AN ECONOMIC APPROACH TO IMPROVING WATER MANAGEMENT IN WATERLOGGED AND SALINE AREAS

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ABSTRACT

Waterlogging and salinization arise in arid areas largely because two essential resources, irrigation water and the assimilative capacity of unconfined aquifers, are not priced or allocated correctly to reflect scarcity values and opportunity costs. Farm-level decisions regarding irrigation methods and water volumes will not be socially optimal when such values are not communicated to farmers in the prices they pay for irrigation and drainage resources, or in allocations that define their water supply or drainage capacity. Modifying farm-level prices and allocations may be helpful in reducing the rate of increase in waterlogged and saline areas in many regions.

This paper describes why farm-level irrigation and drainage strategies often differ from those that would be considered socially optimal. In the absence of appropriate economic incentives, farmers are not encouraged to consider the off-farm and long-term impacts of their decisions regarding irrigation and drainage inputs. Policies that can be implemented to provide such encouragement include volumetric water pricing, water markets, tradable water allotments, adjustments in area-based cost recovery programs, and incentives for farmers to use irrigation methods that reduce deep percolation.

WATERLOGGING AND SALINIZATION

Waterlogging and salinization have reduced the productivity of agricultural land in arid regions since the rise and fall of Mesopotamia, even though the irrigation-induced causes of these conditions have been known for nearly as long (Jacobsen and Adams, 1958; Kovda, 1983; Szabolcs, 1987; Ghassemi et al., 1995). Known also as the "twin menace" of irrigated agriculture, waterlogging and salinization affect most of the world's large-scale irrigation systems and they continue to impose farm-level and public costs in the form of lost production and efforts to reduce the rate of increase in affected areas.

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Waterlogged and saline soils are found naturally in many areas, but inappropriate irrigation also causes waterlogging and secondary salinization, resulting in economic losses when crop yields are reduced by high water tables and soil salinity (Barrow, 1987, 1991; Szabolcs, 1987; Rhoades, 1990; Smedema, 1990; Dregne, 1991; Abdel-Dayem, 1997). The primary irrigation-induced causes include leakage from poorly lined irrigation canals and reservoirs, excessive water application, and inadequate drainage of agricultural land (Barrow, 1991; Scott, 1993). Seepage from irrigation facilities and deep percolation from farm fields enter unconfined aquifers that have become saline after many decades of irrigation. When a water table rises within 2 m of the soil surface, the root zone available to plants becomes restricted, salts rise to the surface by capillary action, and the resulting salinization can render land unsuitable for agriculture (Stone, 1984, p. 141; Arnon, 1987 p. 147; Abernethy and Kijne, 1993; Abrol and Sehgal, 1994; Hillel, 1994).

Some deep percolation is required in arid regions to remove salts from the root zone and sustain productivity, over time (Oster, 1984; Hoffman, 1990; Rhoades and Loveday, 1990). However, actual leaching fractions often exceed leaching requirements, because the non-water costs of irrigation rise with farm-level efforts to increase irrigation efficiency (Letey et al., 1990; Dinar and Zilberman, 1991). In addition, many water allocation and pricing policies do not motivate farmers to use water efficiently (Abrol et al., 1988; Prasad and Rao, 1991; Sampath, 1992; Meinzen-Dick and Mendoza, 1996; Rosegrant and Meinzen-Dick, 1996). Excessive deep percolation occurs in rotational water delivery systems in which farmers irrigate according to calendar-based schedules that do not match crop water requirements (Dhawan, 1989; Qureshi et al., 1994). In many systems, water prices are too low to encourage farm-level improvements in water management or to justify investments in irrigation methods that minimize deep percolation (Mageed, 1994; Hillel, 1994, p. 217).

AN ECONOMIC PERSPECTIVE

From an economic perspective, irrigation-induced waterlogging and salinization in arid areas arise largely because irrigation water and the assimilative capacity of unconfined aquifers are not priced or allocated correctly to reflect scarcity values and opportunity costs. Volumetric water prices are lower than optimal or non-existent in many irrigated regions, and allocation procedures are often based on rotational schedules that do not provide the flexibility or certainty required for farmers to optimize water use. In most irrigation systems, farmers may "discharge" deep percolation to unconfined aquifers at no charge and with no restrictions, even though assimilative capacity is often limited. As a result, the scarcity values of irrigation water and unconfined aquifer capacity are not communicated to farmers in resource prices or allocations, providing them with little incentive to consider the opportunity costs or the off-farm effects of irrigation and leaching activities.

