Interaction Between Design and Operation and Maintenance of Farmer-Managed Irrigation Systems

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INTRODUCTION

FARMER-MANAGED IRRIGATION SYSTEMS are located all over Bangladesh where most of the fertile agricultural land is either low-lying flood plains under deltaic influence or flood-free upland beyond the scope of gravity-flow water supplies. Unlike in other countries, the farmers are less acquainted with gravity irrigation which is limited due to the absence of water-diversion opportunities. However, lift irrigation is prominent. There are a few primitive devices for lifting water for limited irrigation. Modern lift irrigation either from surface sources by low lift pumps or from groundwater aquifers through deep or shallow tube wells has taken the key role in both agricultural and rural development programs in Bangladesh for the purposes of increasing farm outputs against recurring food deficits and growing rural unemployment. Because of the costs involved in installing and managing lift systems the government has sponsored a program in both public and private sectors to involve the farmers in increased agricultural production.

Agriculture is Bangladesh's primary industry and lift irrigation has a vital role in the nation's economy. The role of minor irrigation in increasing food production and employment is already well-documented (Hamid 1977; Hanratty 1983; Palmer-Jones 1985). Introduction of irrigation technology may open new outlooks and create an impact on both the social structure and the rural economy, but in reality, experience has shown that only a few elite farmers have gained enormous benefits (Hamid 1977; Hanratty 1983; Biswas 1988). The performance of these irrigation systems was in general unsatisfactory (Hamid 1977; Biswas 1988). Engineering, economic, social, political, legal, and especially institutional problems were responsible for creating greater inequities in the rural areas (Biswas and Mandal 1982; Hanratty 1983; Palmer-Jones 1985). Improved management strategies were sought in order to combat the inequality in benefit

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distribution and make the irrigation installation workable at full capacity (RD-I Project Series 1980). The irrigation schemes are primarily planned by state planners while the irrigation systems are managed by the farmers. The latter is neither independent of state bureaucracy nor able to tackle local problems easily in a complex socioeconomic environment. Thus, operation and maintenance activities are not simple although the farmers are made responsible for providing water to the fields using the minor irrigation installation.

In the early stage of introducing modern irrigation technology water was neither considered a priced commodity nor thought a scarce resource (Hanratty 1983). However, the growing demand for irrigation water and the increasing trend of rising irrigation costs have created an awareness of the wastefulness of present methods of irrigation and made the farmers concerned about crop water requirements and losses in the conveyance system. In addition to the poor performance of the irrigation systems the pumps in some cases cannot supply adequate irrigation nor can they cover the area as planned (Biswas 1988).

Use of the irrigation installations is limited to the dry season only remaining idle for the rest of the year despite the potential for providing supplemental irrigation in other seasons. Ordinarily, irrigation is applied only on high-yielding rice and some wheat. Nevertheless, other high-value crops could simultaneously receive water through improved water allocation and distribution systems (Biswas 1988; Gisselquist 1989).

Given the limited availability of both surface water and groundwater which constrains the expansion of irrigated area under low lift pumps and shallow tube wells and the costs involved with deep tube-well installation and maintenance, new strategies are being sought to increase irrigation efficiency, to replace traditional and water-loving crops with high-value crops requiring less water, and to improve water distribution and water-application methods (Palmer-Jones and Mandal 1988; Gisselquist 1989). These strategies are aimed at making the irrigation systems more productive with increased participation by the farmers. However, to achieve increased productivity, considerations for appropriate methodological interventions need to be incorporated in the design of an irrigation system to encourage crop diversification and increase crop intensities.

Though literature documents, and experience exists for evaluating water requirements of plants the design of an irrigation system is usually based on either thumb-rules or "field experience." Because it is complex, plant-water relationships are deliberately ignored in designing irrigation systems in Bangladesh.

