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Performance evaluation of a shallow tubewell irrigation project

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ABSTRACT

An attempt was made to evaluate the performance of a shallow tubewell (STW) irrigation project situated at the village Boira near BAU campus in Mymensingh district. The performances were evaluated by collecting data on some technical parameters. Data on actual tubewell discharge, command area, daily operations hours and crop yield were collected. By using these data, technical parameters like water loss in the canal, duty, command area ratio, water use efficiency and water management efficiency were determined. The discharge of the STW was found to be 8.91 lps. Conveyance loss of the project was 31.71 percent (with an average value) of the pump discharge. Duty was 133.22 ha/cumec. Water management efficiency was 74 percent. Canal density was 207m/ha. Command area ratio was 0.37. Water productivity of rice was 0.63 kg/m3. Benefit cost ratio was found to be 2.62. The higher seepage losses in the study area were due to earthen canal networks which were not compacted properly and were not designed following any engineering principle. The performance parameters are expected to be improved to the satisfactory extent if earthen canals are compacted properly and optimum quantity of water is applied as and when necessary.

INTRODUCTION

Availability of land for agriculture is decreasing day by day in Bangladesh because of increasing population. In these circumstances, production per unit area needs to be increased to meet the demand of growing population. Agricultural production could be increased by increasing crop intensity and introducing modern technologies. Because of the crucial role of water in crop production, irrigation is to be considered along with other agricultural inputs. Irrigation, as an input, is important because the productivity of other inputs, such as seed and fertilizer, depend on the availability of water supply to the crop fields.

Farmers, in this country, used to irrigate their lands in the long past using traditional devices like Don and Swing basket. By these devices, they could irrigate only a very small piece of land by lifting surface water to a small height.

Small scale irrigation using modern technologies was introduced in early sixties. These technologies included low lift pumps (LLP), deep tubewells (DTW) and shallow tubewells (STW). While LLPs were limited to areas where surface waters were available, tubewell irrigation was feasible anywhere in the country because of existence of vast ground water resource at a relatively shallow depth.

Of the two types of tubewell technologies, STW began to be more popular soon after its introduction for its low cost and simpler technology. In the eighties, components of STW became readily available in the market at reasonable prices. As a result, the STW technology

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began to spread all over the country at an accelerated rate.

The National Minor Irrigation Development Project (NMIDP) with the assistance of the Development of Agricultural Extension (DAE) undertook a national minor irrigation census. The results showed that, there were about 8 lacks shallow tubewells operative in the country. STW, the major contributor to minor irrigation, commands 60 percent (66 lack acres) of total irrigation and 81 percent of groundwater irrigation (NMIC, 1999/2000).

One of the major weaknesses of the minor irrigation sector is the huge amount of losses of irrigation water that occurs due to lack of knowledge of management, as well as to some extent, due to negligence of farmers. Only a portion of the irrigation water delivered to the farm fulfils its intended purpose that is of providing essential water for the crops grown. Some of the water is lost by evaporation or seepage from farm ditches; visible leakage through and over the banks (overtopping and leakage though banks closed outlets) more is lost from runoff and/or percolation below the root zone in the field due to uneven distribution of the water or excessive duration of irrigations.

Michael (1978) in a consultancy report mentioned that the farmers in Bangladesh mainly used earthen canals for conveying water to irrigate their fields because of low initial cost, and considerable conveyance losses occurred mainly due to leakage. Recent literatures reveal that, this loss may be as high as 50-60 %, although it varies with soil type and channel conditions. Channel water loss adds to the pumping cost in minor irrigation systems, and thus reduces the command area, as well as overall efficiency of irrigation

Considering the above fact the present study was undertaken to evaluate the performance of the minor irrigation project comprising of a shallow tubewell to determine various performance indicators like well discharge, conveyance loss, duty of well, water management efficiency, canal density command area ratio, water productivity and benefit cost ratio.