Some Useful Economic Concepts

Opportunity cost is the incremental value of a resource or input in its next best alternative use. For example, when a farmer's water supply is limited, the opportunity cost of water used to irrigate a tomato field is the value that could be generated if that water were used instead to irrigate a cotton field.

Scarcity value is the implicit value of a limited resource that may or may not be priced in a market setting. For example, the scarcity value of water on a farm with a limited water supply is the value that could be generated with an additional acre-foot of irrigation water.

A socially optimal allocation of resources maximizes the net benefits generated in production, minus any costs that are not generally considered by firms or consumers, such as the environmental or off-farm effects of irrigation and drainage activities. The socially optimal combination of inputs and outputs will differ from the farm-level profit-maximizing combination when farm activities generate external costs. The social optimum will vary, over time, with changes in society's preferences regarding resource allocation.

External costs and benefits are the off-farm effects of agricultural activities. These generally are not considered by farmers when choosing profit-maximizing input and output combinations. Economic incentives such as effluent fees and cost-sharing programs for improving irrigation technology are designed to encourage farmers to consider external costs and benefits.

A discount rate can be used to describe the preference of an individual or society for receiving net returns or net benefits in the near term, rather than receiving those returns or benefits in future years. Higher discount rates describe stronger time preference. For example, an individual with a discount rate of 6% would prefer to receive net returns more quickly than an individual with a discount rate of 4%, if all other characteristics of the individuals are the same. The discount rates of individual firms and consumers will be higher than social discount rates if society places greater emphasis on net benefits available to future generations.

Off-farm effects are considered external costs in economic models of farm production because they are not paid by farmers when selecting crops or choosing irrigation inputs (Young and Horner, 1986; Chisholm, 1987; Upstill and Yapp, 1987; Ellis, 1992, p. 264; Izac, 1994; Strojan, 1995). Economic incentives and other policies that encourage farmers to internalize external costs can be identified by examining the farm-level and public goals regarding irrigation, and noting the differences in optimizing criteria that describe how farm-level and societal net benefits are maximized. Appropriate policies will provide farm-level incentives that are consistent with the criteria for maximizing societal net benefits.

Farm-Level Goals and Criteria

The farm-level irrigation objective can be described as maximizing the present value of net revenue, over time, while maintaining the quality of productive resources. The standard optimizing criterion for farmers in a humid region where soil salinity is not a problem is to equate the incremental value of water in crop production with its incremental cost, or price (Upton, 1996, Ch. 9). Incremental values are determined by crop-water production functions and crop prices, while water cost may be an explicit price for surface water delivery or the unit cost of pumping groundwater (Howell, 1990; Dinar et al., 1991). As water price or cost increases, farmers will reduce the volume of water applied, often by increasing the use of labor or technology to maintain crop yields, while irrigating more efficiently.

In arid regions, farmers must also consider the long-term impacts of irrigation and leaching on soil salinity. The net change in salinity is usually positive following irrigation events because plants use the water, while leaving salts in the soil. Leaching events displace salts from the profile by flushing soils with relatively good quality water. The farm-level optimizing criterion for saline areas includes the long-term impact of adding salts and the long-term benefit of moving salts through the soil profile when applied water exceeds crop water requirements.

Farmers in arid regions will achieve their profit maximizing goal if they equate the incremental value generated with irrigation or leaching water, plus the value gained by removing salts from the soil, with the price paid for water and the long-term, incremental damage caused by adding salts. Farmers will consider similar issues when selecting irrigation methods and water management practices. Surface irrigation methods (furrows, borders, and basin) are less expensive than sprinklers or drip systems, but they can also be less efficient and can generate more deep percolation during irrigation and leaching events. Farmers using more efficient methods can achieve irrigation goals with a smaller volume of water and they can achieve greater distribution uniformity that may enhance crop yields (Barrow, 1987, Ch. 7; Letey et al., 1990; Agnew and Anderson, 1992, Ch. 6).

