A cost recovery model for tertiary canal improvement projects, with an example from Egypt

Dennis Wichelns*

Department of Environmental and Natural Resource Economics,
University of Rhode Island, Kingston, Rhode Island 02881, USA

Accepted 17 March 1999

Abstract

The potential farm-level gains from improvements in a tertiary canal vary among farmers according to their location along the canal. An economic model describing that variation is developed using the concept of irrigation success, which considers the degree to which water volume and quality, and the timing of irrigation events match the requirements of plants throughout a season. A bid-rent model in which farm-level costs and returns are viewed as a function of irrigation success is used to describe the appropriate roles of public agencies in supporting or financing tertiary canal improvement projects and to evaluate cost recovery programs. An empirical version of the model is used to develop cost recovery alternatives for Egypt’s Irrigation Improvement Project. A potentially viable cost recovery program is designed using the following criteria: (1) the net benefits of the improvement project are non-negative for all the farmers after making any required payments; (2) the net benefits are the same for all the farmers required to make annual payments, and (3) the total revenue collected each year is equal to the average annual cost of the project. Such a program would require estimated payments of $175 per ha for middle-reach farmers and $412 per ha for tail-end farmers along a typical canal in Egypt’s Irrigation Improvement Project. The net benefits for farmers in each of those groups would be an estimated $102 per ha. Head-end farmers would not be required to pay an annual fee, though they would receive a net gain equal to an estimated $40 per ha reduction in annual pumping costs. Alternative programs that require smaller payments from middle-reach and tail-end farmers, while imposing costs also on head-end farmers, are designed using a combination of fixed and variable charges. Volumetric water charges ranging from $4.00 to $7.00 per 1000 m$^3$ are examined, in conjunction with annual assessments ranging from $40 to $170 per ha. The installation of single-point pumping stations at the head ends of improved tertiary canals provides an opportunity to implement...
1. Introduction

The tertiary portions of large-scale irrigation systems are often operated and maintained by farmers, either individually or in water user associations. In many cases, the lack of well-defined property rights to tertiary canals, and to the irrigation water they carry, results in poorly maintained facilities and inequitable distribution of water among farmers. This generates uncertainty and insecurity regarding water deliveries, particularly among farmers located farthest from main and secondary canals (Bromley, 1982). Efforts to improve water distribution and reduce insecurity may increase aggregate production substantially (Bromley et al., 1980).

Given the lack of well-defined property rights, the inequitable distribution of water, and the financial constraints that are common in many rural areas, public involvement is often required to support the design and implementation of tertiary canal improvement projects. The farm-level demand for such projects may range from very strong along some portions of a tertiary canal to very weak or non-existent along others. Public funding of an improvement project can be justified if the value of increased agricultural production exceeds the total cost, provided that the cost can be recovered from those farmers receiving benefits from the project.

Cost recovery efforts along tertiary canals are made challenging by the variation in potential gains among farmers located at different sites along the canals. Farmers located nearest to a main or secondary canal often have greater (or more secure) access to water than farmers located farthest away. Therefore, head-end farmers may have less to gain from an improvement project than tail-end farmers, and in some cases head-end farmers may prefer that such a project is not implemented (Bromley, 1982, p. 36). A cost recovery program that addresses the variation in net gains from an improvement project may increase the likelihood that a desirable project is implemented and sustained.

The Government of Egypt, with funding from the US Agency for International Development and the World Bank, is implementing a large-scale program to improve tertiary canals in many areas of the Nile Valley and Delta. The goals of the Irrigation Improvement Project are to improve the distribution of water among farmers and to encourage farm-level improvements in water management (Hvidt, 1996; Depeweg and Bekheit, 1997; Hvidt, 1998, p. 6). Key features include the replacement of earthen, below-grade tertiary canals (mesqas) with raised, concrete-lined mesqas or buried pipelines, and the installation of single-point pumping stations to lift water from secondary canals into the new mesqas or into storage tanks that serve the buried pipelines.

The original mesqas are small-capacity earthen ditches that carry water from secondary canals to farm-level ditches. Raising and lining the mesqas, or installing buried pipelines, will eliminate farm-level pumping costs and reduce seepage losses. Farmers along the improved mesqas are required to form water user associations to operate the single-point
pumping stations, manage the delivery of water to farm ditches, and collect fees for operation and maintenance and to reimburse the government for capital expenditures.

A cost recovery program has not yet been implemented to support the Irrigation Improvement Project. Egyptian farmers are accustomed to receiving water at no charge from the Ministry of Public Works and Water Resources, which operates and maintains all main and secondary canals (Ward, 1993; Allam et al., 1994; Hamdy et al., 1995; Nassar et al., 1996; Attia, 1997). While farmers have always operated and maintained the mesqas, they have little experience with capital improvement projects, and they may be reluctant to share in the full cost of improvements that benefit some farmers more than the others. The challenge of developing and implementing a viable cost recovery program in Egypt is similar to that in many countries where the individual benefits of a community-level or regional improvement project vary among the beneficiaries.