CONSIDERATIONS FOR IMPROVING WATER DISTRIBUTION

Water Losses at Pumping Sites

Water is lost through seepage, leakage, overflow, and in excess application. The pump delivers flows with high velocity that cause soil erosion, and water spills cause drainage problems resulting in inferior crop production near the pump sites. Regulated water flow is desirable and a brick discharge box is ordinarily constructed with a view to protecting the soil surface, avoiding water spills, and directing the flow to the field. Alternatively, small ponds are sometimes dug to form water cushions although water flow to the main canal suffers from insufficient head developed in the pond. Other low-cost measures such as placing sheet metal, wood planks, bamboo strips or straws around the pump may diminish soil erosion substantially. However, water spills and logging and loss of space cannot be avoided with these alternatives. Eventually, inclusion of a control structure at the pump site is essential to the water-distribution network.

Improving Conveyance Systems to Reduce Water Losses

Most of the water-distribution systems in minor irrigation scheme areas are locally initiated, constructed, and managed by the farmers. Ordinarily, a small earthen canal is used to convey water and losses occur in various ways. Losses of water may account for about 50 percent of the total water pumped (Khair and Hossain 1978; Biswas et al. 1984). This loss varies according to the soil and relative elevations of the canals (Biswas et al. 1983). Extra pumping is necessary to compensate for losses or the command area is reduced for want of water, and overall irrigation efficiency declines (Biswas et al. 1983; Gisselquist 1989).

Some of the losses including waste can be greatly minimized through efficient water-management practices (RD-I Project Series 1980). In addition, some physical interventions including structural measures are recommended to avoid water losses (Jenkins 1983; Biswas et al. 1983 and 1984; Arif 1984; Hoque 1984; Ahmed 1984). Of these, improvement of existing earth canals is about the most effective. Other suggestions include shortening and straightening the canal. However, existing land-tenure patterns, fragmentation, and irregular subdivisions of the command area make some of these measures difficult to implement (Biswas and Mandal 1982). Construction of raised and graded canal beds including compaction of the canal subgrade are also advocated. Local labor can be trained in the skills required for these tasks but obtaining extra earth for raising the canal bed and the extra land area needed is difficult (Biswas et al. 1983 and 1984; Hoque 1984). The low-cost lined canal, being the second choice, also suffers from similar problems of establishing right-of-way for shortening and straightening. Nevertheless, lined canals reduce both costs and materials. The low-cost canals are cast concrete, soil-cement, and asphalt-mat. The concrete canals may be pre- or in-situ cast. Consolidation and compaction of canal subgrades, casting of joints, uniform cross-sections, maintaining sufficient bed slope, and uniform thickness and passage for random movements at the sides are some of the critical design issues of low-cost linings (Hoque 1984; Arif 1984). Flood-free sandy soil areas may favor soil-cement canals, while asphalt-mat cover has limited use (Biswas et al. 1983).

Buried concrete pipe is an alternative although it needs high initial investment and construction skills (Palmer-Jones and Mandal 1988). To its advantage, it does not consume valuable agricultural land, offers regulated water flow even against undulation and broken topography, and promises to irrigate more area at minimum water loss (Jenkins 1983; Gisselquist 1989). Besides low-pressure concrete pipe other main components of the system are standpipes to act as both discharge boxes and sediment traps, risers with suitable valves to serve the area blocked, dividers for diverting flow, anchors for balancing the internal forces, and vents for releasing entrained air. The standpipe also provides the necessary head and dampens surges or water hammer during unsteady flow. But the flow between risers may be affected by both differences in elevation and pipe-friction losses. Above all, the design of a buried pipe system requires technical knowledge of the applications of hydraulic principles including the impact of hydrostatic pressure, surges, and changes in momentum.

The success of an irrigation system relies on ease of operation and maintenance as well, and the system should be kept simple and flexible so that farmers can easily resolve the problems on site. Quite often, major maintenance work jeopardizes the system under many socio-political-cum-economic variables (Biswas 1988). The importance of these variables should be considered and incorporated in the design for a farmer-managed irrigation system.

DESIGN ISSUES

Institutional Interventions

In Bangladesh, different categories of farmers are engaged in irrigation, making the formation of users' groups that take into consideration the social and economic characteristics of the farmers, an important issue in achieving farmer participation in irrigation. Policy formulations including bylaws for procurement, construction, operation, and adoption of management strategies are necessary keys to the success of farmer-managed irrigation systems.

