DESIGN AND CONSTRUCTION OF A DEVICE FOR MEASURING STREAM FLOW IN SMALL IRRIGATION CHANNELS

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ABSTRACT

A low cost technology device for measuring streamflow in small streams and irrigation channels was designed, constructed and tested. Adequate monitoring of stream flow will provide a good information for planning and management of any irrigation project. Hydrograph which shows depth of flow was produced through the plotting mechanism from which also discharge can be calculated. The plot identifies peak rates of flow and distribution of rates of flow. It is recommended for further improvement.

KEYWORDS: Irrigation, streamflow measurement, hydrograph, discharge, low cost device.

1. INTRODUCTION

The need for accurate stream flow measurement cannot be over stressed as effective measurement and monitoring will lead to the solution of soil and water management problems. The conservation of these vital resources implies utilization without waste so as to make possible a high level of production that can predict erosion yield, evapotranspiration, and water balance etc. Sound streamflow measurement will reduce the engineering problem involved in soil and water conservation such as erosion control, drainage, irrigation, flood control, moisture conservation, and water resources development. More importantly, information concerning the relationship between water, soil and plant cannot be utilized in irrigation practice without the correct and efficient measurement of water flow.

The irrigation or hydraulics engineer involved in the design of structures to handle natural surface flow is mainly and basically concerned with peak rate of stream flow (runoff), volume, and temporal distribution of the rate and volume. If the rate and volume are excessive or high, it may become undesirable and may result to erosion, flood and consequent disturbances of plant and animal life on the agricultural land (Walters, 1979). The effective and efficient use of water for irrigation depends largely on runoff measurement.

The problem of estimating runoff of rivers is very complex, as it involves the consideration of the area and time variation of the input (rainfall), the geological structure of the basin, variation in climatic conditions, vegetation cover, water use, etc. The time variation of precipitation includes differences with respect to an individual rainfall event as well as daily, monthly and seasonal changes. In dealing with large basins, therefore, daily, monthly or yearly average of rainfall are used. In working with time averages, the length of time of records becomes important. The longer the periods of observations the more valid the average computations. Forecast for future stream flow could also be based on the graph of some of the streams with similar periodic variations (Bonella et al 2000; Weight and Sonderegger, 2001; Mason, et al., 1995; Rantz, 1982).

The shape of any runoff measuring device is mainly influenced by the choice of the designer, cost of manufacture installation, and maintenance of the device etc. The shape (geometry), roughness and permeability of a channel affect the flow through it. Irregularities and other minor obstacles (stones, vegetation etc) to flow are represented by a friction factor for each particular reach of channel (Gerraro 2000; Uzege, 2011 and Onyeamu, 2012).

The objective of the study is to design and construct an effective and efficient lowcost device for measuring stream flow on small streams and irrigation channels for low income irrigation farmers.

2. MATERIALS AND METHOD

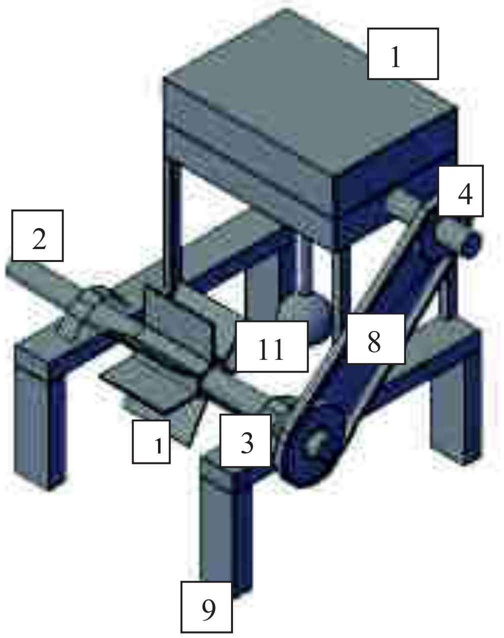
2.1 Study Area

Makurdi (Benue State of Nigeria) which is situated in the Lower Benue River Basin is located between 7˚ 45"North and Longitude 8˚ 32"East. The climatic condition in Makurdi is influenced by two air masses; the warm moist Southwesterly and the warm dry Northeasterly. The Southwesterly air mass is a rain-bearing wind that brings about rainfall from the month of April to October and the dry Northeasterly air mass brings dry season from November to March. The mean annual rainfall is about 1,290mm. The land is generally low lying, gently undulating, broad open valleys and flood plains.