This paper describes a framework for evaluating the cost recovery potential of a tertiary canal improvement project that enables farmers to improve the distribution of irrigation water. The concept of irrigation success is introduced to describe the potential gains from such a project, and to analyze the variation in those gains among farmers. The resulting economic model is used to describe the appropriate roles of public agencies in supporting improvement projects and to examine alternative cost recovery programs. The model is applied to the challenge of developing a viable cost recovery program for Egypt’s Irrigation Improvement Project.

2. Economic issues along tertiary canals

Several authors have described the economic and cultural implications of inequitable water distribution among farmers at the head and tail ends of tertiary canals (Bromley et al., 1980; Bromley, 1982; Skold et al., 1984; Chambers, 1988; Bhutta and Vander Velde, 1992a, b) and among villages located at different sites along secondary or main canals (Wade, 1988, 1992; Price, 1995). In many developing countries, property rights to water are not defined and equitable water deliveries to individual farmers are not enforced. As a result, head-end farmers often divert more water than is allocated to them in the delivery scheme, while tail-end farmers receive less than a fair share (Easter and Welsch, 1986a; Shanan, 1992; Sarma and Rao, 1997). Allocative efficiency is not achieved when the incremental value of water on head-end fields is less than the incremental value on tail-end fields (Easter and Welsch, 1986b). Incremental productivity may even be negative on head-end fields if farmers divert excess water to reduce risk or to ensure future access to the resource (Skold et al., 1984; Mondal et al., 1993).

Measures for improving the allocation of water along tertiary canals include physical improvements that reduce seepage and improve the control of water in distributary and tertiary canals, and institutional changes that include forming water user associations, implementing water rights or water prices, and allocating water supplies among farmers (Coward, 1986; Coward and Uphoff, 1986; Wade, 1987; Chambers, 1988; Hecht, 1990; Hunt, 1990; Van Steenbergen, 1992; Meinzen-Dick, 1997). While the aggregate economic benefits of improving a tertiary canal may exceed the total cost, the gains to individual farmers will vary according to their location along the canal. As a result, it may
be difficult for tail-end farmers to persuade head-end farmers to participate in a locally funded and maintained improvement program. This has encouraged public agencies to provide funds for improvement projects, with the goal of recovering some portion of total costs from farmers, over time. However, efforts to recover capital costs and collect funds for operation and maintenance often are not given sufficient attention by project planners (Easter, 1993).

Several problems can arise when public agencies fund the construction, operation, and maintenance of improvements in tertiary canals: (1) input from farmers may be limited, resulting in sub-optimal design of system improvements, (2) ownership of the new or improved systems may be ambiguous, resulting in poor operation and maintenance (Coward, 1986), and (3) collection of revenue to support operation and maintenance may not be successful if farmers resist paying for improvements implemented by the government. In addition, there is often no guarantee that funds collected from farmers by tax collection agencies will be used for operation and maintenance. Finally, the limited amount of public funds available for improving tertiary canals may limit the pace at which desirable improvements are implemented. That pace might be accelerated by using public funds to motivate greater farm-level involvement in improvement activities and greater participation by private sector firms.

3. Defining irrigation success

The primary goal of irrigation, from a farmer’s perspective, is to deliver the volume and quality of water required by plants, throughout a season, to optimize plant growth and crop production. Small and Svendsen (1990) define irrigation as “human intervention to modify the spatial or temporal distribution of water, . . . , and to manipulate all or part of this water for the production of agricultural crops” [italics in the original text]. They suggest that irrigation system performance can be described by three time-dated dimensions: the discharge of water, the area served, and the physical characteristics and composition of the water (Svendsen and Small, 1990). They state that “a continuous record of the values of these dimensions throughout a given season provides all the raw information that is needed, or that is available, to measure irrigation performance for that season.” Chambers (1988) suggests that from a farmer’s perspective, good irrigation service involves the delivery of “an adequate, convenient, predictable and timely water supply for preferred farming practices.”

These perspectives of irrigation goals and performance are used to define the concept of irrigation success, as viewed from a farmer’s perspective. Irrigation success considers the degree to which water volume and quality, and the timing of irrigation events match the requirements of plants throughout a season. Perfect success occurs when the volume, quality, and timing of water deliveries would generate maximum crop yield if other, non-irrigation inputs are not limiting. Actual yield will be less than maximum yield when irrigation success is less than perfect.

Farmers attempting to maximize net revenue, subject to resource constraints, will select irrigation inputs to achieve a desired level of irrigation success. Given positive input prices, the profit-maximizing level of irrigation success will be less than the
maximum value attainable. The existing water delivery and drainage systems will influence a farmer’s ability (and, hence, the cost) to achieve any desired level of irrigation success.

Endogenous variables that determine irrigation success include the volume, quality, and timing of water delivered during a season, the irrigation inputs (such as labor, management, and technology), and the drainage inputs (such as the operation of drainage relief pumps or the volume of drainage water discharged in gravity-flow systems). Exogenous variables include the existing water delivery and drainage systems, as changes in these are beyond the scope of farm-level decisions within any production season. These systems define the opportunities available to farmers regarding irrigation and drainage activities within a season, but changes often require capital expenditures, the involvement of other farmers, and the support of regional water delivery or drainage agencies.