Public Goals and Criteria

The public's goal regarding a publicly funded irrigation project may be described as maximizing the present value of societal net benefits generated, over time. Societal benefits include the value of farm products and other agricultural and non-agricultural benefits provided by an irrigation project, while costs include farm-level production costs, operation and maintenance of irrigation facilities and any off-farm impacts of irrigation and leaching. Societal costs also include the opportunity costs of water resources in regions where demand for water exceeds supply.

The net social benefit of an irrigation project is maximized when the incremental social benefit is equal to the incremental social cost. In particular, the sum of incremental agricultural and non-agricultural benefits must be equal to the incremental cost of water delivery, plus the long-term cost of adding salt during irrigation and leaching, the opportunity cost of water, and the long-term cost of rising water tables.

Farm-level decisions regarding water use will not be socially optimal unless water prices reflect incremental delivery costs, opportunity costs and the off-farm impacts of irrigation and leaching activities. In addition, farm-level discount rates used to calculate the present value of the long-term costs and benefits of irrigation and drainage activities must be the same as social discount rates. In practice, farm-level rates will likely exceed those used by the public to evaluate returns from irrigation projects, as individuals often place greater relative values on near-term net revenues than public agencies, which may assign greater relative value to the welfare of future generations (Sen, 1984, p. 175). When this occurs, farm-level choices regarding irrigation water and other inputs may result in a faster rate of waterlogging and salinization than is socially optimal (Quiggin, 1987; Greiner, 1997). This effect, in combination with inappropriate water prices and allocation methods, may explain why many large-scale irrigation projects encounter problems of waterlogging and salinization sooner than expected by project planners (Abul-Ata, 1977; Kapoor and Kavdia, 1994; Ramanathan and Rathore, 1994).

POLICY IMPLICATIONS

Differences in the criteria for maximizing the present value of farm-level or societal net benefits explain why farm-level choices of irrigation and leaching inputs are not socially optimal. Farmers have no economic incentive to consider the external effects of deep percolation on a regional water table and farm-level discount rates may exceed the social rate. In addition, farm-level water use will exceed the social optimum when the price of water is less than the incremental cost of delivery or when farmers are not presented with opportunity costs. Farm-level choices of water management inputs will also differ from societal optima when prices do not reflect off-farm effects. Policies that modify the farm-level price or availability of water and other inputs may be useful in closing the gap between farm-level and socially optimal input choices. We examine the potential role of water pricing and allocation policies, water markets, land assessments, and subsidies to encourage improvements in water management practices.

Water prices

Economic theory suggests that if the farm-level price of water includes the incremental delivery cost, the opportunity cost, and the long-term impact of rising water tables, farmers will choose the socially optimal levels of water use. In theory, the optimal water price should vary among farms according to differences in delivery costs and the impacts of irrigation and leaching on regional water tables. However, in most irrigated areas farm-specific water table effects cannot be estimated accurately, and farm-specific water prices are either very costly to implement or politically infeasible. A uniform water price, or a price that varies by region, is more likely to be implemented. In those situations, an estimate of average water table effects can be obtained using hydrologic data that describe irrigation water deliveries and rising water tables, over time, or technical coefficients that describe the proportion of applied water that becomes deep percolation when using various irrigation methods. The estimated average value could be used in place of farm-specific values when determining a uniform water price.

The opportunity cost of water can be estimated by considering the increase in regional net revenue that could be generated with additional water supply. In regions with an active water market, this may be estimated using water market prices, as these would reflect a major component of the opportunity cost of water. The incremental cost of water delivery includes operation and maintenance costs for the water delivery system. The portion of those costs that should be included in water prices may vary with public goals and the distribution of benefits from irrigation projects (Sampath, 1992).

Implementing a uniform water price in place of farm-specific prices will negate some of the efficiency gains implied by optimal water prices, but this should not dissuade public officials from considering a uniform pricing policy. In many irrigated regions, any effort to implement or enhance volumetric water prices will likely motivate farm-level improvements in water management that will improve the productivity of scarce water resources and reduce deep percolation. The societal value of this result may be substantial, even if water prices are not precisely the optimal prices prescribed by theory.