The soils are mainly oxisols and ultisols (tropical ferruginous) which vary over space with respect to texture, drainage, gravel content, etc. A typical profile is highly weathered with sandy surface layer overlying clay mottled subsoil. Benue State lies in the Southern Guinea Savannah, and agriculture is widely practiced and this has earned the State the appellation, 'Food Basket of the Nation'.

2.2 Description of the Device (The Components)

Figures 1a and 1b show an orthographic and top views of the device respectively. The design was conceived to overcome the problem of high cost of imported device for measuring flows in small channels or streams. It was fabricated locally with available materials and it is affordable; easy to operate and to maintain. Figure 2 shows the plotting mechanism. The component parts are described below.



Key

No.	Component	No.	Component
1	Turbine wheel	7	Turbine pulley
2	Turbine Shaft	8	Belt Drive
3	Bearings	9	The Frame
4	Helical Gears	10	Glass window
5	Rollers	11	Float Ball
6	Plotter wire	12	Plotting box

Figure 1a: Orthographic diagram of the measuring device

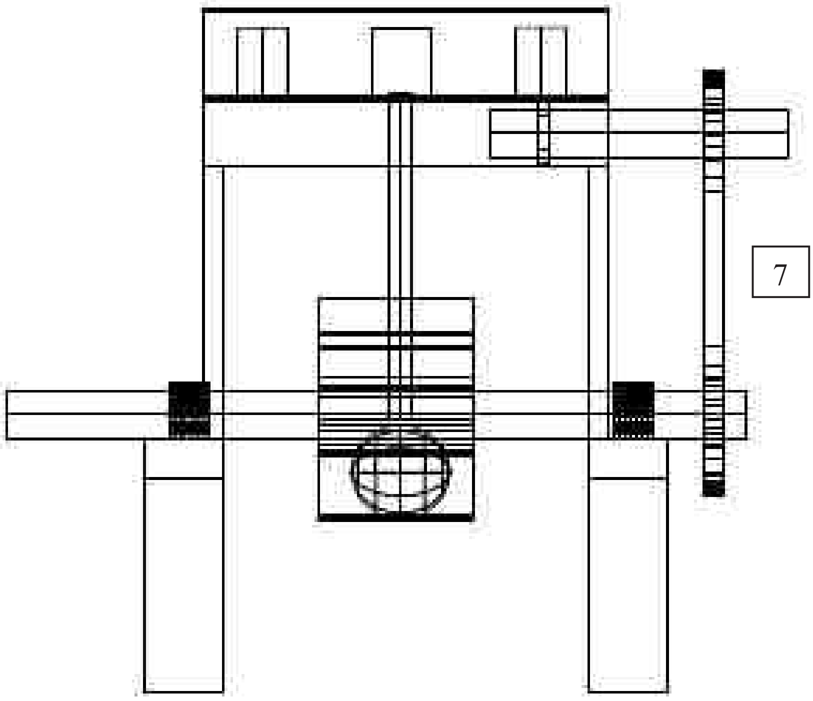


Figure 1b Top view of the measuring device

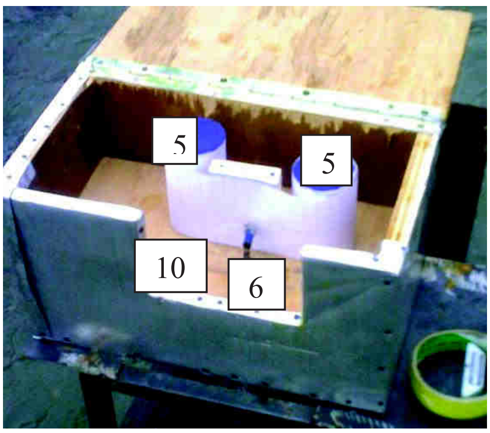


Fig 2: Showing the graph and plotting components

2.2.1 Turbine Wheel

A turbine wheel (also called a rotary wheel) propels as flowing water strikes the blades or paddles at the bottom of the wheel. There are eight blades of size 25 X 18.5 cm coated with rust resistant material and distributed 22.5^o on the circumference of the turbine shaft. The power from the wheel is transmitted to the roller by means of pulley, rope drive and gear system.

