POLICY RESEARCH WORKING PAPER 2449

Pricing Irrigation Water

A Literature Survey

Robert C. Johansson

Getting prices right and allocating water efficiently will become increasingly important as demand for food and water increases and as water scarcity becomes more of a problem. Pricing water efficiently will help meet the increasing demand, but what is the best way to make pricing more efficient?

The World Bank
Rural Development Department
September 2000

Summary findings

As water scarcity and population pressures increase, more countries are adopting water pricing mechanisms as their primary means of regulating the consumption of irrigation water.

The way to allocate water efficiently is to "get the prices right," but how to accomplish this is open to debate. Water pricing methods are sensitive to the social, physical, institutional, and political setting. To assess the costs and benefits of a particular irrigation project, the pricing method must be tailored to local circumstances.

Johansson's survey of the resource economics literature on irrigation services and pricing will be useful for developing comprehensive guidelines for water policy practitioners. He synthesizes accumulated knowledge about the implementation and performance of various water pricing methods used over the past two decades: volumetric pricing (marginal cost pricing), output and input pricing, per area pricing, tiered pricing, two-part tariffs, and water markets.

Theoretical and practical issues will become increasingly important as demand for food and water increases. Pricing water efficiently will help meet that demand, but what is the best way to make pricing more efficient?

Many argue that water markets offer a solution, but under what circumstances are water markets viable? What effect will decentralization have on farm production and the rest of the economy? What forces are moving toward decentralization or (re)centralization?

The answers to these questions are complex and often site-specific. To help compare them, Johansson lists case studies, data sources, and relevant methodologies in the appendixes.

This paper—a product of the Rural Development Department—is part of a larger effort in the Bank to improve the efficiency of water use. The study was funded by Rural Development, Development Research Group, and the Bank's Research Support Budget under the research project "Guidelines for Pricing Irrigation Water Based on Efficiency, Implementation, and Equity Concerns." Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Melissa Williams, room MC5-724, telephone 202-458-7297, fax 202-522-3308, email address mwilliams4@worldbank.org. Policy Research Working Papers are also posted on the Web at www.worldbank.org/research/workingpapers. The author may be contacted at joha0081@tc.umn.edu. September 2000. (80 pages)

PRICING IRRIGATION WATER:

A LITERATURE SURVEY

Robert C. Johansson

The World Bank
Washington, D.C.

CONTENTS

ABSTRACT

In addressing water scarcity and increased population pressures many countries are adopting water-pricing mechanisms as their primary means to regulate irrigation water consumption. "Getting prices right" is seen as a desirable way to allocate water efficiently, but how to accomplish this remains a debatable issue. Water pricing methods are sensitive to the physical, social, institutional and political setting in each location. It is therefore necessary, when assessing the costs and benefits of a particular irrigation project, to cater the pricing method accordingly.

This paper surveys current and past views on the many aspects of irrigation services and pricing. The result will be useful in developing a comprehensive guideline for water policy practitioners as they address the growing demand for these services and need to allocate scarce water resources efficiently. This survey is organized to illustrate efficient pricing methods followed by alternatives to market failure and considerations of income distribution, water institutions and political economies of irrigation water pricing. Existing irrigation case studies, data sources, and methodologies are compared and referenced.

ACKNOWLEDGEMENTS

This literature review was commissioned as a part of a wider research project, entitled "Guidelines for Pricing Irrigation Water Based on Efficiency, Implementation and Equity Concerns," funded by the research committee of the World Bank. This project headed by Ariel Dinar, Yacov Tsur, and Terry Roe will include this survey as a chapter in their final manuscript for this research project. I have gratefully incorporated many of their comments, observations, and work on irrigation water pricing into this literature review.

The goal of this survey was to provide an exhaustive literature review of relevant articles surrounding irrigation and its pricing over the last two decades. In doing so, I hoped to have included salient discussion of the major contributors to this large body of literature, but acknowledge that valuable works may have been overlooked or omitted due to constraints on time and access. Lastly I would once again like to acknowledge the extensive comments and editorial suggestions provided by Geoffrey Spencer, Shobha Shetty, Alex Norsworthy, R. Maria Saleth, Yacov Tsur, Terry Roe, and Ariel Dinar.

EXECUTIVE SUMMARY

As a result of the Bank's implementation of the 1993 Water Resource Policy, loans for investment in water projects often include a component requiring the implementation of some form of water pricing. If this condition is to serve a useful purpose, water pricing should be implemented appropriately. Yet, the notion of desirable (or optimal) water pricing does not at all command consensus among economists, let alone policy makers. Despite the pervasiveness of water pricing in developed countries, there is still disagreement regarding the appropriate means by which to price water and the levels of water charges. This is partly due to confusion of basic fundamentals, and also because the performance of a water pricing method is quite sensitive to the prevailing conditions. Moreover, many countries lack the tradition, experience, and appropriate institutions to price irrigation water. This enhances the need for a comprehensive study that will (a) resolve common misconceptions and myths associated with irrigation water pricing, (b) define precisely the notion of efficient water pricing, account for implementation costs, (c) define and incorporate equity criteria, and (d) put together a guideline for water pricing in a wide variety of circumstances. The project, "Guidelines for Pricing Irrigation Water Based on Efficiency, Implementation and Equity Concerns," funded by the research committee of the World Bank will address this issue.

This literature review then serves to provide the necessary foundation of existing normative and positive studies relevant to pricing irrigation water as related to this project and will be included as a chapter in the aforementioned project. In addition, it is hoped that the included literature and discussion will provide a useful reference and foundation of relevant pricing issues for irrigation practitioners.

Tsur and Dinar (1995, 1997) analyzed different pricing practices vis-à-vis their efficiency performance, cost of implementation, and equity effects. Along these lines, this literature survey seeks to review and synthesize the most relevant and current research available pertaining to the many aspects of irrigation water pricing. The body of literature examining these movements is vast and diverse. Most works are normative in nature, dealing with how water should be priced, with some description of actual practicalities and applications. A few are purely description (e.g., Dinar and Subramanian, 1997). There are many compilations, which include the literature of a particular aspect of water pricing and irrigation:

- *Conflict and Cooperation on Trans-Boundary Water Resources*, edited by Richard Just and Sinaia Netanyahu.
- *Markets for Water: Potential and Performance*, edited by K. William Easter, Mark W. Rosegrant, and Ariel Dinar.
- *Decentralization and Coordination of Water Resource Management*, edited by Douglas D. Parker and Yacov Tsur.
- *Economics of Water Resources: From Regulation to Privatization*, edited by Nicolas Spulber and Asghar Sabbaghi.
- *The Economics and Management of Water and Drainage in Agriculture*, edited by Ariel Dinar and David Zilberman.

However, a comprehensive review is lacking. This survey seeks to addresses this issue by summarizing the accumulated knowledge regarding the implementation and performance of existing water pricing methods over the last two decades. This is confined to the resource economics literature pertaining to irrigation water, including external material only when particularly pertinent.

These indicate that the methods surrounding irrigation water pricing have many dimensions, both theoretical and practical. That these issues will become increasingly important, as future water and food demands increase, is not in question. Efficiently pricing water will help meet these increasing demand, but what is the best way to increase pricing efficiency? Many argue that water markets offer one solution, however, under which circumstances are water markets viable? What effect will decentralization have on farm production and the rest of the economy? What are the forces that are moving towards decentralization or (re)centralization? The answers to these questions and related methodologies are complex and often site specific. To help contrast these, a list of case studies and relevant methodologies are included in the appendices.