Technical Interventions

Mapping. A map of the irrigation project area is needed. It should show the pump site and the water-distribution network based on relative land elevation. Stratified crop areas based on soils and topography should be identified on the map as one of the design steps. Cropping patterns including sequential rotation should be evaluated for the potential area. The potential command area must be delineated on the map, with blocks and sub-blocks earmarked with reference to topographical settings, cropping areas, and water-application techniques.

Assessing irrigation water. A chart should be prepared which should include information on the water requirements for each crop at each growth stage. Additional water requirements for land preparation or pre-sowing should be included. Water allocation based on crops, soils, land positions, and irrigation methods should be estimated for different locations within the scheme area and evaluated.

Assessment of water sources. Sources of irrigation water in terms of water-level status, replenishment opportunities for surface water (especially in the dry season), and augmentation scopes for groundwater with the indices relating to storage coefficients, transmissibilities, and permeability of the aquifers need to be investigated. Pumps selected for the system must be appropriate for the water source and for the power available.

Water-conveyance systems. Improved open earth canals, low-cost open lined canals, and buried low-pressure pipe systems are primarily referred to as irrigation water-conveyance systems. Any one or a combination of these systems may be considered in relation to cost and the farmers' preferences.

Improved earth canal is an obvious choice unless the other two types are partly or fully subsidized. The design of earth canals for the best flow using stream size, permissible velocity, side slope, bed slope, and roughness coefficient calculations is not complicated. The design dimensions for freeboard and berm can also be readily calculated. Designs to carry sufficient water with minimum loss must be sought. Raised and graded canal beds with adequate right-of-way improve the efficiency of the water-conveyance system. Aqueducts may be placed over the ditches or the depressions to help maintain grade, and humps need to be leveled. Above all, the canal subgrade should be well-compacted to reduce seepage. The effectiveness of this technique depends on the soil textures of the canal subgrade.

Some water losses occur in earth canals even after the canal beds are raised, graded, and compacted. Whenever financial assistance is available the farmers want brick-lined canals. However, because of the cost brick lining is usually discouraged (Biswas et al. 1983) and low-cost canal linings are often advocated (Khair and Hossain 1978; Biswas et al. 1983; Hoque 1984; Arif 1984). Nevertheless, brick-lined canals do minimize water loss as well as provide potential to control and regulate water flow according to need. Basic construction requirements for earth-lined and brick-lined canals are almost identical. Canal subgrades require extra land and earth. Retaining walls and other support structures are sometimes necessary to avoid breakage and to safeguard the canal from external pressures.

Some critical issues should be carefully watched when constructing a low-cost lined canal to assure durability:

a) Cracks in the reaches of the canal subgrade should be avoided by careful compaction and consolidation before installing the lining materials. Proper casting of joints is essential and the embankment should be protected from side cutting.
b) Uniform canal slope should be maintained to avoid overflow. Careful siting of the pumping unit can overcome these problems as well as make it possible to extend irrigation to higher elevations.
c) The edges of the canals should be uniform and protected with concrete to prevent random movement caused by people and animals.

Allowance for right-of-way for the canal causes serious problems in the midst of acute land scarcity. Topographical variables and unplanned settlement patterns discourage the use of open-canal conveyance systems. Buried low-pressure pipe may be considered as an alternative conveyance system, although it is more expensive. Nevertheless, buried pipe systems can be stretched over hilly areas and broken topography to serve different blocks and sub-blocks using risers fitted with suitable valves. Water is directly pumped into the buried pipe lines and the flow is influenced by hydrostatic pressures. Accordingly, a sufficient knowledge of hydraulics is necessary, and certain precautions should be taken when designing a buried pipe system:

a) The standpipe should assure structural stability and sustain hydrostatic forces. The inlet of the standpipe should have a flap valve to prevent flow back to the well. The inlet and outlet should be offset a minimum of twice the sum of their diameters and the outlet invert should be at least 0.65 meters above the bottom of the standpipe. The cross section of the standpipe must be large enough to assure a maximum downward velocity of 0.60 meters per second (m/sec) for a deep tube well irrigation project. If the standpipe is to serve as a sediment trap the downward velocity should not exceed 0.10 m/sec. Access to the standpipe for cleaning is essential. A minimum of 0.70 meters freeboard is desirable to avoid overflow.