Volumetric water prices may also provide an economic incentive for public water agencies to improve delivery service and to reduce seepage along main and secondary canals, particularly if agency budgets are made dependent upon the collection of revenue from water sales (Moore, 1989; Small and Carruthers, 1991, pp. 52-53; Ellis, 1992, p. 271). Water agency personnel in regions where water is delivered at no charge to farmers and water rights are not assigned have little incentive to spend limited funds on canal improvement projects (Repetto, 1986). Placing a value on water at the agency level may reduce waterlogging and salinization caused by seepage from main and secondary canals.

Water markets and water rights

Formal and informal water markets are effective in communicating scarcity values among potential buyers and sellers, by providing farmers with an opportunity to lease or sell a portion of their water supply for a specific time interval or in perpetuity (Dudley, 1992; Rosegrant and Binswanger, 1994; Rosegrant and Meinzen-Dick, 1996; Dinar et al., 1997). Markets also encourage farmers to consider opportunity costs explicitly when they choose cropping patterns and irrigation methods (Dinar and Letey, 1991; Weinberg et al., 1993). Farmers with attractive market opportunities may choose to improve water management practices to make water available for sale or lease. Farm-level efforts to "convert" surface runoff or deep percolation into marketable water volume will reduce pressure on regional water tables. In areas where surface runoff or deep percolation is used by downstream farmers, it may be necessary to compensate those farmers for reductions in their water supply.

Water markets eliminate the need for public agencies to determine the opportunity cost or scarcity value of water, as market participants will express their desire to purchase or sell water at prices that reflect prevailing perceptions of scarcity. However, markets do require that property rights to water, or water use rights, are defined and enforced (Hearne and Easter 1995; Anderson and Snyder, 1997, pp. 22-25; Perry et al. 1997). In many regions, this will require improvements in water measurement and control capability, but those improvements would also support volumetric water pricing and may enable water agencies to provide farmers with greater flexibility in scheduling water deliveries.

Describing international experience with water markets, Briscoe (1997) concludes that "from a conceptual, practical and political perspective, the appropriate approach for ensuring that the scarcity value of water is transmitted to users is to clarify property rights and to facilitate the leasing and trading of these rights." Svendsen and Meinzen-Dick (1997) include a "net shift of authority for allocating water use rights from public agencies to the use right holders themselves through private transactions and arrangements" in their list of themes regarding future water management policies and institutions. Rosegrant (1997) suggests that the most important water policy reforms will involve changing the institutional and legal environment in which water is supplied to one that enables individuals to make their own decisions regarding water use, while at the same time presenting them with the true scarcity value of water.

Many examples of water markets have been described in the literature, including those in California (Cummings and Nercessiantz, 1994; Howitt 1994), Chile (Gazmuri 1994; Gazmuri and Rosegrant, 1996), India (Janakarajan, 1993; Shah, 1993; Saleth, 1996; Shah and Ballabh, 1997), and Pakistan (Chaudhry, 1990; Meinzen-Dick, 1994). In many cases, markets have improved the productivity of water resources while providing farmers with income-enhancing opportunities.

Water allotments

Some of the world's largest irrigation systems are operated by central government agencies that control the release and delivery of water along main and secondary canals, and determine how much water will be delivered to farmers or water user associations (Upton, 1996, pp. 200-201). There may be little or no formal experience with water markets or water rights in those systems, and the political desire to implement such programs may be limited. A potentially useful alternative is a program of water allotments that define how much water or delivery capacity is available to individual farmers or water user associations, each year, as a function of water supply or an environmental goal, such as reducing deep percolation. Allotments would provide farmers with clear information regarding water availability, without assigning ownership, as is usually implied in a system of formal water rights. The economic efficiency of an allotment program can be enhanced by allowing farmers to trade their allotments, either individually or as members of water user associations.