1. INTRODUCTION

World water demand is increasing in all areas of the world. In many areas it is becoming difficult to meet those demands due to scarce water resources. It is evident that these pressures will require more effective allocations and use of existing resources. Many approaches exist that policymakers use to allocate water, some more efficient than others. Water pricing, whether by administrative mandate or by market forces, is an important way to improve water allocations and to encourage conservation. There have been significant movements in recent years towards decentralized methods of water pricing. The body of literature examining these movements is vast and diverse. There have been quite a few works including literature of particular aspects of water pricing and irrigation, but a comprehensive review is lacking. This survey addresses this issue by summarizing the accumulated knowledge regarding the implementation and performance of existing water pricing methods over the last two decades[1]. Due to the volumes of related material, I have confined my review primarily to the resource economics literature pertaining to irrigation water, including external material only when particularly pertinent. The goal of this survey is twofold. The first is to provide a comprehensive literature review for the parent project, "Guidelines for Irrigation Water Pricing." Secondly, it is hoped that the included literature and discussion will provide a useful reference and foundation of relevant pricing issues for irrigation practitioners.

The survey is organized as follows. A brief discussion of water scarcity and irrigation and related literature is outlined in section 1. Section 2 describes the prevalent pricing methods in common use for irrigation projects in the world today. Section 3 lays out normative theories of water pricing. In section 4, recent literature surrounding water institutions is reviewed. This includes sections on the current views on water laws and property rights as they pertain to the provision of irrigation water supply, water administration (government management, water user associations, and water supplier associations), and various water policies ranging from centralized regulation to decentralized markets. Section 5 delves into the important literature dealing with political economy concerns with water allocation. A summary overview is presented in Section 6. With the parent project on water pricing guidelines in mind, the appendix contains a survey of current irrigation case studies and a reference section on relevant methodologies and data sources for calculating crop-water requirements.

1.1 Water Resources

The Earth's renewable fresh water resources are derived from the excess evaporation from oceans over and above precipitation to oceans. Calculations reveal this to be approximately 47,000 km^3/yr. Of this about 41000 km^3 are potentially exploitable[2]. Of the fresh water available

[1] It should be noted that an exhaustive literature review of all the relevant articles surrounding irrigation and its pricing is an arduous undertaking. In doing so it is hoped that salient discussion of the major contributors to this large body of literature are included, but I acknowledge that valuable works may have been overlooked or omitted due to constraints on time and access.

[2] See Seckler et al. (1998) for a diagrammatic display of water balance flows including global agricultural, domestic, industrial, and environmental consumption.

for human consumption, we are now using between 38% and 64% (Rogers, 1993). In the long run the amount of freshwater available to any country is nearly constant, although technological advances can increase the percentage of the water that is economically extractable. Recycling and reuse are two examples of technology that can increase total supplies (Asano, 1997; Willardson, et al., 1997; Yaron, 1997b). Of course, the supply of water per capita is decreasing. The world's population is estimated to be 5.930 billion in 1998 and projected to reach 8.039 billion and 9.367 billion by the years 2025 and 2050, respectively (World Resources, 1998). Correspondingly, fresh water availability for 1998, 2025, and 2050 are estimated to be 6918, 5103 and 4380 m^3 per person per year. These figures indicate that there is no foreseeable shortage in per capita availability.

Unfortunately, this fresh water is distributed very unevenly in space and time. In 1994, twenty-six countries had insufficient renewable water supplies within their own territories to meet most needs of their current population. Population growth rates are relatively high in some of these countries, particularly in Africa and the Middle East (Gleick, 1993; Postel, 1994). If we examine some spatial water distributions in different regions we can see the disparity in per capita fresh water distribution by continent. Asia enjoys abundant annual fresh water per capita on averages (above 2400 m^3 per person in 2050). However, India seats at the lower end of the Asian water distribution with 1207 m^3 per person in 2050 and, within India, the state of Tamil Nadu will have only 490 m^3 per person in 2050, a sever water shortage by any standard. Some suggest that 1000 m^3 $year^{-1}$ per capita is an approximate minimum necessary level for an adequate quality of life in a moderately developed country or that 500 m^3 $year^{-1}$ per capita is sufficient in semi-arid regions with extremely sophisticated water management (e.g., Israel - Gleick, 1993). At levels below 500 m3 $year^{-1}$ per capita water availability becomes the primary constraint to life. This is therefore commonly used as the standard indicator of water scarcity (Seckler et al., 1998). If we examine the water situation in the Jordan River Basin we can see that for the region renewable fresh water per capita will be halved by 2050 given current population and consumption growth rates. A closer look reveals critical levels of water availability occurring within the next two decades for all countries, but Lebanon. Similar patterns can be seen in Africa's Maghreb and Northeastern sub-regions.

1.2 Food Demand and Water

In addition to increasing levels of per capita demand for water consumption are water needs for agricultural purposes. Irrigated agriculture is practiced on 18% of the total arable land in the world (approximately 237 million HA) and produces more than 33% of the total agricultural production. Of these irrigated areas, 71% are found in LDCs (60% in Asia alone). For most of human history irrigated lands expanded at a faster rate than did populations. However, irrigated land coverage peaked in 1978 and has fallen off nearly 6% since then (Postel, 1994). One reason for this trend is a decline in public irrigation investments as a result of debt loads, political resistance, rising real costs of irrigation development, and declining real prices for food (Rosegrant and Svendsen, 1993). As an illustration, World Bank lending for irrigation projects has fallen 50% between 1978 and 1992 (Wichelns, 1998). In addition, it has become increasingly expensive to supply irrigated water. Some examples of increasing costs of irrigation development can be found in Rosegrant and Svendsen (1993) and Sampath (1992). In India and

Indonesia real costs of irrigation water provision have doubled since 1970's; in the Philippines costs have increased by more than 50%; in Sri Lanka real costs have tripled; and in Thailand irrigated water costs have increased by 40%. The shockingly high cost (and subsidization) of irrigation water under the many projects found in the American West is detailed in Reisner's *Cadillac Dessert* (1993).

Other reasons that may explain the decline in irrigation coverage are a 2% loss of irrigated land each year to salinization (e.g., Israel – Yaron, 1997b), to urban sprawl, and to growing sectoral[3] competition for scarce water. In Asia irrigation necessary for Green Revolution crops will continue to be an important component of agricultural development. There agriculture is expected to remain the dominant sector in providing employment, contributing to GNP, and alleviating poverty and malnutrition. Similarly for Africa, agriculture is the biggest water user. However, only about one-third of potentially irrigated lands are under irrigation (Rosegrant and Perez, 1997). Populous agrarian countries such as India and China still use 85% of their water supply for agricultural uses, but this can only be expected to decline as their economies shift to industrial output. Industrial water-use yields a much higher value-added factor than does agriculture. Few governments have specified how agricultural water supplies will be protected or even legally defined (Johnson, 1997).

1.3 Future Needs

Projected global water withdrawals are expected to increase by 35% by 2020 this will equal 5,060 km^3 water (Rosegrant, Ringler, and Gerpacio, 1997). Of these developed countries will increase usage by 22%, of which approximately 80% will be for industrial usage. More serious withdrawal increases will be in developing countries where withdrawals are estimated to increase by 43%. The likelihood of new irrigation projects sufficient to overcome increasing population, mounting concerns over the adverse environmental-social effects of large dam projects, and losses to salinization[4] is questionable (Postel, 1994; Rosegrant and Svendsen, 1993; Sampath, 1992). More likely is the modernization of existing systems to cater to the new institutional structures, technology, and cropping demands (e.g., in Pakistan – Bandaragoda, 1998).

To meet growing food and population demands it will be necessary to maintain crop yields and output growth, to increase the efficiency of agricultural water use (including reallocation between different agricultural sectors), and to accommodate increasing urban and industrial use. A logical starting place is through water savings, improving use efficiency, and boosting crop output per unit of water via the reform in existing water use policies. Seckler et al. (1998) estimate that 50% of future demand increases (through 2025) can be met by increasing irrigation efficiency. Institutional and legal reforms must empower water users to make their own decisions regarding resource use, and provide a structure that reveals the real scarcity value of

[3] In 1900 agriculture accounted for nearly 90% of all water used, by 2000 it is expected that this decline to about 62% (Biswas, 1997). When examining world water use trends over the past century, it is important to realize that significant industrial demand for water in many parts of the globe did not begin to become realized until after 1940. The percentage share of total water use for industry in this century is projected to increase from 6% to 24% (Biswas, 1997).