b) Selection of pipe size is usually based on maximum permissible velocity and head loss encountered in the flow system.
c) Vertical risers with appropriate valves at the top should be fitted to the pipe line for releasing water to the ground surface or the field canals.
d) A vertical standpipe fitted at the top with overflow weirs should also be accommodated in the pipe network in order to divide the flow proportionally. Installation of flow dividers is essential for regulating flow in variable topography.
e) Any abrupt change in pipeline grade or alignment must be secured with an appropriate anchor. This will balance internal forces caused by hydrostatic pressures, surges, and changes in momentum.
f) Vent stands should be installed on the pipeline, preferably near the junctions, for releasing the entrained air in the pipe.

Particular attention must be paid to the installation of the pipe in respect to grade and alignment, placement in the trenches, curing of collar joints, and backfilling the trenches. The bases of the standpipes must be carefully constructed in order to reduce the need for repair.

Control structures. A discharge box, some division boxes, and turnouts may be needed for open canal systems. A discharge box will help avoid soil erosion and water spills. Concerns to be considered when designing the discharge box are the impact of flowing jets on the floor, storage capacity, and appropriate openings. Division boxes with control gates can divide the stream according to the water-allocation plan. Similarly, turnouts with control gates allow water to be distributed to the blocks. If the canal bed is at a higher elevation than the area to be irrigated, a drop structure is essential. For buried pipe systems, the principles of pipe flow influence the structural design of standpipes, risers, flow dividers, anchors, and vent stands.

Drainage outlets. Drain outlets should be installed at low elevations in the irrigated area to remove excess water. Construction of simple culverts is also needed to avoid ponded water.

PARTICIPATION OF THE FARMERS

The designer of a farmer-managed irrigation system should carefully examine operation aspects so that both institutional and technical interventions can be adjusted to local resources and needs. Efficient management of a farmer-managed irrigation system depends on the reliability of a power supply (electricity/diesel), ability to respond quickly when repairs and maintenance are needed (including mechanical servicing), and training facilities for updating irrigation practices including production technology.

Table 1 provides details of the involvement of the farmers and the agency at various stages of projects to improve water-conveyance systems in Bangladesh. As Table 1 reveals, field investigation showed that most decisions for improved water-conveyance structures are made by persons outside the irrigation system which contradicts the basic concept of incorporating the participation of the farmers in decision making for both design and construction. Nevertheless, operation and maintenance are left to the farmers who can generally carry out such activities if external cash assistance is provided. On withdrawal of such help, operation and maintenance do not function effectively (Biswas 1988).

Even for decisions involving the construction of discharge boxes controlled by the farmers' cooperative society, farmer involvement is low. The field investigation revealed that 3 out of 21 boxes were below specifications, causing overflow, water spills, and drainage problems near the pump sites. Another nine boxes have bulky designs involving excess masonry works and materials. In addition, one discharge box has an outlet that is too small, resulting in overflow. Complaints of design errors related to canal alignment, flow requirements, and weak construction are often heard. (Design defects are fewer in certain special project areas where technicians are involved in construction and are charged for their mistakes.) Most of the design and construction defects are due to poor extension services. As a result, the farmers face problems with operation and maintenance of the system.

Table 1. Involvement of the farmers and the agency at various stages of some projects to improve water-conveyance systems.

Stage	Buried pipe		Low-cost lined canal		Earth canal		Discharge box	
	F	A	F	A	F	A	F	A
Initiative	0	9	0	6	17	0	5	16
Design	0	9	0	6	14	3[a]	4	17
Construction	0	9	0	6	16	1[b]	4	17
Operation and maintenance	8	1[c]	6	0	17	0	19	2[b]

Notes: F = Farmer involvement
A = Agency support:
[a]government extension service
[b]supervision from a nongovernment organization
[c]project component
F+A = Total number of structures investigated

Source: Field investigation 1989.

