determined and recommendation made. Using continuity equation for water flow through pipes the water supply network pipe sizes were established and recommendation made after due consideration of initial cost, economy of use and effect on pump size as well as technical limitations of velocity of suction and delivery of water. The papers therefore identified the irrigation water abstraction and supply design parameters and proceeded to determine the value of the parameters for Atayi stream irrigated rice paddy using appropriate mathematical models.

Ethical issues

Not applicable.

Informed consent

Not applicable.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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