[4] A discussion of saline affects on cropping patterns and irrigation and related literature can be found in Plessner and Feinerman (1995).

water. In the following sections I survey the existing methods of irrigation water pricing and summarize their main properties vis-à-vis achieving an efficient water allocation. Existing water pricing methods differ in their implementation, the institutions they require, and the information on which they are based. They also differ with regard to the efficiency and equity performance of their outcomes and cost of implementation.

2. IRRIGATION WATER PRICING IN PRACTICE

The fundamental role of prices is to help allocate scarce resources among competing uses and users. One way to achieve an efficient allocation of water is to price its consumption correctly. Pricing of water affects allocation considerations by various users. Consequently, a variety of methods for pricing water have arisen, depending on natural and economic conditions. In this section the prevailing pricing methods for irrigation water are described. These include volumetric pricing, non-volumetric pricing methods, and market-based methods. Volumetric pricing mechanisms charge for irrigation water based on consumption of actual quantities of water. Non-volumetric methods charge for irrigation water bases on a per output basis, a per input basis, a per area basis, or based on land values. These methods often result from inadequate information concerning actual consumption quantities. Market-based mechanisms have recently arisen as a need to address water-pricing inefficiencies inherent in existing irrigation institutions. These rely on market pressures and well-defined water rights to determine the irrigation water price.

2.1 Volumetric Methods

Volumetric pricing methods charge for water using a measurement of the volume of water consumed. This requires information on the volume of water used by each user or some other way to infer a measurement of water consumption. Implementation costs associated with volumetric pricing are relatively high and require the central water authority (CWA) or water user association to set the price, monitor use, and collect fees.

Water meters make volumetric pricing straightforward, involving routine maintenance and periodic meter readings. When water flow is reasonably constant, implicit volumetric pricing is possible by charging for time of delivery. This requires much less information and can be found in small irrigation projects with few users per day (Easter and Welsch, 1986; Small and Carruthers, 1991; Bandaragoda, 1998). If volume of water delivered by the water source per hour were to decrease throughout the cropping season, then the effective price per water unit would be expected to rise proportionally. An example of this termporal block pricing method is found in the varying surface irrigation charges in Maharashtra, India, where the water charge varies by crop and by season (Easter et al., 1997).

For regions with sophisticated monitoring technology, tiered pricing (multi-rate volumetric method) and two-part tariff pricing (volumetric marginal cost pricing plus a fixed admission charge) are found. Tiered pricing for irrigation water is common in the state of California (Rao, 1988) and Israel (Yaron, 1997b). Boland and Wittington (2000) review the recent movement towards increasing block tariffs in developing countries.

2.2 Non-volumetric Methods

In many cases, volumetric pricing is not feasible or desirable. In which case, non-volumetric pricing is utilized. There are several such pricing methods found in common practice for irrigation service: output pricing, input pricing, area pricing, and betterment levy pricing. Output pricing methods charge a water fee for each unit of output produced by the user. This requires knowledge of user outputs, but obviates the need for water use measurement (prohibitively expensive in many cases). In the case where output is readily observable this method will save in transaction costs. Input pricing methods charge users for water consumption through a tax on inputs. An example of this might be a per unit charge for each kilogram of fertilizer purchased.

Area pricing is the most common method of irrigation water pricing found. Bos and Walters (1990) in their survey of farmers on 12.2 million HA globally, found that in more than 60% of the cases water is charged on a per unit area basis. Under this pricing mechanism users are charged for water used per irrigated area, often depending on crop choice, extent of crop irrigated, irrigation method, and season. Rates are typically greater for pumped water from storage than for gravity flow from stream diversion. This method is easy to implement and administer and are best suited to continuous flow irrigation, which may explain its prevalence in the irrigated world (Easter and Welsch, 1986; Easter and Tsur, 1995). Area pricing does not necessarily imply lack of sophistication however. For example the *warabandi* system in Punjab, Pakistan and Haryana, India is a relatively complex system that combines elements of volumetric pricing with area pricing. This rotational method for equitable allocation of irrigation water fixes flows by day, time, and duration of supply proportional to irrigated area (Bandaragoda, 1998; Perry and Narayanamurthy, 1998).

Betterment levy pricing is used to capture the implicit value of irrigation water by charging water fees per unit area, based on increases in land values. This is essentially a hedonic approach to the valuation of crop irrigation services (Young, 1996). Theoretically irrigation services should increase economic activity in a region benefiting all those living there. Levy charges are used to share these benefits (costs) amongst all direct beneficiaries in the service area (Easter, 1980; Easter and Welsch, 1986b).

2.3 Market-based Methods

There are significant water resources available from water conservation and reallocation in areas with irrigation and scarce water supply (Hearne and Easter, 1995; Vaux and Howitt, 1984; Tsur, 1997; Easter and Feder, 1998). To accomplish this it has been argued that water utilities should charge higher prices from water (Rogers, 1992). The problem often is that users have been able to use political power to prevent major increases in water prices, especially irrigation water (Easter, Dinar, and Rosegrant, 1998; Thobani, 1998). Water rates that may have been at one time accurate may be inappropriate 10 years later if they have not been adjusted for inflation (Easter, Becker, Tsur, 1997). One way to circumvent this drawback is to provide the correct incentive structure to lead to efficient water markets (Rosegrant and Binswanger, 1994).

It has long been recognized that markets provide a means to allocate water accordingly to is real value, which should then lead to efficiency gains and conservation (Hearne and Easter, 1995). Furthermore, markets provide a more flexible mechanism to allocate water then are administrative means (Marino and Kemper, 1999). It should be noted that water markets are distrusted by traditional water authorities and consequently are underutilized in many areas where they are appropriate (Wilson, 1997). The general applicability of formal water markets in LDCs has been questioned (Pigram, 1999). There are a number of characteristics associated with water production and delivery that make competitive markets difficult to realize. These market failures include substantial externalities, recharge considerations, imprecise information, large fixed investment costs, and declining average costs of delivery[5].

Water markets can be distinguished on the spectrum from informal to formal. At times both exist simultaneously (Pakistan - Rinaudo et al., 1997). Water markets are often established informally when scarcity occurs (Renfro and Sparling, 1986; Shah, 1993; Anderson and Snyder, 1997) and when governments have failed to respond to rapidly changing water demands (Thobani, 1998). Examples of such informal markets include: South Asia (Shah, 1991; Saleth, 1996), Pakistan (Bandaragoda, 1998) and Mexico (Thobani, 1998). Typically such informal trades consist of farmers selling surplus ground or surface water for a period of time (crop season) to a neighboring farm or town.

For formal water markets to work there needs to be buyable and sellable water rights. A transferable water permit or right is a permission to use a previously specified amount of water and the right to sell it at a price which is determined by the market. This is difficult if public water agencies are unwilling to relinquish their control of the water rights (Howitt, 1998). Several governments, however, have recently passed legislation to establish tradable property rights for water so that the efficiency gains from informal markets can be extended while regulating their unrestricted nature (Marino and Kemper, 1999; Thobani, 1998; Saleth, 1998).

3. WATER PRICING THEORY

An efficient allocation of water resources is that which maximizes the total net benefit able to be generated under the existing technologies and available quantities of that resource (Easter, Becker, and Tsur 1998). In other words the efficiency of water allocation can be regarded as the equalization of marginal benefits from the use of the resource across sectors to maximize social welfare (Dinar, Rosegrant, Meinzen-Dick, 1997). In the absence of taxes or other distortionary constraints, an allocation that maximizes total net benefits is called *first-best* or *Pareto efficient*. If the maximization problem involves variable (short-run) costs only the resulting allocations can

[5] These factors are discussed in Section 4 to a larger extent, but are also summarized in Easter and Feder (1998).

be regarded as *short-run efficient*. When long-run fixed costs are included in the maximization problem *Pareto efficient* allocations are achievable. When maximization occurs under distortionary constraints (e.g., informational, institutional, or political) the allocation is termed *second-best efficient* (Mas-Colell, Whinston and Green, 1995; Tsur and Dinar, 1997).