EXTENDING COMMAND AREAS

Table 2 shows that there is no real difference in the size of command areas that are irrigated by buried pipe systems or earth canals despite earth canals incurring greater water losses. Nor does a change in cropping patterns occur as a result of installing either buried pipe or lined-canal systems, despite lined canals being generally found in flood-free highlands capable of growing a variety of crops. However, earth canals are predominantly found in low-lying rice-growing areas. Thus, technology has failed to influence changes in cropping patterns -- instead, land morphology is the determining factor.

The concentration of pump installations or limitations of the pipe extension may be reasons for such disappointing irrigation coverage by buried pipe systems. These problems, resulting from planning errors, frustrate the achievement of improved agricultural production.

Table 2. Command area, crops irrigated, and water usage in the dry season.

Conveyance system	Area[a]	Water distributions: Applied		Used by crop		S & P in field		Conveyance losses
	ha	ha.m[b]	%	ha.m	%	ha.m	%	%
Buried pipe	11.1	14.0	76	1.0	54.1	3.7	20	1.9
(Q = 46)	10.4	3.5	19	2.9	14.0	0.8	4.2	0.8
(H = 1,158)	1.3	0.5	3	0.5	2.6	0.1	0.4	-
	1.4	0.4	2	0.3	1.8	0.0	0.2	-
	24.2	18.4	100					2.7
Low-cost Lined canal	15.6	21.6	81	14.0	52.6	5.2	19.5	8.9
	10.8	4.0	15	2.6	9.8	0.9	3.2	2.0
(Q = 47.5)	1.2	0.5	2	0.4	1.6	0.1	0.3	0.1
(H = 1,561)	1.3	0.5	2	0.4	1.4	0.1	0.3	0.3
	28.9	26.6	100					11.3
Earth canal	21.0	30.6	95	16.8	52.8	5.8	17.9	24.9
(Q = 48.9)	0.8	0.3	1	0.2	0.6	0.1	0.2	0.2
(H = 1,828)	2.8	1.3	4	0.8	2.4	0.2	0.7	0.9
	24.6	32.2	100					26.0

Notes: Q = Average flow rate in liters per second
H = Hours of pump operation
S&P = Seepage and percolation
[a] Refer to Table 3 for the sequence of crops cultivated in the area given.
[b] Hectare meters: One hectare meter is the volume of water required to cover one hectare of land one meter deep, or 10,000 m^3.

Source: Field investigation 1988.

POTENTIAL FOR CROP DIVERSIFICATION

Improved water-conveyance systems should also have the potential for increasing agricultural production by providing irrigation year-round, making it possible to grow diversified crops. Table 3 shows that while irrigation water is applied in the dry season as is usual, very little use is made of irrigation in both the early monsoon and main monsoon seasons.

Table 3 shows that irrigation facilities are used only for a few hours in both monsoon seasons. Early monsoon irrigation may overlap with some dry-season watering. The use of irrigation is limited to land preparation for early-monsoon rice and as supplemental water for some main-monsoon rice, particularly during the grain-filling stage. These practices are neither remarkable nor significant irrespective of the type of conveyance system. The physical improvement of a system does not necessarily increase cropping intensities throughout the year. Improvements in

Table 3. Use of different irrigation installations in different seasons.

Conveyance system	Crop	Dry season[a]		Early monsoon[b]		Main monsoon[c]	
		Area (ha)	Time (hrs)	Area (ha)	Time (hrs)	Area (ha)	Time (hrs)
Buried pipe	Rice	11.1	--	11.5	--	14.9	--
	Wheat	10.4	--	--	--	--	--
	Vegetable	1.3	--	1.6	--	1.8	--
	Others	1.4	--	2.0	--	1.8	--
		----	----	----	--	----	--
		24.2	1158	15.1	28	17.5	86
Low-cost lined canal	Rice	15.6	--	16.2	--	26.3	--
	Wheat	10.8	--	--	--	--	--
	Vegetable	1.2	--	0.8	--	1.3	--
	Others	1.3	--	--	--	--	--
		----	----	---	--	----	---
		28.9	1561	17.0	17	27.6	116
Earth canal	Rice	21.0	--	5.9	--	19.5	--
	Wheat	0.8	--	--	--	--	--
	Others	2.8	--	--	--	--	--
		----	----	---	--	----	--
		24.6	1828	5.9	6	19.5	42

Notes: [a]Dry season = November-February (Rabi)
[b]Early monsoon = March-May (Kharif I)
[c]Main monsoon = June-October (Kharif II)

Source: Field investigation 1989.

cropping intensities reported by Ahmed and Gisselquist (1989) are not generalized; they were possibly gained with non-irrigated crops grown annually and seasonally in the potential command area. Nevertheless, the cropping intensities were higher in the dry season with improved water-distribution techniques.