2.2.2 Shaft

The shaft is a rotating member used to transmit power by torsion. It is usually of circular cross section. Mild steel was used for the hollow shaft of 15mm outer diameter and 10mm inner diameter because of its ductility and fatigue resistance properties. The shaft can withstand the rotational force and does not buckle due to action of the component on it vertically. Two shafts made of mild steel were used. Shaft 1 supports the turbine wheel and transmits power through rope and pulley system while shaft 2 connects the gears and the second pulley. Shaft 1 which is hollow is 22mm in diameter and 40mm in length. Shaft 2 is solid with 15mm diameter and 220mm in length.

2.2.3 Bearings

A bearing is a machine member or component which permits other members connected together to either rotate or translate relative motion to one another. Two ball bearings of 25mm internal diameter were used for the turbine wheel shaft while two bearings of internal diameter 15mm were used for the gear shaft. This will help to reduce the friction from a particular point and balance the shaft from wobbling effect.

2.2.4 Rope Drive and Pulley

A rope drive was employed to transmit power from the driving pulley to the driven pulley. Two pulleys made of iron were used which gave an advantage of continous operation of device in water without damage. The bigger pulley (155mm in diameter) was used for the shaft whereas the smaller pulley (25mm in diameter) was used for the turbine shaft. Rope was selected to transmit power between the two pulleys. This was choosen for its flexibility and to minimize slip between the pulleys and the belt.

2.2.5 Roller and Roller Frame

Two plastic cylinderical rollers 80mm in length and 50mm diameter were positioned vertically on the plot board. The two rollers were separated by a distance of 120mm. The master roller is mounted on the gear shaft and it recoils the hydrograph after plot. The slave roller on which the graph is wound releases it to the plot board where the plotter marks the level of the stream on the graph. The roller frame was made of the plywood (covered with aluminium sheet) and its dimension is 330 X 180 X 180mm. It has two chambers – the upper chamber which houses the two rollers, plot board and the plotter; the lower chamber houses the gears, gear shaft and gear shaft bearings. The chamber is provided with door at the top to enable the operator load chart (graph) and collect hydrograph. Glass window is also provided at the front to enable the operator view the condition of the rollers without opening the door. The wooden frame was covered with alluminium sheet which is an advantage in operating the device all through the year.

2.2.6 Gear

Gears are used for transmitting power generated at a constant velocity ratio between two shafts whose axes intersect at a certain angle. Helical gears were used to provide smooth drive with a high efficiency of transmission. On one helix is wound right handed and on the other it is wound left handed. The arrangement of the helix gave advantage of transmitting motion from horizontal to vertical axis.

2.2.7 Plotter

The plotter is made of pencil (pointing perpendicular to the plot board) attached to a thin wire which dropped down through a small pipe of 5mm diameter fixed in front of the plotting board. The plotter is connected to the float ball (a plastic ball of 80mm in diameter attached to the wire connected to the plotter) with a wire and the float ball rests on the surface of water during operation. The plotter rises and falls as the level of water increases and decreases.

2.3 Operation of the Device

The device mechanically converts a counter weight float resting on the surface of the flowing water into curve or a straight line depending on the level of the stream. As the flowing water turns the turbine wheel, the turbine shaft transmits motion to the gear shaft by the means of rope and pulley system. The horizontal motion of the gear shaft is converted to vertical motion with the help of two helical gears positioned perpendicular to each other. The master roller fixed on the second helical gear turns the graph sheet over the surface of the board. As the graph sheet moves over the plot board which is fixed between the master and slave rollers, the plotter (on which a pencil is fixed) makes traces of the water level on the graph sheet as the float ball moves up and down due to the level of the flowing water.