Equity of water allocation is concerned with the "fairness" of allocation across economically disparate groups in a society or across time and may not be compatible with efficiency objectives (Seagraves and Easter, 1983; Dinar, Rosegrant, and Meinzen-Dick, 1997). The concept of "fairness in allocation" is vague and can either be *descriptive* or *normative* in nature (Sen, 1973; Tsur and Dinar, 1995). These refer to which yardstick ones uses to measure inequality. For example, Sampath (1991) uses a Rawlsian concept of fairness to investigate equity in India's irrigation systems. This concept seeks to maximize the welfare of the least well off in society and allows one to evaluate reform strategies in these terms.

However, water pricing mechanism in general are not very effective in redistributing income (Tsur and Dinar, 1995), but it may be in a government's national interest to increase water available for certain sectors or citizens. To meet this goal it is often necessary to provide subsidized water provision or adopt differing pricing mechanisms that account for disparate income levels (Dinar, Rosegrant, and Meinzen-Dick, 1997). Seckler, Sampath and Raheja (1988) admirably separate efficiency and equity into two distinct problems when evaluating an irrigation system: a managerial problem and a policy problem. They note that the performance of a system should be judged according to the managerial problem, i.e., does the system meet the policy objectives. Discussion of the appropriateness of the policy objectives is separate and removed, held in the context of the broader societal environment. In this section, a similar division has been incorporated allowing for both partial and general equilibrium discussions. Furthermore, an outline of the water quality management literature on has been included as a separate a section. Although, the studies found here can be regarded in terms of partial or general equilibrium, they represent a significant and growing strand of irrigation water theory.

3.1 Partial Equilibrium (PE) Analysis

PE analysis refers to analysis focusing solely on the principle agents affected by the policy under question. For example, when examining a new irrigation project, PE would include such aspects as the effects on farm outputs, water prices, and possible environmental effects. It would ignore the impacts of this project on prices of other crops, movements of productive resources in and out of the agricultural sector related to these changes, and possible affects on domestic and industrial water consumption. The following discussion concerning efficiency and equity will be based on partial equilibrium.

3.1.1 First Best

The economically efficient allocation of water is one that results in the highest return for the given water resource. To achieve this efficiency the price of water should be equal to the marginal cost of supplying an additional unit of water plus the scarcity value of the resource.

An important facet of the economically efficient price is that all users face the same price (Easter et al., 1997; Howe et al., 1986)[6].

There are several ways to determine this efficient price. One is to derive the water demand and supply curves and thereby determine the optimal allocation and price (Easter, Becker, and Tsur, 1997; Spulber and Sabbaghi, 1998). Differing methods for estimating water demand are: price and quantity data estimation (Griffen and Perry, 1985) valuation methods (Gibbons, 1986; Colby, 1989; Dudley and Scott, 1998), and farmland sales estimation (Colby, 1989). Next water supply curves reflecting increasing available supply with increasing costs need to be estimated. These include the marginal cost of delivering and processing the water and depend on the source from which the water is derived. The cost of water that draws down an existing stock includes an intertemporal scarcity rent[7]. Once supply and demand curves have been estimated the optimum water allocation can be determined. The optimal price in this generalized environment will be that which equates aggregate supply with aggregate demand. More applied approaches to the valuation of irrigation water can be found in Young (1996). These include the "Change in Net Income" (CINI) method, the most commonly used method to determine to determine the shadow price of irrigation water. This entails calculating farm income in several scenarios: a "with irrigation water" and a "without irrigation water".

Marginal Cost Pricing

One way to equate marginal benefits of an additional unit of irrigation water to its additional supply cost is via marginal cost pricing (a special case of volumetric pricing). Marginal cost pricing (MCP) equates price with the marginal cost of supplying the last unit of water. In the absence of implementation costs, the marginal cost of supply includes only delivery costs. In this case the allocation resulting from MCP is Pareto efficient. However, water supply costs include such things as the collection of water and fees (Small and Carruthers, 1991), maintenance (Easter, 1987), infrastructure, scarcity, extraction cost externalities, and social costs/benefits. If supplying different users results in differentiated marginal costs, this should be reflected in the prices[8] (Tietenberg 1988; Spulber and Sabbaghi, 1994). Similarly, if water supplied is of different quality the marginal value of supply should be reflected in the price (e.g., Israel – Yaron, 1997). If this is accomplished the water price will now equal the sum of marginal delivery costs and marginal implementation costs (Tsur and Dinar, 1996). For this reason, marginal cost pricing has also been called *opportunity cost pricing* (Thobani, 1998), implying that the price of water should be set equal to the opportunity cost of providing it.

The main benefit of MCP is that it is capable of achieving an efficient allocation. The main drawback of MCP is the difficulty in including all the marginal costs and benefits when determining the correct price to charge. For example, the marginal cost of water provision will vary over months and over years. This intertemporal aspect of water supply is particularly cumbersome (Tsur and Tomasi, 1991; Sampath, 1992). In addition, MCP ignores equity concerns (Seagraves and Easter, 1983; Dinar, Rosegrant, and Meinzen-Dick, 1997). In periods of scarcity the marginal cost (price) of providing water will increase, which may adversely affect

[6] This holds when the cost of supplying water to users is equal across the system. When the marginal cost of supply is different across users, the price they will face will differ.
[7] See Easter, Becker, and Tsur (1997) for a discussion of future demand and uncertainty effects on scarcity values.
[8] An example of this is found in Mendoza, Argentina (Marre et al., 1998).

lower income groups. The implicit need to volumetrically measure water use in order to employ MCP necessitates higher implementation costs than do some other pricing mechanisms. For this reason and the difficulties mentioned earlier the effective and accurate implementation of opportunity cost pricing has not been observed, and suggest that such pricing in practice could be disruptive socially and politically (Thobani, 1998).

Once implementation costs are incorporated into volumetric pricing methods we enter the world of second-best (Tsur and Dinar, 1997). Under second-best conditions it can be optimal to price water below its long-run marginal cost (Rhodes and Sampath, 1985). Consequently, there may be other methods of pricing water that yield higher net social benefits. Sampath (1992) summarizes the literature dealing with why many LDCs depart from marginal cost pricing.

- There are millions benefiting from irrigation services apart from the farmers and so the farmers should not bear the entire cost of delivery[9].
- Pricing is dependent also on method of delivery[10]. The main types of irrigation water delivery systems include continuous flow, rotation[11], demand and closed pipe systems. Volumetric pricing is feasible under the demand and closed pipe systems, but is extremely difficult under the rotation system and nearly impossible under the continuous flow system.
- In general the closed-pipe sprinkler system are more efficient than the continuous flow and rotation systems, but are more expensive and usefulness in irrigating paddy crops are not yet fully known.

Water Markets

Under certain conditions (no externalities, full information, complete certainty, perfect competition, and non-increasing returns to scale) markets will achieve first-best allocations. When trades are free from government constraints and high transaction costs the resulting water allocation will be Pareto efficient and the resulting price will be equal to that determined under MCP methods. However, the question of what to include in water transactions is a difficult one. Such things as monitoring, return flows, third-party effects, and instream uses have to be considered. Easter, Becker and Tsur (1997) list six essential arrangements for an efficient, equitable and sustainable water market.

- Institutional arrangements that establish water rights that are separable from land rights.
- A management organization is needed to implement water trades.
- A flexible infrastructure is needed to transfer quantities of water.
- Third party effects (externalities) must be internalized by the system.
- Water conflicts require effective resolution mechanisms.