MATERIALS AND METHODS

Description of the study area

The study was conducted during the rabi season at the village Boira near Bangladesh Agricultural University campus under sadar upazilla in the district of Mymensingh. The topography of the farm land in this area is relatively low and flat. The area is under the "Old Brahmaputra" flood plain.

Selection of the experimental project site

A shallow tubewell was selected at the place mentioned above for this study. The selection of STW was mainly based on their command area. For performance evaluation of the STW irrigation project, various basic information related to the tubewell, such as prime mover for the pump, the well diameter, tubewell depth, filter length, and command area were collected through interviewing the farmer. The discharge rate of the tubewell was measured in the canal by a cut-throat flume. The basic information related to the selected irrigation project is presented in Table 1.

Table 1: Basic information related to the selected irrigation project

Technology	prime mover type	Tubewell diameter (m)	Length of pipe (m)	Filter Length (m)	Discharge (cumec)	command area Ha(acre)
STW	Motor	0.1016	16.77	6.10	$8.91x10^{-3}$	1.187(2.93)

Discharge measurement

To measure the discharge of STW, volumetric method was used. A simple method of measuring discharge of small irrigation stream was to collect the flow in a container of known volume for a recorded period of time and discharge was calculated by dividing the collected volume with time. Figure 2 shows the collection of water in a known volume of a container. Figure 3 shows the canal discharge measurement using cut-throat flume. Figure 4 shows an earthen irrigation canal in the project area.

Figure 2: Pump discharge measurement of STW

Figure 3: Discharge measurement in a canal of the experimental STW Project

Figure 4: Irrigation canal in the STW Project area

Canal discharge measurement

Canal discharge was measured by placing a cut-throat flume in the canal. For accurate measurement, any leakage was sealed by mud to ensure the whole flow to pass through the flume. When there was no turbulence in the canal water and the flow rate was constant, the upstream depth "h_a," and the downstream flow depth "h_b" were measured from the scales attached to the flume wall (Figure 5). The flow is free flow if the ratio $h_b/h_a \leq 0.65$ and submerged flow if $h_b/h_a = 0.65$ to 0.95. Flow computation is not valid if this ratio is greater than 0.95.

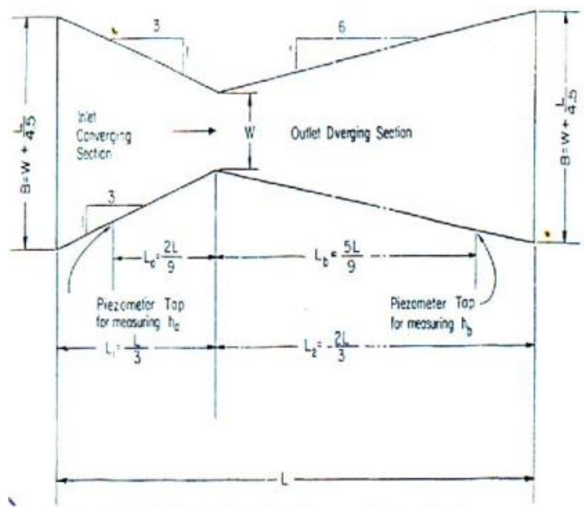

Figure 5: Definition sketch of a cut-throat flume

Under free flow conditions

Critical flow occurs in the vicinity of minimum width, w, which is called the flume throat or flume neck. The attainment of the critical depth makes it possible to determine the flow rate knowing only an upstream depth (e.g. h_a). This is possible because whenever critical depth occurs in the flume, the upstream depth, h_a is not affected by changes in the downstream depth, h_b.

For free flow operation, the flow rate, Q. is plotted as a function of upstream depth, h_a .The equation for this free flow rating can be written as (Skogerboe, 1973):

$$Q = C_1 h_a^{n_1}$$

Where Q = flow rate, in cubic meter per second, C_1= free flow coefficient. The value of n_1 is dependent only upon the flume length L. The value of n_1 can be determined for any flume length between 1.5 to 9 feet by simply reading the value from graph.