The discharge of the stream at a section is calculated using equation 1 below.

$$Q = VA \ \ (m^3/s) \qquad (1)$$

where $V = \frac{1}{n} R^{2/3} S^{1/2}$ (2)

$A = by$ (3)

and $R = \frac{by}{b+2y}$ (4)

where V = Velocity of flow across the section (m/s), A = Area of cross-section (m^2), y = height of flow as recorded by the device (m), b = breath of channel (m), S = slope of the channel, n = Mannings roughness coefficient.

2.4 Costing

The cost of producing the device in terms of materials and labour based on the prevailing market prices at the time of design and construction was ₦13,860.00 (Nigerian currency) or USD 90.00 (at the exchange rate of ₦154/ $).

3. RESULT AND DISCUSSION

Sample of runoff graph (hydrography) as plotted by the plotter of the device is shown in Figure 3.

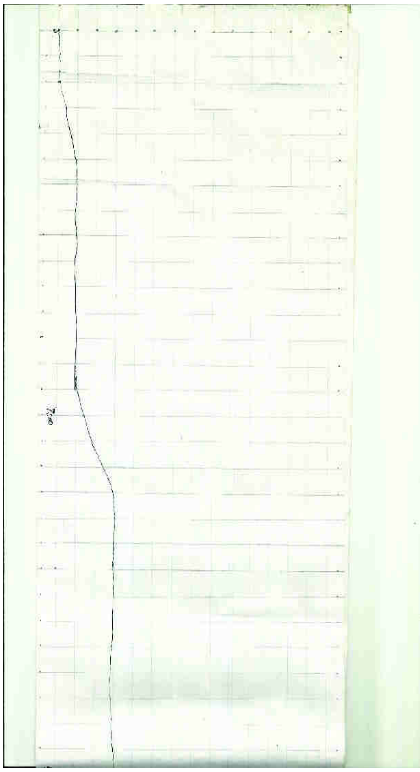


Figure: 3 Runoff hydrograph as plotted by the device.

Stream guaging will provide information to the farmer whether the stream will have enough yield for his irrigation through the year for effective and continuous crop production. Flood- flow prediction that is sometimes based on permanent characteristics can also be achieved with this hydrograph. Transient influences include the storage capacity of bedrock and soil, the interrelationships of infiltration, evaporation, and interception and detention (especially by vegetation), storm characteristics, which vary widely in amount, duration, intensity, and location.

The time-discharge or time-stage characteristics of a given flood peak tends to assume a trend for a given station in response to a given input of water. The peak flow produced by a single storm is superimposed on the base flow, the water already in the channel and being supplied from the groundwater reservoir. Rise in peak discharge is relatively swift in small basins and on torrents where the duration of the momentary peak is also short. On very large streams, by contrast, peak discharge can be sustained for lengths of days. Recession from peak discharge is usually exponential as shown in the sample hydrograph. The form of hydrograph for any station or stream is affected by characteristics of the channel, drainage net, and basin geometry. This means that the channel's configuration and pattern, and the presence of vegetation in and along the channel will also have effect on the hydrograph shape. A stream with longitudinal profile will show a more rapid response and will produce high peak discharge than one that is not as steep. Shorter and wider catchments produce more discharge than longer and narrower ones because of the shorter travel time.

For the equipment to perform optimally the following recommendations are imperative:

i. the upstream area must be kept free of weeds and trash. Sediment must be removed as it accumulates.
ii. the bearings should be lubricated regularly as lubricants periodically in small amounts will slow the rate of wear.
iii. yearly painting is recommended to prevent corrosion and rust formation.

4. CONCLUSION

The device for guaging small streams was designed and constructed. The device was installed and tested. The installation and maintenance are simple. The device was able to produce a hydrograph that shows the flow pattern. From the hydrograph the discharge across a stream or channel section can be calculated.

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