[9] See also Sampath (1983) for welfare analysis on the returns to public irrigation development concerning the issue of who should pay for this development.

[10] For a discussion and examples of irrigation systems commonly found in many areas of the world see the book collection on this issue edited by Easter (1986). Efficiency comparisons of these systems for a number of case studies can be found in Molden et al. (1998).

[11] In Asia the rotation system is the most prevalent method of irrigation water delivery (UN, 1980; Seagraves and Easter, 1983).

- Equity concerns, such as future and social goals, need to be addressed.

When these arrangements are distorted or there exist significant implementation costs market allocations are unlikely to attain first-best allocations. For example, water is expensive to transport and therefore the development of water markets is generally localized. Due to the localized nature of many water markets the number of users and suppliers is limited. Such situations may lead to noncompetitive markets, and preclude first-best allocations. However, even when distorted, second-best market allocations may surpass volumetric pricing in efficiency[12]. How equitable market-based allocations are is still an open question (Bjornlund and McKay, 1999).

3.1.2 Second Best

The pricing of water is made difficult considering the many peculiarities associated with the provision of water services[13]. For example, Kirda and Kanber (1999) estimate that losses for conveyance systems alone can be as high as 30% in some cases. When including application practices, water losses can reach 55-60% in some developing countries. Generally, due to these and other particularities associated with the provision of water the management of irrigation water systems is characterized by public intervention of some sort. Easter, Becker, and Tsur (1997) summarize some of the characteristics of water-resource development that lead to public intervention.

- Many water investments include large capital investments and long periods before payoff making it difficult to attract private investors.
- Often water supply exhibits increasing returns to scale and is prone to underinvestment and monopoly pricing[14].
- Many water projects incorporate aspects such as recreation, electric power and irrigation, which complicate the decision-making environment.
- The Central Water Authority (CWA) often lacks complete information on water supply, demand, and consumption, all of which can vary widely between years.
- Some water services are of public good nature and provide benefits up to congestion or degradation.

These main departures into the literature of second-best theories of water allocation are now discussed beginning with the public good nature of water provision.

Public Goods

Easter, Becker, and Tsur (1997) classify the provision of services using the following categories: public goods (low excludability and subtractability), price goods (high excludability and subtractability), toll goods (low subtractability and high excludability), and open-access goods (high subtractability and low excludability). It is useful to use these categories to describe the

[12] Water markets typically internalize the cost of collecting information. This eliminates a major source of implementation costs. In addition, the corruption incentives associated with centralized allocation mechanisms are often eliminated with water markets.

[13] Spulber and Sabbaghi (1998) provide a good discussion of the historical development of second-best pricing and theoretical illustrations.

[14] See Spulber and Sabbaghi (1998) for discussion of natural monopolies and related literature.

type of irrigation service. Goods may migrate from group to group depending upon the evolution of technology or institutions. For example, tube-well technology has reduced the economies of scale for tube-well irrigation such that it can be now viewed as a private good category, even for relatively small-scale farmers (Vermillion, 1997).

For large-scale irrigation projects water services have low excludability because of the large number of farm plots and monitoring difficulties. In such a situation it will be difficult to involve private firms and market forces will not provide the optimal level of investment. Similarly the provision of goods in large portions (e.g., flood control or large dam projects) that is not readily divisible for private purchase also manifest low excludability. Unregulated markets may therefore be sub-optimal in terms of a country's social or developmental goals in terms of poverty alleviation, food security, equity, and public health.

Water from both underground and surface sources often is an open-access good. As has been mentioned before, there are finite amounts of water that must be shared in common between various sectors, regions, and their users (see also Section 3.1.2.5 *Scarcity*). Over-exploitation of these resources is commonly referred to as the "tragedy of the commons" (Hardin, 1968). This occurs when users ignore the effects of their actions on the resource and other users when pursuing their own self-interests. To address this problem economists often advocate the definition of private water rights and formation of water markets (see also Section 4). The uncertain nature of water supply its political nuances can make privatization difficult, especially if the resource is exhaustible, nonrenewable (Disgupta and Heal, 1979) or uncertain (Provencher, 1995).

Implementation Costs

Implementing a pricing method requires appropriate institutions, such as a central water agency (CWA), and entails costs. The physical, institutional, and political environment is manifested in the form of implementation costs. Implementation, or transaction, costs may render some pricing methods impractical and narrow the list of methods from which to choose. The effects of these costs on welfare are both direct and indirect. They generally make first-best allocation pricing methods impossible by modifying optimal prices from their efficient level. Valuing these constraints under various pricing methods is not a trivial task and there appears to be no general rule that one can apply in any given circumstance. Roumasset (1987) extends a public economics approach to the examination of management costs associated with irrigation services. This extension advocates an integrated bottom-up and top-down approach to minimize such costs. Systems that include water permit trades should be tailored to their specific natural and economic environment (Roumasset, 1987).

Beyond administrative costs, relatively easy to value, implementation costs include such things as compliance costs, which can be quite substantial. Due to the nature of farming systems in many areas of the world (i.e., variance across seasons, crops, regions, and climates) complex pricing systems that are efficient may be constrained by the informational and administrative costs needed for implementation (Sampath, 1992; Rosegrant and Binswanger, 1994; Barrett and Sinclair, 1999). Tsur and Dinar (1997) found that effects of implementation costs on the performance of different pricing methods are significant in the sense that small changes in costs can change the order of optimality of those methods. It is therefore possible that a simple and inefficient pricing method such as per area pricing, which is relatively inexpensive to implement, yields a higher social welfare than that obtained with the potentially efficient volumetric pricing method (Tsur and Dinar, 1995, 1997). While these observations may be straightforward, very little empirical evidence or methodology exists for evaluating the practical limitations of various implementation costs

Incomplete Information

One such implementation cost is incomplete information. Whenever irrigation water is priced by some public agency, problems related to incomplete information arise. The user has complete information on his/her marginal water value. Some of this information is private and unavailable to the CWA. For this reason we often see literature referring to this situation as *asymmetric information*. This is so because rational individuals will use private information to advance their own interests (moral hazard) or the CWA may have to spend considerable effort (in the form of increased implementation costs) at society's expense. Zusman (1997) uses the Ramsey-Boiteux formula to assess the total social costs of imperfect information. A comprehensive account, as well as an exhaustive literature survey of regulation with asymmetric information can be found in Laffont and Tirole (1993). Applications to agricultural production are mainly in the context of environmental pollution (e.g., Segerson, 1988; Russel and Shogren, 1993).

Under various conditions, regulators can circumvent the problems associated with certain types of mechanism design. For example, if the CWA charges for irrigation water using per area pricing, it is not necessary to know users' marginal value for water. It is, however, possible to infer the users' marginal value of water through various revelation mechanisms. This burgeoning strand of economic literature (direct revelation mechanisms) springs from the pioneering work on informationally decentralized systems (Hurwicz, 1972) and on mechanism design and principal-agent theory (Hurwicz, 1973; Groves, 1973; Laffont and Tirole, 1987). There are few examples directly related to water pricing; initial efforts include the works of Loehman and Dinar (1994) and Smith and Tsur (1997).

The pervasive case of unmetered water well illustrates one aspect of incomplete information. Because the CWA does not have complete information on the value of the water to heterogenous farmers (adverse selection) there is the incentive for the farmer to under report actual usage (moral hazard) if water is priced volumetrically. Due to the high costs of implementing a meter system often times the CWA will use per unit area pricing in these cases. Smith and Tsur (1997) use mechanism design theory to propose a water-pricing scheme, which depends only on observable outputs. They find in the absence of implementation (transaction) costs that this mechanism will achieve first-best allocations. If transaction costs are included, first-best allocations are not possible, but second-best allocations are. It is assumed that the CWA does have complete information on farmer (i)'s technology. However, by introducing a series of nonlinear taxes on ouputs, this technology can be deduced, hence revealing directly farmer (i)'s marginal water values. The use of this mechanism may involve prohibitive monitoring costs, i.e., the CWA needs to observe farm output for each farmer. Monitoring may be relatively simple, as in the case of Egyptian wheat marketed through a government marketing board, or very difficult as in the case of a large irrigation project supplying many small subsistence farmers[15].