The value of the free flow coefficient (C_1) is function of flume length, L and throat width, W. This relationship is: $C_1=K_1W^{1.025}$

Where C_1 = the free flow coefficient; K_1 = the flume length coefficient; and
W = the throat width in feet. The values of K_1 can be obtained from graph presented in Figure 6.

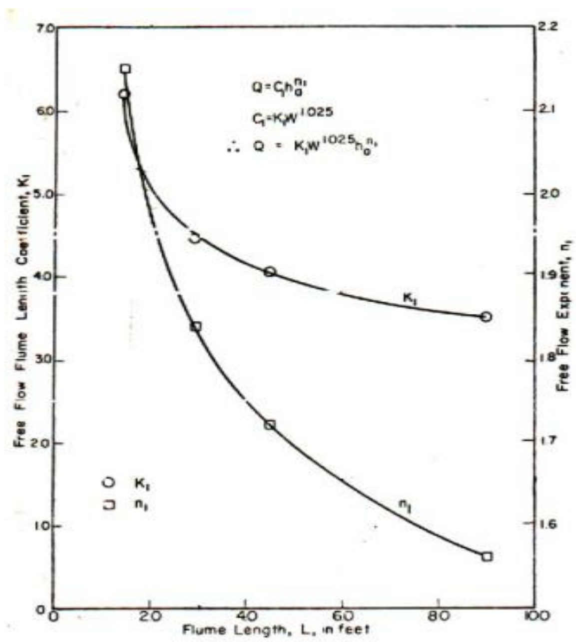

Figure 6: Generalized free flow ratings for Cutthroat flumes

Under submerged flow conditions

A flume operating under submerged flow conditions requires that two flow depths be measured, one upstream (h_a) and one downstream (h_b) from the flume neck. The submergence, S, is defined as the ratio of the downstream to upstream depths, and is often expressed in percentage. $S = h_b/h_a$

Submerged flow calibration curves are determined for the cut-throat flume by preparing logarithmic plots of the parameters describing submerged flow. The discharge, Q is ordinate the difference in upstream and downstream depths of flow $h_a - h_b$, is the abscissa; and the submergence, h_b/h_a, is the varying parameter. Lines are then drawn connecting points of equal submergence. These are straight lines having a slope identical to the slope of the free flow rating curve (n_1.).

From the submerged flow plots, an equation has been developed (Skogerbie, Hyatt, Anderson, and Eggleston, 1967) which describes the flow rate through the cut-throat flume.

The equation is $Q = C_2 (h_a-h_b)^{n_1}/(-\log S)^{n_2}$

Where C_2 = submerged flow coefficient and n_2 = submerged flow exponent. The value of n_2 also depends only upon the flume length, L. Therefore, the value of n_2 can be obtained for any flume length between 1.5 to 9 feet by simply reading the value from the Figure 7.

The submerged flow coefficient is a function of both flume length and throat width. This relationship is

$$C_2 = K_2W^{1.025}$$

Where C_2= the submerged flow coefficient; K_2=the flume length coefficient; and W=throat width, in feet. The value of K_2 can be obtained from the Figure 7.

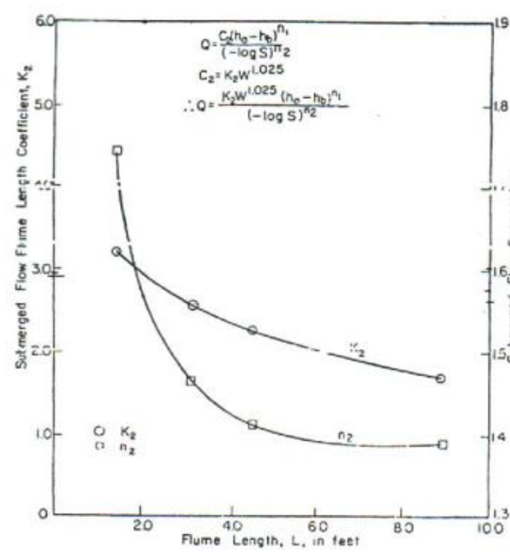

Figure 7: Generalized submerged flow ratings for Cutthroat flumes

Conveyance loss measurement

In the STW project area, two sections were selected in the main canal to measure the seepage loss. The distance between the two sections were measured by a tape. The discharges at these sections were measured by a cut-throat flume. The seepage loss was calculated from the difference of discharges between the two sections. Seepage loss per 100 feet was calculated by the following equation:

$$S = \left(\frac{Q1 - Q2}{L}\right) x\ 100$$

Where, S = seepage loss per 100 feet, Q_1= discharge at section 1 in cubic feet per sec, Q_2= discharge at section 2 in cubic feet per sec. and L= distance between the two sections in feet.

Daily operating hours

Operating hours of pumps, engines and water distribution system are important management performance indicators. Daily operating hour's data were collected from farmers through interviewing and seasonal operating hours were calculated from the daily values and the operating days.

Weighted canal density

Weighted canal density of an individual irrigation scheme may be defined as the ratio of the total length covered by the canal system to the total area irrigated by the scheme.

$$\text{Weighted canal density} = \frac{\text{Total length of the canal}}{\text{Area irrigated by the scheme}}$$

Command area ratio

Command area ratio is the ratio of actual command area to potential command area. Potential command area was determined considering certain assumptions. Potential command area of an irrigation scheme is a term which varies greatly with the prevailing situation. It varies with pumping condition and its efficiency, cropping practice and its time, topographic limitations, system efficiency etc. However, as suggested by different investigators, estimation of PCA should be based on peak monthly crop water requirement, system efficiency (70% assumed in many cases) and pump operating hours taken as 20 hours/day (Mojid. 2006). The peak demand of boro rice in the period from March to May depending on the transplanting data. For growing season from January, the peak demand is in May. So, from the study of Jenkins (1981), it is found that potential evapo-transpiration (PET) and crop coefficient (K_c) for the month of May are 15.75cm and 1.25, respectively. Hence, ET for peak period can be estimated as follows:

ET = *K x PET* = 1.25 x 15.75 = 19.68cm for May

Therefore, daily peak crop ET is given by
DET = *(*19.68x10)/31 = 6.34*mm/ days*

Daily water requirement = DET + Daily S&P

$$\text{PCA} = \frac{\text{Pump discharge x Daily operation h.}}{\text{Daily water requirement}}\ x\ \text{System efficiency}$$

Hence, $PCA = \frac{q\ x\ t}{DWR}\ x\ N\ x\ K$

Where,
PCA = Potential command area in hectare
q = pump discharge in lit./sec.
t = pump operation time in hours/day
DWR = Daily peak water requirement in mm
S & P = Seepage and Percolation loss
N = System efficiency in percent
K= Conversion factor = 3.6 x 10^{-3}

Hence,

$$\text{Command area ratio} = \frac{\text{actual command area}}{\text{potential command area}}$$

Water productivity

Field water productivity is expressed as the ratio of production per cubic meter of water applied per hectare. Water productivity is also known as water use efficiency (WUE). Water productivity may be calculated from

$$\text{Water productivity} = \frac{\text{Amount of crop production}}{\text{Volume of water applied}}$$

Duty measurement

Duty is the ratio of the actual irrigated area to the actual pump discharge. It is expressed in ha/cumec.