A plausible relationship for irrigation success, which depicts the exogenous role of the existing water delivery and drainage systems is:

\[ S = S(V_C, V_D, Q_C, Q_D, X_I, X_D | \text{Delivery System, Drainage System}) \] (1)

where \( S = S(\cdot) \) denotes a functional definition for irrigation success, \( V_C \) and \( V_D \) represent the volume of canal water and drainage water used in irrigation, \( Q_C \) and \( Q_D \) represent the quality of canal water and drainage water used in irrigation, and \( X_I \) and \( X_D \) are measures of other irrigation and drainage inputs.

This description of irrigation success allows for substitution among inputs as relative prices or availability change, over time. For example, when canal water supplies (\( V_C \)) are limited, farmers may increase the labor and capital (\( X_D \)) used in irrigation or increase the use of drainage water (\( V_D \)) to maintain a given level of irrigation success. Improvements in a water delivery or drainage system may allow farmers to reduce the volume of drainage water or other inputs used in irrigation. Substitution among water volume and quality are also possible.

Crop production can be expressed as a function of the area planted in a crop and the yield per unit area, which varies with the level of irrigation success achieved during a season. In particular, crop yield can be described as an increasing function of irrigation success and non-irrigation inputs, and a decreasing function of soil salinity. A plausible relationship for crop production within any season is:

\[ Y_i = A_i \times y_i(S_i, X_{Ni}, EC_i) \] (2)

where \( Y_i \) is the total production of crop \( i \), in units of output, \( y_i \) is yield per unit area, \( A_i \) is the area planted in crop \( i \), \( S_i \) is a measure of irrigation success, \( X_{Ni} \) is a measure of non-irrigation inputs, and \( EC_i \) is a measure of soil salinity, which is included in the yield function to describe the potential impacts of changes in soil quality, over time. Farmers using saline drainage water as a substitute for canal water must evaluate the long-term implications of that practice.

The conceptual relationship between crop yield and irrigation success may be viewed as one in which crop yield increases as the value of \( S_i \) ranges from zero to one, with the latter value representing perfect irrigation success (Fig. 1). The yield function can be shifted upward or downward with changes in the level of non-irrigation inputs or with changes in soil salinity.
Describing crop yield as a function of irrigation success is consistent with existing literature regarding the role of water in crop production. For example, Doorenbos and Kassam (1979) state the following in their preface to F.A.O. Irrigation and Drainage Paper Number 33: The upper limit of crop production is set by the climatic conditions and the genetic potential of the crop. The extent to which this limit can be reached will always depend on how finely the engineering aspects of water supply are in tune with the biological needs for water in crop production. Therefore, efficient use of water in crop production can only be attained when the planning, design, and operation of the water supply and distribution system is geared toward meeting in quantity and time, including the periods of water shortages, the crop water needs for optimum growth and high yields.

Pandey (1989) provides a similar assessment in his review of crop yield variability, suggesting that the distribution of irrigation water during the growing period is critically important in determining crop yield. Hillel (1990) states that “crops may show a pronounced increase in yield potential when all the controllable variables are optimized so as to avoid any occurrence of moisture stress during the growing season.” Jensen (1968) presents a crop/water production function in which relative yield is determined by the ratio of actual evapotranspiration to potential evapotranspiration during all stages of growth.

Empirical estimates of crop/water production functions reflect the importance of matching water deliveries with crop water requirements. For example, Stewart et al. (1975) and Doorenbos and Kassam (1979) present empirical estimates of crop yield functions in which relative yield is a function of relative evapotranspiration deficit during well-defined stages of plant growth. Dinar et al. (1986) estimate production functions for cotton using the timing and quality of water deliveries. Holzapfel et al. (1985) present data describing strong correlations between relative yield and two measures of irrigation performance (requirement efficiency and deficit efficiency distribution) that describe the
adequacy of irrigation events. Several authors have examined the impact of salinity on empirical crop production functions (Dinar et al., 1985, 1991; Letey and Dinar, 1986; Letey, 1993).

4. An economic model

The total cost of achieving any level of irrigation success is a function of irrigation and drainage technology and the variable inputs used in irrigation and drainage activities. For example, farmers using gravity-flow methods can achieve higher levels of irrigation success by hiring additional irrigators to manage water in furrows or bordered checks more carefully, to minimize the time required to irrigate a given land area. Farmers irrigating with sprinklers can use portable systems that must be moved frequently on large fields, or they can purchase solid-set systems that reduce the time and labor requirements, while increasing the fixed costs of irrigation.

The total cost function for irrigation success will likely exhibit increasing incremental costs, as farmers must employ labor with greater skills and utilize higher technology irrigation systems, such as drip or microsprinklers to match crop water requirements with greater accuracy than is possible with typical, gravity-flow systems.

A set of plausible total revenue and cost curves is shown in Fig. 2. Total revenue has the same shape as the crop yield function, as farmers are assumed to receive competitive market prices. The optimal level of irrigation success, from the farmer's perspective, occurs where incremental revenue equals incremental cost, at $S_i^*$. Net revenue ($NR_i$), which is measured as the vertical distance between total revenue ($TR_i$) and total cost ($TC_i$), is maximized at that level of irrigation success.