Externalities

There are externalities associated with water provision to the environment (pollution) or to other interest groups (third party effects), that is, when one person's decisions do not take into account the negative effects on others. Economists have advocated the use of pollution taxes as a means to address environmental externalities (Baumal and Oates, 1989). When implementing water irrigation systems and the marketing of those services often there are conflicts that arise out of such things as return flows (third party externalities). The potential for these depends on the nature of the irrigation system. One example concerns recent reluctance to engage new large dam projects both in LDCs and in the MDCs (e.g., Sardar Sarovar Dam, India – Postel, 1999). Third party effects of return-flow from large irrigation dam projects recently have accounted for environmental degradation in Colorado. The irrigation and hydroelectric projects along the Snake and Columbia Rivers have significantly altered flow quantity and timing, which has adversely affected salmon populations (Willis et al., 1998). MacDonnell et al. (1994) discuss the third party effects of American West dams and water banking. They investigate three types of third party effects: impacts on other water users, local economic impacts on parties other than water users, and impacts on environmental values. The difficulty in managing these effects is measurability of the impacts. A variety of water conditions, irrigation systems, and their potential stock externalities are summarized in Easter (1999).

Scarcity

There are many ways that pricing mechanisms can be used to address scarce water supplies. During seasonal shortages, higher marginal cost prices should be used to ration all of the water and to recover fixed costs during peak demand (Seagraves and Easter, 1983). Many informal allocation systems have developed in the absence of prices or formal markets to address scarcity. These traditional, communal arrangements have often operated successfully for many years, but may not be efficient or equitable: *warabandi* system in Pakistani (Easter and Welsch, 1986) and India (Perry and Narayanamurthy, 1998), *subaki* system in Bali (Sutawan, 1989), and the *entornador-entornador* system in Cape Verde (Langworthy and Finan, 1996). When flows are uncertain, shares rather than volumes of water can be allocated to individual farms. When these shares are tradable, efficient allocations can be achieved by equating marginal values across users (Seagraves and Easter, 1983).

Another mechanism to cover scarcity costs is the introduction of a fixed charge to balance the budget of the CWA. In this manner the short-run efficiency of marginal cost pricing can be extended (using a two-part tariff method) to account for long-run fixed cost considerations. Similarly an annual *Pigouvian* tax can be used to manage scarcity. This avoids distortionary affects of other taxing forms and is therefore capable of achieving long-run efficiency (Laffont and Tirole, 1993; Tsur and Dinar, 1995). Examples of endogenously determined water prices under uncertain supply can be found in Tsur (1990, 1997), Tsur and Graham-Tomasi (1991), and

[15] Interesting to note are the advances in satellite remote sensing methods to collect irrigation data in a cost effective manner. An example for India can be found in Thiruvengadachari and Sakthivadivel (1997). These may further reduce costs associated with asymmetric information.

Moreno et al. (1999). Intertemporal allocations under scarcity and uncertain supply are investigated in Easter, Becker, and Tsur (1997).

Uncertain supply also is related to the choice of water source and irrigation system, which will affect the eventual water price. Small and Rimal (1996) using efficiency and equity criteria evaluated water scarcity effects on irrigation system performance in Asia. They note that optimal conveyance strategies to account for scarcity may reduce economic efficiency and equity marginally. Along these lines, Zilberman (1997) develops an optimal water pricing, allocation, and conveyance system over space to capture different upstream and downstream incentives.

Returns to Scale

Another type of market failure exhibited by water provision is increasing returns to water production technology. The costs for water treatment and delivery per unit declines as the number of users increase. In such cases, marginal cost pricing will not cover full costs because the marginal cost will always be lower than the average cost. That large irrigation projects exhibit increasing returns to scale is well documented (Easter and Welsch, 1986a; Dinar, Rosegrant, and Meinzen-Dick, 1997; Easter, Becker and Tsur, 1998). Because of these increasing returns to scale, water supply can be viewed as a natural monopoly. The literature regarding the regulation of natural monopolies is well developed (Spulber and Spagghati, 1998).

3.1.3 Equity Concerns

Equity concerns include such things as the recovery of costs from users, subsidized food production, and income redistribution (Seagraves and Easter, 1983). Considering effects on income distribution of water pricing has merit of its own when justified on ethical grounds (Rhodes and Sampath, 1988; Sampath, 1991, 1992). Moreover, such considerations often appeal to efficiency criteria since they tend to reduce implementation costs (i.e., it is easier to gain cooperation for a policy that is fair and just). Easter (1993) illustrates the effect of "fairness" on efficient management of four irrigation systems (Philippines, Sri Lanka, Nepal, and Maharashtra, India). Tsur and Dinar (1995) remark that the majority of pricing mechanisms have little potential effect on income distribution (when farmers are homogenous), as equity effects of pricing are primarily dependent on land endowments. Gill and Sampath (1992) argue with an application to Pakistan, that despite inequality in land distribution, equality in irrigation supply can be improved using a lexicographic distribution favoring small farmers. These trade-offs between equity and efficiency are well illustrated in Small and Rimal (1996). They simulate various distribution rules on efficiency and equity for typical Asian irrigation systems.

Considerations of income distribution are occasionally used to justify departure from efficient allocations and it is important to understand their effects. Proponents use arguments of fairness or social awareness to use redistributive pricing policies. They often argue that consumers benefit from agricultural investments through lower food prices and so should be expected to share in covering the costs (Sampath, 1983). In addition equity concerns pertaining to irrigated agriculture are important when addressing international aid and development issues. Many argue against water charges of any kind in LDCs, as the higher income farmers are often exempt from paying (Easter and Welsch, 1986b). Opponents, on the other hand, may argue that subsidized inputs/outputs (e.g., water) distorts production decisions, inflicts domestic social (deadweight) costs and adversely affects international trade (Kruger, et al., 1991). They argue that if governments were to support farmers, they should find non-distortionary ways to do so.

When examining equity concerns between hetrogenous water users and sectors, pricing policies may provide the most effective means to redistribute income. Sampath (1990) notes equity concerns surrounding income redistribution via irrigation distribution have become one of the most important objectives across disciplines[16]. Water pricing may have a role in policies aimed at affecting income distribution between farming and non-farming sectors (Diao and Roe, 1998) as well as between irrigation districts (Brill, Hochman and Zilberman. 1997). In addition, equity considerations may coincide with political interests. Just, Netanyahu, and Horowitz (1997) note that in arid countries where water may be a limiting resource, an increasing block-rate structure may be a valid means of trading efficiency for equity in the distribution of a scarce resource. These considerations suggest that effects of a pricing scheme on income distribution should not be overlooked.

The formation and functioning of water markets has associated equity concerns. These concerns and water market development in the American Southwest are described in Saliba and Bush (1987). They note that higher costs associated with the purchase of water rights or distribution based on seniority may force redistribution of water rights to different sectors or users leaving others out of the market for water. Some consequences of water trading and its potential for equitable reallocation of water resources have been examined for Victoria, Australia (Bjornlund and McKay, 1999). Similarly Meinzen-Dick and Bakker (1999) evaluate water rights and methods for allocating water between sectors. Therefore, it is necessary to take the other users into account when allocating rights for irrigation water supplies.