A program of water allotments can be designed to achieve specific program goals, while minimizing distortion of farm-level crop choices. For example, if the goal is to reduce deep percolation in a region where the aggregate water supply is not limiting, crop-specific allotments defined according to crop water and leaching requirements would provide farmers with sufficient water to irrigate crops they choose, provided they apply only the required water. Alternatively, if the aggregate water supply is limiting, and waterlogging problems are due to uneven distribution of water among farmers, a program of uniform water allotments defined according to the available supply may be more effective in reducing deep percolation, while improving aggregate production. Such a program would encourage farmers to consider the scarcity value and opportunity costs of water when choosing crops and irrigation methods.

Examples of crop-specific and uniform water allotments are compared in Table 1. A farmer with 3 ha of land planted in equal portions of alfalfa, cotton, and sugarbeets would be allotted 31,350 m^3 of irrigation water in a crop-specific program, while a farmer with the same land area would be allotted 27,000 m^3 in a uniform program. The second farmer may be able to produce the same crops by improving water management practices and, possibly, by allowing a shallow aquifer to provide a portion of crop water requirements. This would further enhance efforts to reduce the rate of increase in waterlogged areas. In this example, the uniform program may cause farmers to discontinue growing sugarcane, but that result may enhance societal net benefits in a region with a limited water supply or delivery capacity, uneven distribution of water among farmers, or problems with waterlogging and salinization.

Some of the farmers receiving 9,000 m^3 per ha in the uniform program may choose to sell or lease a portion of their allotment to other farmers for appropriate compensation. Farmers selling allotments may choose to grow crops with smaller water requirements and improve water management practices, while earning revenue from the sale or lease of allotments. Voluntary market transactions would determine the appropriate prices of allotments, and those prices would likely change, over time, with changes in crop prices and the cost of water, labor, and other inputs.

Land Assessments

Public water agencies in India, Pakistan, and other countries with major irrigation projects charge farmers for water delivery services using area-based assessments intended to recover the costs of operation and maintenance (Puttaswamaiah, 1994, p. 187; Kemal et al., 1995; Tsur and Dinar, 1997). The charges are usually higher for crops with higher crop water requirements and in regions with higher costs of service. These programs are less costly to implement than volumetric water pricing (Small and Carruthers, 1991, p. 141), but do not provide an economic incentive to use water efficiently because the farm-level cost of additional water within a season is zero.

An economic incentive to reduce deep percolation can be incorporated in area-based assessment programs by enhancing the crop-specific price structure to reflect the deep percolation objective. In particular, an area-based

Table 1. Examples of crop-specific and uniform water allotments to encourage reductions in deep percolation

Crop	Estimated Crop Water Requirement	Estimated Leaching Requirement	Crop-Specific Water Allotment	Uniform Water Allotment
		(m^3 per hectare)		
Alfalfa	12,000	1,200	13,200	9,000
Cotton	10,000	1,000	11,000	9,000
Sugarbeets	6,500	650	7,150	9,000
Sugarcane	20,000	2,000	22,000	9,000
Wheat	5,500	550	6,050	9,000

Notes: Crop water requirements are the midpoints of ranges in crop water requirements reported by Doorenbos and Kassam (1979, pp. 6-7).

Leaching requirements are estimated as 10% of crop water requirements, as recommended for irrigation water with an electrical conductivity (EC) of 0.75 mmhos/cm and drain water with an EC of 8.0 mmhos/cm (Doorenbos and Pruitt, 1975, p. 127).

Uniform water allotments describe an example in which the total water supply or delivery capacity in a canal command area is limited to an average delivery of 9,000 m^3 per hectare.

surcharge can be imposed on fields that receive larger water deliveries than crop-specific targets determined by the water agency, in consultation with farmers and water user associations. The targets could be established at levels that enable farmers to satisfy crop water and leaching requirements without generating excessive deep percolation, such as the crop-specific water allotment volumes shown in Table 1. Farmers exceeding those volumes could be required to pay an area-based surcharge determined by estimating the external cost of deep percolation, which is the present value of future reductions in regional net revenues due to rising water tables. The estimated opportunity cost of water also could be included in the surcharge to provide an additional incentive for farmers to achieve the targets.