PRODUCTION TECHNOLOGY TRAINING FOR FARMERS

Improvements in the water-conveyance system are not the only input for improving farmer-managed irrigation systems. Other production technologies are equally important for achieving efficient operation and maintenance of the irrigation system. Field investigations (Table 4) show that traditional sources are the main means by which farmers learn about agricultural practices. Projects have trained some farmers in high-yielding varieties, fertilizer use, water allocation, and irrigation scheduling. Local-level training in the Irrigation Management Programme (IMP) has trained some farmers in water allocation and irrigation scheduling. However, training in the production techniques mentioned in Table 4 is uncoordinated and unbalanced so that the expected results in farmer operation and maintenance are not achieved.

Table 4. Unbalanced training in production technology for farmer-managed irrigation systems.

Source of training	HYV	Ferti-lizer	Tillage	Water alloca-tion	Irrigation scheduling	Banking
Traditional methods	32	31	77	--	--	66
Extension services[a]	0	0	0	0	0	0
Projects	37	40	--	18	15	3
IMP training[b]	10	2	--	45	26	2
Booklets	2	4	--	--	--	1
Unknown	11	15	15	29	51	17

Notes: Number of respondents = 92 (farmers)
[a] Extension refers to the government extension service
[b] Locally organized training through the Irrigation Management Programme
HYV = High Yielding Varieties

Source: Field investigation 1989.

CONCLUSIONS

Farmer-managed irrigation systems are an integral part of Bangladesh's irrigation program for increasing agricultural output. All phases of activities starting from procurement and installations to operation and output disposal need to be included in this program. However, such a synchronized action program is unfortunately not found in Bangladesh. Moreover, frequent changes in government policies breed socioeconomic disorders which seriously affect operation and maintenance of farmer-managed systems. Therefore, farmer-managed irrigation systems are not free from state bureaucracies. A firm and steady government policy is important towards achieving the design goals for farmer-managed irrigation systems. Nevertheless, a few basic issues which influence both design parameters and operation and maintenance activities for farmer-managed irrigation systems should be investigated:

1. The farmers' participation in all stages of planning, design, and installation should continue to be emphasized. How can a participatory approach be made effective?
2. State planners need to ponder and develop a proven irrigation policy. Design and installation criteria must be coordinated with a state policy while satisfying the operation and maintenance requirements of the farmer-managed systems.
3. In many farmer-managed irrigation systems, physical interventions are sponsored without investigating local resources such as water reliability, land productivity, energy reliance, and the capability of the farmers' cooperative society. A thorough inventory of all these resources is essential.
4. The farmers' interests, choices, involvement, and commitment are vital to operation and maintenance of irrigation facilities. How can the designer get a true picture of these vital aspects?
5. All production inputs are not equally stressed during planning and operational stages. For example, the importance of adequate plowing is deliberately ignored for want of draft-power sources. Should not all the cultural aspects be emphasized in designing the irrigation system?
6. Irrigation activities concentrate on the dry season. Can the irrigation systems be designed so that they will stimulate the use of supplemental irrigation of high-value crops in other seasons, and encourage crop diversification?
7. Most production technologies are learned informally using traditional sources, and local-level training conducted by the Irrigation Management Programme (IMP) has been found ineffective. Should not the Programme's training be reoriented to provide more effective training?

The imposition of new technology is less important than achieving the active involvement of the farmers. The best way to encourage the farmers to participate is to make them understand the benefits or profit potentials they may obtain from irrigation and to promote their participation in planning, designing, and constructing their systems.

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