The shape of the total cost curve depends on the existing water delivery and drainage systems, as viewed from the farm-level perspective. For example, the total cost function

![Fig. 2. Determining the optimal level of irrigation success, from the farm-level perspective.](image-url)
for farmers served by a pressurized water delivery system in which sprinkler systems can be operated without additional pressure would lie below the total cost function for farmers served by a gravity-flow canal system in which booster pumps are required to support sprinkler systems. Similarly, farmers located at the tail end of a gravity flow delivery system in which the distribution of water among head-end and tail-end farms is uneven would face higher costs of improving irrigation success.

Head-end farmers typically have greater flexibility in scheduling irrigation events and choosing irrigation volumes than do tail-end farmers. In addition, water quality is often better at the head ends of delivery systems, where the proportion of return flows in irrigation water is smaller. Tail-end farmers wishing to achieve greater flexibility may install shallow groundwater wells or pump low-quality water from drains carrying surface runoff and subsurface drain water. Those efforts require labor, capital, and energy that increase the cost of achieving a given level of irrigation success.

Improvements in a water delivery system that provide farmers with greater availability, reliability, or flexibility of irrigation water supply may have one or more impacts on total cost and total revenue: (1) the total cost curve pertaining to irrigation success for a given crop may be shifted downward, (2) the total revenue curve with respect to irrigation success may be shifted upward, and (3) the number of crop alternatives available to farmers may increase as the potential net revenue increases for some crops that are not economically viable before a system is improved.

Some improvements in a delivery system may benefit all farmers along a tertiary canal, while others may provide benefits largely to those at the tail ends of the system. For example, changing a tertiary delivery system from an open canal, gravity-flow system to a pressurized pipeline would lower the variable cost of achieving a greater level of irrigation success for all farmers. Similarly, replacing a below-grade, earthen ditch with an abovegrade, lined canal would reduce pumping costs for all the farmers using the tertiary canal.

Changes in a delivery system that improve the equity of water distribution along a tertiary canal, so that tail-end farmers are able to receive a more reliable supply of canal water, shift the total cost curves for those farmers downward. The direction and degree of shifting will vary among farms according to their location along the tertiary canal. The total cost curve for farmers located near the head end of tertiary canals might shift upward as a result of improvements that enable a more uniform distribution of water among farmers.

Two sets of plausible total revenue and cost curves for tail-end and head-end farmers, before and after an improvement in a water delivery system, are shown in Fig. 3. In the first set (Fig. 3(A,B)), both the farmers would be able to increase their level of irrigation success, and their net revenue, as a result of the improvement project. The potential gain in net revenue \( (NR^a - NR^b) \) is greater for the tail-end farmer, as the improvement causes a proportionately greater downward shift in that farmer’s total cost curve. The total revenue curve is assumed to be the same for both farmers in that example, and does not change as a result of the improved water delivery system.

The second example (Fig. 3(C,D)) depicts total revenue curves that shift upward for tail-end farmers, while total cost curves shift downward for both tail-end and head-end farmers. This would occur if pumping costs were reduced for all the farmers along a
tertiary canal, while tail-end farmers also benefit from an increase in the reliability of their canal water supply. This enables tail-end farmers to choose higher valued crops that are not economically viable when water supplies are unreliable. Alternatively, tail-end farmers might gain availability of canal water supplies, enabling them to reduce soil salinity to levels that will support higher valued crops.

In either of the examples described above, the maximum payment that a farmer would be willing to make to secure an improvement in the water delivery system is the present value of the future increases in net revenue made possible by the improvement. The sum of these values among all the farmers is the change in the present value of net returns (PVNR) generated by the project:

$$\text{Change in PVNR} = \sum_{j=1}^{J} \sum_{t=0}^{T} \Delta NR_{jt} (1 + r)^{-t}$$

(3)

where $\Delta NR_{jt}$ is the potential change in net revenue for one farmer in year $t$, $r$ is the discount rate, $t = 0, \ldots, T$ years, and $j = 1, \ldots, J$ farmers.
Eq. (3) describes the relationship between one farmer’s potential gains from an improvement in the water delivery system and the potential gains to all farmers. In most cases, the potential gains to any one farmer will be a small portion of the total potential gains, and the farm-level gains may vary considerably with location along a tertiary canal. That variation, and the transaction costs of organizing a group of farmers to design, construct, and maintain an economically viable project, may prevent such an effort from going forward. As a result, some farmers may request that a public agency design and construct such a project using public funds, with or without support from a donor agency. However, it may not be necessary, nor efficient, for a public agency to pay for design and construction. The appropriate role of a public agency and the potential for recovering costs can be determined by examining the expected costs and benefits in a bid-rent framework.

5. Bid-rent analysis

The variation in farm-level changes in net revenue that occur when a tertiary canal is improved can be examined using bid-rent curves that describe the maximum amount each farmer would be able to pay each year to secure an improvement project. That amount, which varies with location along the canal, is precisely the annual potential net gain from the improvement for each farmer, or the $\Delta NR_{jt}$ term in Eq. (3). The potential net gains likely increase with distance from the head end of the canal, as tail-end farmers are likely to gain more than head-end farmers from an improvement project.