Water Management Inputs

Improvements in water management practices can generate farm-level benefits by reducing the volume of water applied to soils and, thus, reducing the rate of salt accumulation. This provides an economic incentive to implement such practices, which include using sprinkler and drip systems, laser leveling, and hiring additional labor to improve the management of surface irrigations. Delivering water with greater precision enables farmers to reduce deep percolation, while maintaining or improving crop yields. However, farm-level expenditures for irrigation increase with the use of higher technology systems and a long-term cost may arise if the reduction in deep percolation reduces the rate at which salts are removed from soils. Farmers selecting irrigation methods will evaluate near-term and long-term effects, but will not consider the off-farm benefit of increasing regional water table depth.

The societal benefits of improvements in irrigation methods may be sufficient to justify public policies that motivate farm-level adoption, such as subsidizing the hiring of additional labor or the purchase of selected irrigation systems. Providing small farmers with access to credit and offering low-interest loans may encourage them to purchase new irrigation systems or install private tubewells to pump water from shallow aquifers. In regions with area-based water service charges, lower rates might be offered to farmers using irrigation methods that generate less deep percolation.

Transaction Costs

Some of the economic gains achieved by implementing volumetric water prices or establishing water markets will be offset by transaction costs that include efforts to measure water deliveries, collect revenue from water sales, record market transactions, and protect water rights. Transaction costs of market activity include the costs of identifying viable purchase and sale opportunities, negotiating terms of agreements, and mitigating or compensating for any third-party impacts (Rosegrant and Binswanger, 1994). The transaction costs of implementing water rights and pricing programs may be particularly high in developing countries where large irrigation systems deliver water to many small farms (Rosegrant and Binswanger, 1994). Public agencies can reduce private transaction costs by collecting and sharing water market information, and providing an efficient and secure procedure for transferring water rights.

The administrative costs of water pricing, allocation, and marketing programs can be substantial, particularly in countries where improvements in delivery channels, measuring devices, and operational procedures are required t o enable better control and measurement of water deliveries. Institutional enhancements may also be required to support volumetric water pricing and trading of water rights or allotments. However, administrative costs can be reduced by choosing the appropriate level at which to implement innovative programs and by adopting technologies that support program goals. For example, Small (1989) and Meinzen-Dick and Rosegrant (1997) describe volumetric "water wholesaling" in which a public agency sells water to a water user association at some point in the delivery system where volumetric measurement is feasible. The association is then responsible for recovering water costs from individual members. Measurement capability might be extended to lower levels of the delivery system by designing and installing new metering devices that provide volumetric measurement at a reasonable cost (Martinez et al., 1994).

CONCLUSIONS

Economic incentives and other policies that motivate farmers to improve water management may enhance resource use and sustainability in arid regions, and reduce the rate of increase in waterlogged and saline areas. Several engineering, administrative, and political issues will require attention in some countries to enable implementation of such policies, and transaction costs may not be trivial. Public investments may be required to improve irrigation systems to support better control and measurement of water deliveries before volumetric pricing, water allotments, or water marketing can be implemented successfully. The administrative costs of water delivery will likely increase when incentive programs are implemented and political support may be needed to gain approval for any changes in farm-level expectations regarding water supply when rights or allotments are defined and traded.

Public officials often describe the potential engineering and political costs of system improvements as binding constraints on policy enhancements, particularly in developing countries and in regions where water scarcity is not yet receiving national attention. However, in many arid countries, competition for land and water resources, and the value of output from irrigated agriculture, will continue to increase with rising populations and income levels. Therefore, it may be useful to begin improving water delivery systems and enhancing the policy environment in the near-term, while pressure on resources is not yet severe. This may enable public officials to implement economic incentives successfully in future, when water scarcity and the losses from waterlogging and salinization become ever more costly.

Economic incentives may also provide a valuable complement to engineering efforts that address waterlogging and salinization. For example, the cost of regional subsurface drainage systems, public tubewell programs, or tree planting efforts could be funded partially with revenues collected from water sales or land assessments designed to reduce deep percolation. This would reduce public expenditures for drainage relief programs, while providing farm-level incentives that may reduce the size and extent of facilities needed to collect and manage subsurface drain water. An appropriate combination of economic incentives and engineering efforts may enable farmers and the public to sustain the benefits derived from agricultural production in arid regions, despite the perpetual threat from waterlogging and salinization.

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