Mathematically, $A = \frac{\text{Actual irrigation area}}{\text{Actual pump discharge}}$

Water management efficiency
It is the ratio of total volume of water demand to total volume of water supply. Hence,

$$WME = \frac{\text{Total volume of water demand}}{\text{Total volume of water supply}}\ x\ 100$$

Total volume of water supply = Actual discharge x Seasonal operating time

Total volume of water demand = Expected irrigation demand for Boro rice X Actual command area (Biswas and Mondal, 1993)

Management performance ratio

It is the ratio of total volume of water supply to total volume of water demand. Hence,

$$MPR = \frac{\text{Total volume of water supply}}{\text{Total volume of water demand}}$$

Total volume of water supply = Actual discharge x Total time

Total volume of water demand = Expected irrigation demand for Boro rice x Actual command area (Biswas and Monda,l 1993)

Benefit cost ratio

It is the ratio of gross return to the total cost
Benefit cost ratio = Gross return / cost
Total cost includes - Seed / seedlings, Fertilizers Plough (Tractor, power tiller or bullock), Labours Insecticides and Fuel or electricity cost

Gross return

It includes the value of paddy and straw in Tk./ha
Net return= Gross return - Total cost

RESULTS AND DISCUSSION

Pump discharge measurement

The average discharge of STW was found to be 0.00891 cumec or 8.91 lps (Table 1). The value is lower than the discharge of a standard STW, which should be equal to 0.012 cumec. The actual discharge is about 74% of the theoretical discharge.

Table 1: Discharge measurement of STW by volumetric method

Serial No.	Time (Sec)	Volume of Water (m^3)	Discharge (cumece)	Discharge (lps)
1	19.56	0.1779	0.00909	9.09
2	20.37	0.1779	0.00873	8.73
3	19.95	0.1779	0.00891	8.91
Average			0.00891	8.91

Canal discharge measurement

The condition of flow (free flow, submerged flow or not valid) is identified by the ratio h_b/h_a. A value of h_b/h_a less than 0.65 indicates free flow, from 0.65 to 0.9 submerged flow and a value greater than 0.9 indicates not valid situation.

Table 2: Flow measurement of earthen canal by cutthroat flume (8``)

Discharge from pump in m	Upstream flow depth h_a(cm)	Downstream flow depth h_b(cm)	$S = h_b/ h_a$	Types of flow	Discharge (lps)
12.19	8.30	3.84	0.463	Free flow	7.17
24.4	7.62	3.81	0.50	Free flow	5.97
41.45	7.36	3.25	0.441	Free flow	5.57
56.69	7.20	3.20	0.444	Free flow	5.33
76.2	7.25	6.35	0.875	Submerge flow	4.77

Table 3: Conveyance loss measurement

Distance (m)	Discharge (lps)	Loss per 30.48m (lps)	Average Loss per 30.48m(lps)	% Loss per 30.48m	Average % Loss per 30.48m
0	8.91	----	3.4	----	31.71
12.19	7.17	4.35		49.00	
24.40	5.97	3.67		41.24	
41.45	5.57	2.46		28.00	
56.69	5.33	1.93		21.66	
76.2	4.77	1.66		18.63	

Conveyance loss

Conveyance losses were calculated by taking the difference of discharges measured at two sections of the canal. Conveyance losses of STW are presented in Table 4.3.

In this method, STW discharge was 8.911ps at the pumping point, 7.17 lps at a distance of 12.19m from the pump, 5.97 lps at a distance of 24.4m from the pump and 5.57 lps at a distance of 41.45m and 5.33 lps at a distance of 56.69m, 4.77 lps at a distance of 76.2m from the pump using an 8" cut-throat flume. The average conveyance loss per 30.48 m. length of canal was 2.81 1ps (Table 4.3.)

In the farmer's field, water losses in irrigation canals under Bangladesh condition are due to uncontrollable cracks, holes and borrows. On the other hand, seepage losses are greater when water is conveyed over a long distance and hydraulic gradient is influenced by depth of water in the canal. The seepage problem is highly variable and no single corrective method or material can be applied in all situations, so, most of the seepage problems may remain unsolved. Therefore, the methods and materials that are strictly effective, economical and practical for many situations should be developed.

Duty

Small area irrigated by a project resulted in decreased duty. Low irrigation coverage increases the costs of capital investment and operation and maintenance of irrigation system per unit area. This results in increased production cost. The value of duty in boro season of the STW project is presented in Table 4.