A conceptual version of a bid-rent curve is shown in Fig. 4, where the maximum ability to pay for the improvement is plotted with the inverse of distance from the head end of the tertiary canal. Each point on the downwardsloping bid-rent curve represents one farmer’s ability to pay for the improvement, and the area under the curve represents

![Bid-Rent Curve](image_url)

Fig. 4. Bid-rent curve depicting the maximum ability to pay for a tertiary canal improvement.
the annual value of the benefits of the project, or the sum of potential gains for all farmers. The bid-rent curve in Fig. 4 describes a project that generates potential gains for all farmers, including those at the head end of a tertiary canal.

A group of farmers or a public agency considering an improvement project can use an empirical version of the bid-rent curve in Fig. 4 and information describing the total cost of implementing and maintaining an improvement to determine if the project can be justified economically, to examine the appropriate roles of public agencies in supporting or financing the project, and to advise water user associations regarding cost recovery alternatives. Bid-rent curves are very similar to demand curves in economic analysis, as they describe the ability of farmers to pay for system improvements, which is determined by the farm-level incremental benefits. The area under a bid-rent curve, and above a pertinent cost curve, describes the cumulative net benefits of an improvement project.

5.1. Net benefit scenarios

Four scenarios can be described regarding the relationship between the potential gains in net revenue from crop production and the cost of improving a water delivery system. The scenarios vary according to the estimated net benefits of the project and the impact on farmers at different locations along a tertiary canal. The economic viability of an improvement project, the importance of transaction costs, and the appropriate roles of public agencies in supporting or financing a project vary among the four scenarios.

An improvement project that generates potential gains in net revenue for all farmers along a tertiary canal is described by a bid-rent curve that lies above the average cost curve at all distances from a main or secondary canal (Fig. 5(A)). The total cost of the project is the area beneath a horizontal line representing the average cost per unit area served by the tertiary canal. The average annual cost curves in Fig. 5 include the amortized cost of design and construction, and the annual cost of operation and maintenance. Each farmer in this scenario (Fig. 5(A)) could afford to pay the average annual cost and still earn greater net returns than were possible before the project was implemented. The aggregate net benefits of the project are represented by the area below the bid-rent curve and above the average cost line, denoted as Area A in Fig. 5(A).

The improvement project in this scenario is economically viable, as the potential increase in net returns exceeds the average cost at all locations along the tertiary canal. The appropriate roles of public agencies in this scenario include reducing transaction costs and providing financing for farmers who are unable to obtain such support from commercial sources. For example, a public agency might assist farmers in forming an organization to design and construct the project, with funds collected from farmers. Such assistance might include disseminating information regarding project benefits among farmers and scheduling meetings to discuss project plans and alternatives. A public agency might also assist a farmer organization in developing an effective cost recovery program. Given that project benefits exceed the average cost for all farmers, public agencies should be able to recover the costs of their efforts from farmers.

The potential gain in net revenue may be less than the average cost per unit area for head-end farmers who do not gain appreciably from the improvement of a tertiary canal. Such a scenario (Fig. 5(B)) may require that tail-end farmers and those located in the
middle portion of a tertiary canal pay a greater portion of the total cost of project design and construction than farmers located at the head end of the system. The transaction costs of forming a local organization will likely exceed those of the previous scenario, because farmers must determine and agree upon the cost structure, which might include payments that vary according to location along the tertiary canal.

The appropriate roles of public agencies in this scenario are similar to those in the previous one, though greater effort may be required in forming a local organization and designing a viable cost recovery program. The importance of public involvement may be greater in this scenario, because the higher transaction costs may preclude formation of a local organization and prevent the project from going forward without public agency involvement. This would result in a loss of potential aggregate net benefits along the tertiary canal, shown as Area A – Area B in Fig. 5(B).

In regions where water is scarce and there is considerable inequity in the distribution of water among head-end and tail-end farmers, a project designed to achieve greater equity of distribution may cause the total cost curve regarding irrigation success to shift upward.

![Fig. 5. Bid-rent curves and average cost curves for a tertiary canal improvement project. Note: The horizontal axis in each graph describes the inverse of distance from the head end of a tertiary canal.](image-url)
for head-end farmers, resulting in a potential loss in net revenue. Other farmers near the head end of the tertiary canal may experience a potential gain in net revenue that is less than the average cost of the project. The aggregate economic benefit of the project may be positive, but some farmers will require compensation to gain their voluntary support for the project. Such a scenario is depicted in Fig. 5(C), in which the aggregate net gain of the project is shown by Area A

\[ \text{Area B}. \]

The appropriate roles of public agencies in this scenario are similar to those in the previous two cases, though the optimal level of public effort may increase with the number of farmers who would lose net revenue if required to pay the average annual cost of the project. Conceptually, it is possible for those who benefit from the project to compensate those who would lose net revenue, while retaining a net gain sufficient to justify the project. However, the transaction costs required to determine the farm-level effects of such a project at each location along a tertiary canal could be substantial, requiring greater efforts by public agencies or a farmer organization.