Carruthers (1996) in his review of the economic aspects of irrigation highlights reasons for further investment in irrigated agriculture. One main reason was irrigation projects are at least as successful as are other development assistance projects and that aid for irrigation must be maintained at least at present levels. His rationale behind this view holds for domestic irrigation projects as well: job creation to reduce migration in rural areas, development flows to impoverished regions, and the need to focus on the dominance of agriculture in many LDC countries. In this vein, Carruthers et al. (1997) make a strong case for increasing irrigation investments on food security grounds. A Zimbabwean application can be found in Shumba and Maposa (1996).

3.2 General Equilibrium (GE) Analysis

GE analysis includes other regions or sectors (sometimes across time), where as partial equilibrium analysis can be viewed as effects to a specific sector (irrigation / agricultural). GE analysis often refers to such things as steady-state paths, or economy-wide effects and is viewed as being macro-level in approach. However, to gain the big picture of economy-wide effects it is often necessary with GE analysis to make sweeping, often unrealistic assumptions about the prevailing economic conditions, which may in real life vary quite substantially from region to

[16] In his examination of Indian farms, irrigation, and inequality, Sampath (1990) concedes that to address inequality it is often necessary to redistribute land.

region. Such assumption include those of voluntary transactions in a level playing field of differentially endowed households in a risky world, where all agents have identical, complete information (Binswanger et al., 1993). The results derived from this analysis must be viewed with these underlying assumptions in mind and the knowledge that often the theoretical results obtained are generalizations of the entire economy and not specific micro-level occurrences.

In the context of water pricing, the difference between these two concepts is illustrated using a simple example. A *partial equilibrium analysis* of the provision of irrigation services would try to set the price such that the marginal cost of supplying the water equaled the marginal benefit to the farmer of receiving that water. A *general equilibrium analysis* of the same provision of irrigation services would examine the effects of setting this price on other sectors such as the urban sector or industrial sector. Meinzen-Dick and Bakker (1999) illustrate the need to incorporate other sectors in analysis when defining rights to water and choosing appropriate irrigation systems. Modeling (theoretically or empirically) additional sectors or regions is by necessity a difficult undertaking, which requires modeling sophistication and/or large data sets. As a result there is not as much literature regarding irrigation pricing issues.

One GE methodology revolves around computable general equilibrium models that calibrate equilibrium conditions using existing empirical data. Berck, Robinson and Goldman (1991) describe how computable general equilibrium (CGE) models can be used to evaluate policies. They summarize the contributions of *general equilibrium analysis* over *partial equilibrium analysis*. In the calculations of a project's direct impact they conclude that CGE models suffer from the same limitations (i.e., definitions of costs and benefits), as does standard cost-benefit analysis. However, for large irrigation projects (e.g., Aswan high dam and California Central Valley Project) where it is conceivable that impacts of the project will have sequential effects on commodity prices, CGE will allow estimates of those endogenously determined variables. In addition evaluations of project alternatives (e.g., fallowing of land or trade alternatives) is facilitated under CGE modeling. Similarly alternative policies outside of water policy can be evaluated for its contribution to the impact of a project (e.g., optimal commodity taxes). In the LDC environment, prices for missing and distorted markets (e.g., labor) can be evaluated in the CGE format, which yields shadow values for those prices. Lastly, the CGE format is useful for generating the potential secondary benefits (costs) for the other sectors in the economy.

3.2.1 First-Best

The definition of first-best allocations and Pareto optimality are as they were for *partial equilibrium*. It should be noted, however, that *general equilibrium* expressly incorporates prices for other goods and sectors and therefore the focus is not necessarily on determining the Pareto optimal water price/allocation. For environmental policy, Hurwicz (1998) derives the optimality conditions for general equilibrium treatments of market failure and second best policies.

3.2.2 Second-Best

Literature concerning second-best GE can be categorized similarly as was partial equilibrium analysis. Binswanger et al. (1993) discuss how GE analysis begins with perfect markets and perfect information (or first best), and as assumptions are relaxed enters the world of second-best (e.g., credit market imperfections, asymmetric information, moral hazard, income risks, and rent-seeking distortions). There are few empirical GE studies examining the environment (Robinson et al., 1993; Roe and Diao, 1995, 1997; Goulder et al., 1999) or water (Diao and Roe, 1998) in all sectors of the economy due to the scarcity of accurate data. One recent GE examination of water pricing was conducted for industrial, domestic, and agricultural consumption in Canada (Renzetti and Dupont, 1999). Their simulations evaluate potential benefits and costs of a two-part pricing policy (permits and volumetric charges) on many sectors.

Externalities

Trade in the presence of externalities has been used to evaluate the optimal choice of environmental protection. A recent example (Kohn, 1998) illustrates that under a simple Nash-game scenario using the traditional Hecksher-Ohlin-Samuelson model both countries will opt for environmental taxes. Similarly, the effect of regulating shared water aquifers between two countries has been modeled using GE theory (Roe and Diao, 1995, 1997). This later study endeavors to describe a situation found where two countries share water resources and thus the water-use decisions of each country will affect the water availability of the other country (e.g., Israel, Jordan, Gaza, and the West Bank). With the introduction of the externality (country A (B) affects the amount of water availability to country B (A) depending on its water generation amount) they view the competitive equilibrium as Nash equilibrium. Contrary to standard Hecksher-Ohlin factor price equalization, the resulting differences in water supply and demand between the two countries will generate different prices for water, labor and capital in countries A and B. The effects of various unilateral and bilateral water policies are then simulated.

Trade

Diao and Roe (1995) examine the welfare effects from liberalizing trade in a North-South framework. They focus on the environmental effects of changing trading patterns when pollution enters into health consumption via a modified Stone-Geary form of utility. This model can be modified to expressly examine water pollution. This model is developed in Diao and Roe (1998), where they examine the effects of trade and water market reform in Morocco. The crux of this study is to determine the optimal sequence of reforms in the Moroccan economy keeping pragmatic political economy consideration in mind[17]. Reform, as such, implies that the efficiency of the existing system will be improved, however, reform is not static and must be viewed as a process. Diao and Roe (1998) do a very compelling job of showing how such reform might be sequenced to allow for the losers in the reform process to be partially compensated, and thereby made to be more willing to engage in the reforms. By doing so, the authors have made a strong empirical argument in favor of using GE analysis to examine water pricing issues.

Vaux and Howitt (1984) developed a GE approach for inter-regional water trade. They use a *spatial equilibrium* approach derived from a quadratic programming model. The Vaux and Howitt model examines the interregional equilibrium supply and demand relationship for California (five demand sectors and eight supply sectors). They estimate that if trade is not allowed and the development of new water sources is exclusively used to meet increasing demand the resulting prices for all regions are dramatically higher. By allowing a market-based

[17] Despite a clear comparative advantage in the production of irrigated exportables (fruits and vegetables) Morocco continues to protect the wheat and industrial crop sectors to its collective disadvantage. Any water development strategy occurring in this biased agricultural system may lead to further inefficiencies in water allocation and be actually welfare decreasing.

interregional trade of water supplies, the increasing demand can be met at much lower social costs. Smith and Roumasset (1998) provide an extension of the spatial/intertemporal model for water management with multiple sources and transport technologies to the Waihole-Waikane aqueduct in Hawaii.

Endogenous Growth
Recent endogenous growth literature should be mentioned here. These models are related to general equilibrium approaches in that they examine several sectors of the economy simultaneously[18]. There have been several recent articles examining optimal growth strategies for countries accounting for environmental quality. These can be adapted for specific water sectors if need be. Elbasha and Roe (1995a) incorporate pollution and abatement efforts into an R&D endogenous growth model. They determine that the effect of the environment on growth depends on the intertemporal substitution of consumption elasticity. Elbasha and Roe (1995b) further develop three types of endogenous growth models (convex models, human capital models, and innovation models) to include environmental consumption and pollution externalities. Mohtadi (1996) and Bovenberg and de Mooij (1997) show how the optimal growth path for a country depends upon the type and extent of environmental regulation. Aghion and Howitt (1998) in their comprehensive text on endogenous growth theory include several relevant sections to our survey: steady-state existence with environmental pollution and with nonrenewable natural resources.