Table 4: Duty of the irrigation project area

Tubewell	Actual command area (ha)	Actual pump discharge (cumec)	Duty (ha/cumec)
STW	1.187	0.00891	133.22

Biswas and Mondal (1993) observed in a study that the average duty of STW schemes in four areas in Bangladesh was 0.372 ha/lps. This value is greater than the duty of 0.133 ha/lps, obtained in this study. However, the duty obtained by Biswas in Ghatail area (0.246 ha/lps) was greater than this value.

Water management efficiency

Performances of the irrigation unit in terms of water supplied to the crop field as compared to the irrigation requirements are shown in Table 5.

Table 5: Water management efficiency of the irrigation project

Tubewell	Water supplied including conveyance (m^3)	Expected water demand (m^3)	Water management efficiency (%)
STW	12830.40	9436.7	74

Canal density

For measuring canal density of shallow tubewell project in the study area, two types of data, such as total length of the canal and actual command area, were collected through field surveying and interviewing the farmers. These data are presented in the Table 6.

Table 6: Canal density data of the STW irrigation project area

Tubewell	Working command area(ha)	Canal length (m)	Canal density (m/ha)
STW	1.87	246	207

Command area ratio

The command area ratio of the irrigation unit is 0.37 (Table 7). Command area ratio depends on actual command area and potential command area. Actual Command area depends on farmer's participation with their irrigated land and interest for cultivation and suitability of the land.

Table 7: Command area ratio

Tubewell	Actual command area (ha)	Potential command area (ha)	Command area ratio
STW	1.187	3.19	0.37

Water productivity

Water productivity of the project is 0.63 kg/m (Table 8). Higher water productivity could be attained by providing training to the farmers on technical knowledge of production and improved water management practices to the farmers.

Table 8: Water productivity of the study site

Tubewell	Working command area (ha)	Yield (kg/ha)	Water applied (m^3)	Water productivity (kg/m^3)
STW	1.187	6793	12830.4	0.63

Total cost and benefit cost ratio

The total cost per ha including seeding, ploughing, labour, fertilizer, insecticide and fuel cost is 41500 Tk (Table 9).

Net and gross return obtained through economic analysis of irrigated rice under STW scheme showed that benefit cost ratio is 3.11 (Table 10). This result is satisfactory and it can be said that this scheme is running economically.

Table 9: Total cost per ha irrigated rice production

Tube well	Seeding (Tk.)	Plough (Tk.)	Labour (Tk.)	Fertilizer (Tk.)	Insecticide (Tk.)	Electric bill and maintenance cost(Tk.)	Total Cost (Tk.)
STW	3000	2500	14000	5500	2500	14000	41500

Table 10: Benefit cost ratio of the study site

Tubewell	Total cost (Tk)	Gross return (Tk)	Net return (Tk)	Benefit cost Ratio
STW	41500	108688	67188	2.62

CONCLUSIONS

The benefit of any irrigation project is largely dependent on the overall performances of the irrigation system. This study provides some valuable information on the performances of the selected STW irrigation project area. In the STW 49% of the water was delivered in the projected area and rest was delivered to that of neighbors for these reason above calculated values were found less than that of expected.

The conveyance loss in the study area is 31.71 percent of the pumped discharge per 30.48m of the canal. The canals in the study area were unlined and uncompacted for which the conveyance losses were high. The average duty of the irrigation project area is low. The overall water management performance of the irrigation project area may be considered satisfactory (efficiency is 74 percent). Command area ratio value of 0.37 indicates that, there are scopes of increasing the actual command area of the STW. Water productivity of the irrigation project area is satisfactory (value is 0.63 kg/m).

The benefit cost ratio of the irrigation project area is 2.62. So this scheme is running economically. The ratio can further be increased if the canal networks be designed properly and compacted to reduce seepage losses.

RECOMMENDATIONS

Farmers can be motivated either to line their canals to reduce conveyance losses or to compacts the earthen canals properly.

Farmers should be trained to make them aware when how much water is to be applied for optimum yield.

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