An improvement project that would impose costs on head-end farmers and those located along the middle portion of tertiary canals in excess of the benefits made available to tail-end farmers is not economically viable and could not be sustained by a farmer organization. Demand for such a project, depicted in Fig. 5(D), may arise from tail-end farmers who would gain net revenue if the project were implemented. However, the compensation required to obtain the support of head-end farmers and others who would lose net revenue if the project were implemented would exceed the potential gains. The aggregate economic loss from such a project is shown as Area A

\[ \text{Area B}. \]

Public agencies may be requested to subsidize design and construction of a non-viable project by tail-end farmers who would benefit from implementation. However, the use of public funds could be justified only if the project generates public benefits that are not depicted in the bid-rent curve, such as the improvement of incomes for tail-end farmers who have been impoverished by their location along the tertiary canal, or a temporary increase in employment and local economic activity during design and construction of the project.

5.2. Research, development, and support

The appropriate roles of public agencies wishing to improve tertiary-level water delivery systems include providing information to farmers about potential improvements, helping to organize farmer organizations, and providing loans to assist farmers with the cost of design and construction (Meinzen-Dick, 1997). A public agency might also wish to support research and development of more cost-effective methods for improving tertiary delivery systems. In addition, it may be appropriate to encourage the formation of small firms that can provide repair parts and technical assistance required to maintain system improvements (Johnson et al., 1998).

Researchers supported by public funds might discover that lower cost materials can be used to improve a delivery system, thereby reducing construction costs. Similarly, researchers might suggest a change in delivery system design that lowers the annual costs of operation and maintenance. Annual costs could also be reduced by forming a network
of rural supply and repair centers at which farmers could obtain repair parts and technical assistance for maintaining system improvements. Such a network or a group of companies providing these services would likely be most efficient if formed within the private sector. However, public sector support may be helpful in stimulating development of this activity, either through investments in infrastructure, such as paved roads or electrical service, or through low interest loans to small firms willing to enter the market. Reductions in either the capital cost of system improvements or the annual costs of operation and maintenance would be reflected in a downward shifting of the average cost curve. In some cases, this will enhance both the economic viability of an improvement project and the likelihood that farmers will form an organization to implement and maintain the improvement. Public expenditures for research, development, and stimulation of private sector support services might be justified by the benefits provided to many groups of farmers throughout an irrigated region or country.

6. The example from Egypt

The US Agency for International Development provided financial support for the first phase of Egypt’s Irrigation Improvement Project, in which tertiary canals serving about 24,000 ha were replaced during 1989 through 1996. The World Bank has implemented a second phase of the project, beginning in 1997 and ending in 2002, with the goal of improving tertiary canals serving an additional 104,000 ha. The total area served by the USAID and World Bank projects is about 5% of the irrigated farmland in Egypt.

The Irrigation Improvement Project has been justified economically on the basis of expected increases in crop yields on 60% of the land served by the improved mesqas (World Bank, 1993). Water supply and reliability will improve for middle-reach and tail-end farmers, enabling them to maintain better soil quality, over time, and to match water deliveries with water requirements more accurately than is possible with un-improved mesqas. Comparison of project costs with the expected gains among farmers along the improved mesqas provides insight regarding the project’s net benefits and the potential for implementing a viable cost recovery program.

The largest cost component of the Irrigation Improvement Project is an estimated $927 per ha for improving or replacing a mesqa and installing a single-point pumping station (Table 1). The cost of installing downstream control structures and other improvements in main and secondary canals to enable continuous flow of water in those channels is an estimated $183 per ha, resulting in a total structural cost of $1,110 per ha. Additional charges summing to $235 per ha are included in the budget for communications and support services, and a charge of $411 per ha is included for contingencies.

The World Bank has estimated that the project will generate an economic rate of return of 25%, but farmers may not be able to repay all project costs if they are required to pay interest on the loan. The World Bank recommends that farmers repay the $1110 per ha cost of upgrading the main and tertiary delivery systems. The Government of Egypt has agreed that farmers will be required to repay capital costs for the single-point pumping stations and other civil works over a period of 10–20 years, and that operation and maintenance costs will be paid by farmers directly to water user associations (World
In this analysis, we amortize all costs over a 20-year project life, using a 12% discount rate that represents the current opportunity cost of capital in Egypt. We then compare the amortized cost of physical system improvements and the annual operating and maintenance costs with expected farm-level benefits. We select this approach because other project activities may generate public benefits that are beyond the scope of farm-level economic considerations. For example, the benefits of establishing institutional support and communication services may accrue to non-farming members of the general public. However, the bid-rent framework can be used to analyze those cost components, if desired.

6.1. Empirical bid-rent analysis

The World Bank Project is being implemented at three locations in the Nile River Delta (Mahmoudia in the Beheira Governorate, and Manaifa and El Wasat in the Kafr El-Sheikh Governorate), where problems of water distribution are causing yield reductions at the tail ends of mesqas (World Bank, 1994, p. 5). The World Bank estimates that yields of winter crops are 10–20% lower at tail ends of mesqas than at head ends, while the yields of summer crops are 30–40% lower at the tail ends. Yield reductions in summer are particularly severe due to the ‘inadequate and untimely supply of water’ at the tail ends. Crop establishment and growth may be delayed at tail ends in both seasons due to delays in water deliveries.
World Bank (1993) (pp. 94–97) crop yield and production cost information is used to construct a representative bid-rent curve for improvements in the tertiary delivery system. Estimated net returns are presented for four major crop rotations in the Nile River Delta (Table 2). Pre-project net returns for tail-end farmers have been estimated by reducing head-end crop yields by 15% for winter crops (short and long berseem, and wheat) and by 35% for summer crops (cotton, maize, and rice). The estimated difference in net returns for head-end and tail-end farmers is viewed as the potential increase in net returns that will be observed by tail-end farmers when a mesqa is improved. For example, the short berseem/cotton rotation generates an estimated net return of $728 per ha for head-end farmers, while tail-end farmers earn an estimated $232 per ha. The average difference in estimated net returns for all crop rotations in Table 2 is $474 per ha.

The World Bank (1993) (p. 31) estimates that about 60% of the 104,000/ha project area would benefit from the improvement project, given the pre-project distribution of water in tertiary canals. We use this information and the estimated differences in net returns among head-end and tail-end farmers to construct a conservative version of an empirical bid-rent curve for mesqa improvement. In particular, we assume that crop yields will not increase for head-end farmers, who represent 40% of land in the project area. Remaining farmers are divided into two groups representing middle-reach farmers (30%) and tail-end farmers (30%), and we assume that the increase in net returns for middle-reach farmers will be one-half of the estimated increase in net returns for tail-end farmers. We also assume, in accordance with World Bank estimates, that annual pumping costs for all farmers will be reduced by about $40 per ha, when below-grade mesqas are replaced with raised ditches or pressurized pipelines.

We consider a representative 40-ha mesqa service area that includes 16 head-end farmers, 12 middle-reach farmers, and 12 tail-end farmers, each with 1 ha of land. The

### Table 2
Estimated net returns for typical crop rotations

<table>
<thead>
<tr>
<th>Crop rotation</th>
<th>Dollars per hectare</th>
<th>Head-end</th>
<th>Tail-end</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short berseem</td>
<td></td>
<td>205</td>
<td>143</td>
<td>62</td>
</tr>
<tr>
<td>Cotton</td>
<td></td>
<td>523</td>
<td>89</td>
<td>434</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>728</td>
<td>232</td>
<td>496</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>480</td>
<td>339</td>
<td>141</td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td>345</td>
<td>39</td>
<td>306</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>825</td>
<td>378</td>
<td>447</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>480</td>
<td>339</td>
<td>141</td>
</tr>
<tr>
<td>Rice</td>
<td></td>
<td>428</td>
<td>58</td>
<td>370</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>908</td>
<td>397</td>
<td>511</td>
</tr>
<tr>
<td>Long Berseem</td>
<td></td>
<td>565</td>
<td>435</td>
<td>130</td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td>345</td>
<td>39</td>
<td>306</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>910</td>
<td>474</td>
<td>436</td>
</tr>
<tr>
<td>Average of these rotations</td>
<td></td>
<td>843</td>
<td>370</td>
<td>474</td>
</tr>
</tbody>
</table>

Source: Estimates of head-end net returns are from crop budgets in the World Bank Country Study: Arab Republic of Egypt, 1993, Table 1, pp. 94–97.
average farm size in the World Bank study area is about 1 ha (World Bank, 1993, p. 5) and mesqas in the Nile Delta typically serve areas of 25–50 ha. The expected increases in net returns and reductions in pumping costs are compared with the average annual cost of the project (Fig. 6), which includes the amortized cost of physical improvements ($149 per ha from Table 1) and the estimated annual cost of operation, maintenance, and administration ($27 per ha, from the World Bank, 1994, p. 86). The average annual cost ($176 per ha) is higher than the estimated bid-rent for head-end farmers ($40 per ha), but lower than the estimated bid-rents for tail-end and middle-reach farmers ($514 and $277 per ha), which include the estimated $40 per ha reduction in pumping costs.

The estimated bid-rent and average cost curves in Fig. 6 resemble those in Fig. 5(C), in which the project is economically viable, but some farmers would lose net revenue if required to make payments equal to the average annual cost of the project. Clearly, the head-end farmers would not be eager to pay $176 per year for a project that provides a benefit of $40 per ha. An alternative repayment scheme in which the annual payments vary among farmers according to the net gains they receive from the project may be appropriate.

6.2. Cost recovery analysis

Information in the bid-rent and average cost curves can be used to examine alternative cost recovery programs, with the goal of designing a program that is affordable and acceptable to all farmers sharing an improved mesqa. This is possible, conceptually, if the aggregate net benefits of an improvement project are positive. However, selecting program parameters and implementing the program are made challenging by the variation in net gains among farmers.

Two criteria that may be useful in designing a viable cost recovery program include: (1) allowing all farmers to retain a positive net gain from the improvement project, and
(2) collecting sufficient revenue to pay for the average annual cost of the project. A third criterion that may improve the likelihood of acceptance is that the net gains from the project are equal among all farmers making annual payments. This may require that some farmers who gain relatively little from the project are not asked to pay annual fees. For example, the head-end farmers gaining only the $40 per ha reduction in pumping costs might not be asked to make annual payments. These three criteria can be summarized as follows:

1. The net benefits of the project, after making any required payments, are non-negative for all farmers using the improved mesqa;
2. The net benefits are the same for all farmers required to make annual payments, and
3. The total revenue collected from farmers each year is equal to the average annual cost of the project.

The average annual cost of physical improvements and operation and maintenance for the mesqa improvement project is $176 per ha. The annual payments that satisfy criteria (1), (2), and (3) are $175 per ha for middle-reach farmers and $412 per ha for tail-end farmers. The net gain for those farmers would be $102 per ha. Head-end farmers would not be required to pay an annual fee in this program, though they would receive a net gain equal to the $40 per ha reduction in annual pumping costs.

This cost recovery program generates large differences in annual payments from farmers, even though the net gains from the project are equal for all the farmers making payments. Such a program may be difficult to implement by a water user association charged with operating and maintaining an improved mesqa for the general benefit of all farmers. An alternative cost recovery program that equates the payment required from all farmers may also be difficult to implement, given the estimated variation in net gains along an improved mesqa. As noted above, an average annual payment of $176 per ha would not be approved by head-end farmers receiving a pre-payment benefit of only $40 per ha.

The relatively large fee required from tail-end farmers can be reduced by implementing an alternative program in which annual payments from middle and tail-end farmers are the same, and a volumetric water delivery charge is implemented for all the farmers. For example, the annual fee could be reduced to $170 per ha for both middle and tail-end farmers if a water delivery charge of $4.00 per 1000 m$^3$ is implemented. That program would generate an average total cost of $80 per ha for head-end farmers and $250 per ha for middle and tail-end farmers, assuming that farmers purchase 20,000 m$^3$ of water per ha during a two-crop annual rotation (Table 3, Program A).

Alternative versions of a cost recovery program that include both an assessment per hectare of land and a water delivery charge are shown in Table 3. Program B includes a smaller land assessment for middle and tail-end farmers, and a water price of $6.00 per 1000 m$^3$, while Program C requires all farmers to pay an assessment of $40 per ha, and a water charge of $7.00 per 1000 m$^3$. The average cost of Program C is the same for all farmers. All of the programs in Table 3 generate at least $7040 in revenue each year, which is the annual cost of the project for the representative 40 ha mesqa service area.

Combining a fixed annual land assessment with a variable charge for water enhances the flexibility available to public officials when designing a viable cost recovery program. In addition, a variable charge for water may be useful in motivating improvements in
farm-level water use efficiency. Some of the programs described here may not be viewed as acceptable by all farmers sharing an improved mesqa. For example, head-end farmers who are accustomed to receiving a relatively abundant supply of water at no charge will likely resist paying for water at any price. As a result, a public subsidy may be required to gain acceptance of a desirable improvement project, in conjunction with a cost recovery program that recovers some portion of total costs.

Analysis of bid-rent curves and the cost recovery framework presented in Table 3 will enable public officials to evaluate the potential viability of alternative cost recovery programs and to select an appropriate combination of land assessments, water prices, and public subsidies. Water prices in the range of $4.00–$7.00 per 1000 m³ are reasonable by western and Middle Eastern standards, but at present there is no charge for irrigation water in the Nile Delta. However, future water policies may include a method for implementing water charges in Egypt (Abu-Zeid and Hefny, 1992).

Technical issues regarding water measurement and the empirical relationship between price and quantity demanded can be analyzed, over time. For example, the assumption that farmers will demand 20,000 m³ of water at any price ranging from $4.00–$7.00 per 1000 m³ can be revised as data become available for estimating price responsiveness. In addition, it may be necessary to collect water delivery charges in the form of a flat fee per hectare of land in areas where volumetric measurement of water is not yet feasible.

7. Concluding remarks

Successful efforts to recover the costs of tertiary canal improvement projects will enhance the likelihood that improvements will be operated and maintained, over time,
and that public agencies and donor organizations will continue to support such projects. Cost recovery efforts are often quite challenging because the potential gains from an improvement project vary among farmers according to their location along the canal. In addition, the inequitable distribution of water prior to an improvement project may generate concern among individual farmers regarding their share of the potential benefits.

The economic model presented here can be used by public officials and water agency staff when considering the design and support of tertiary canal improvement projects. Bid-rent curves depicting the variation in potential gains from a project are developed using the concept of irrigation success, which describes the degree to which water volume and quality, and the timing of irrigation events match the requirements of plants throughout a season. The bid-rent curves, when combined with the average cost information, can be used to examine economic viability, to determine the appropriate roles of public agencies in financing and supporting improvement projects, and to evaluate cost recovery programs.

An empirical bid-rent curve for Egypt’s national Irrigation Improvement Project depicts the variation in potential net gains among farmers along an improved tertiary canal. Cost recovery programs that enable all farmers to retain a positive net gain from the improvement project involve annual payments that vary considerably among head-end, middle-reach, and tail-end farmers. That variation is reduced in alternative programs that include both a land assessment and a volumetric water delivery charge. The installation of single-point pumping stations at the head ends of improved canals provides an opportunity to implement volumetric charges in cooperation with water user associations.

Acknowledgements

This paper is Rhode Island Agricultural Experiment Station Publication Number 3705. The comments of the two anonymous reviewers are appreciated.

References