Scarcity
Rausser and Zusman (1991) explore the affects of water scarcity on the political power balance in a general equilibrium format. Sectors included in the analysis consist of n districts, a CWA and a government, yielding an n+2 game determining water allocations. Alternative supply reduction strategies for environmental improvement are examined in a multi-dimensional format in Sunding et al. (1994). This paper incorporates 3 specific models for Central Valley agriculture to provide a holistic view of environmental protection policies affecting California's Bay/Delta region. These models[19] reveal that increasing water costs (reduction in irrigation diversions) and labor distortions due to environmental legislation can be mitigated through water trading.

Equity Concerns
Nearly any *general equilibrium* analysis will revolve around equity issues, including such things as income distributions. The basis of GE analysis is to discover the repercussions of an action in one sector in one country on other sectors of that economy or other countries. Estimating who wins and who loses and by how much is the typical output from GE analysis. For this reason many of the aforementioned literature will also appear in section 8, dealing with the political economy of water allocation. For example, Just, Netanyahu, and Horowitz (1997) examine the equity considerations of water pricing in a quasi-general equilibrium fashion.

The use of the IMPACT model for IFPRI's 2020 Vision research program enables researchers to generate various scenarios regarding equity concerns as a function of global food supply and

---

[18] Diao et al. (1996) link endogenous growth models and the general equilibrium literature.
[19] These are: California Agriculture Resources Management (CARM) model, and an agronomic model with technical substitution, and a water-rationing model.

demand linked by trade in a general equilibrium framework (Carruthers et al., 1997). As one of the underlying parameters for IMPACT is irrigation investment, the effects on food security of changing investment levels can be evaluated for a variety of regions and periods (Rosegrant et al., 1995).

3.3 Water Quality Management

The question of environmental regulation and degradation has received enormous attention recently. Biswas (1997) provides a review of water development and effects on the environment. These effects include erosion, sedimentation, waterlogging, salinity, eutrophication, and various mechanisms to deal with these problems (Dinar and Zilberman, 1991; Biswas, 1997). Similarly, Gleick (1993) reviews current water uses and environmental consequences for the future. Some pertinent issues included are: water quality problems, water quality management, irrigation's environmental price, scarcity and competition, etc. To address the literature concerning all these issues would be prohibitive. Instead several areas concerning water pricing for agriculture will be reviewed.

3.3.1 Pollution

There are two issues that are particularly important to consider when considering permits or prices (taxes) to deal with water-quality problems. These are: (1) the nonuniformity in the impacts of water use, and (2) nonpoint-source pollution (Easter et al., 1997). Nonuniformity refers to spatial and temporal variation in impact that different emitters of pollution will have on the water resource. Nonpoint-source pollution is that where the source of the pollution is typically unknown. Anderson and Snyder (1997b) trace the developments in water pollution regulation in the US from a command-and-control (CAC) framework to recent developments in market approaches. The latter include systems of taxes and tradable permits to provide the correct incentive structure so that polluters incorporate the net social damages into their decision function.

To achieve an efficient system of taxes or permits to address the problem of nonuniformity, it is necessary to account for the varying impacts of the emitters on the water resource. The optimality of determining these impacts under asymmetric information versus flat rate taxes is a frequently examined question. Goulder et al. (1999) evaluate cost-effectiveness of alternative environmental regulation using general equilibrium simulation models. Kim et al. (1999) find that regulatory instruments chosen endogenously show greater gains to constant-rate taxes than to targeted pollution taxes. Similarly with nonpoint-source pollution there is again a problem of not having the necessary information to correctly price water resources or penalize polluters of that resource. Segerson (1988) examines regulation of nonpoint polluters in a small watershed. She addresses the issue using a command-and-control penalty that provides the incentive for all farmers in the watershed to self-regulate their outputs. Extensions to this are recent game theory studies of environmental regulation (e.g. nonpoint nitrate leaching – Bhat, et al., 1998). The development of tradable pollution rights is traced in Maloney and Yandle (1983) and is well documented for point source pollution (Montgomery, 1972; Baumol and Oates, 1989).

Trading systems for these rights have been adapted for rivers (O'Neil et al., 1983), for sulfur-dioxide emissions (as in the Clean Air Act of 1990), for greenhouse gas emissions (Leiby and Rubin, 1998), and for futures markets (Laffont and Tirole, 1996a). Recent attempts at regulating nonpoint sources using permit trading and optimal taxes include a theoretical model accounting for both spatial and temporal variance of pollution impacts (Kim et al., 1997; Goetz and Zilberman, 1998) and empirically for nutrient reductions in agriculture: for nitrate leeching (Fleming and Adams, 1997; Morgan, 1999) and for eutrophication (Heidiger, 1999; Johansson, 1999; Westra, 1999). Market extensions for tradable pollution permits include futures and options markets. Laffont and Tirole (1996a) examine such markets under asymmetric information and determine optimal abatement and compliance strategies. They note that stand-alone spot markets will induce excessive abatement.

3.3.2 Conservation

It is fairly obvious that in dry regions with scarce water resources, the competition for water between different sectors will intensify. It will become even more important to enforce effective use and water conservation. Due to increases in non-agricultural demand, it is estimated that by 2025 the supply-demand gap in Tamil Nadu (a water-poor state in India) will be approximately 44.72% (Palanisami, 1999). Examples of conservation and water management techniques to increase potential water are numerous. They include: adoption of alternative cropping systems with less dependence on irrigation, improvement of existing irrigation systems (e.g., participatory including water users), salt water utilization for growing crops, waste water utilization for agriculture, and adoption of new irrigation technologies (Kirda and Kanber, 1999; Palanisami, 1999).

There have been several recent economic reviews of the management for groundwater systems (Gisser, 1983; Tsur and Zemel, 1995; Zilberman, 1997) and for conjunctive management with surface water (Tsur, 1990; Boggess et al., 1993; Zilberman, 1997). These indicate a variety of pumping and storage strategies to stabilize supply. For example, Gisser (1983) introduces a system of transferable permits for pumping rights to prevent over-pumping of groundwater aquifers. However, increasing use and stochastic weather shocks will continue to demand conservation efforts. As water becomes more expensive, water conservation will be encouraged. In addition water markets are increasingly being used for environmental restoration (Willis et al., 1998). Water trading between regions can mitigate these increased water costs due to environmental protection efforts (Sunding et al., 1994). For example, Central Valley Project farmers in California now pay restoration surcharges to fund environmental restoration (Green and Sunding, 1997). It should be noted that not all water trades from agriculture to the environment might be efficient as many assume (Isè and Sunding, 1997) due to market failure (such as imperfect credit markets).

The effects of pricing policies on water quality often manifest through choice of farming (irrigation) technology. When pricing reflects increased scarcity of water resources over time resource-augmenting irrigation technology should result. At times the government may explicitly encourage water-saving technology adoption (Wichelns et al, 1996) to improve water quality. Zilberman et al. (1992) confirm that farmers' response to irrigation supply reductions can be predicted by economic theory (i.e. increasing groundwater pumping, adopting conservation technologies, and fallowing land), but that the timing of the responses are difficult to estimate. Varela-Ortega et al. (1998) also show that farmer responses are strongly dependent on the institutional framework (e.g., credit system) involved, which may mitigate the adoption of conservation technology attributed to pricing.

The adoption of and economics of conservation-technology in irrigation has been reviewed and developed for water price and land quality (Caswell and Zilberman, 1985, 1986); for asset quality (Caswell, Lichtenberg, and Zilberman, 1990); for variable resource qualities (Dinar and Yaron, 1990); Dinar and Zilberman, 1991; Caswell, Zilberman, and Casterline, 1993); for land allocation (Green and Sunding, 1997); and for underinvestment due to subsidized water (Zilberman et al, 1997) or due to asymmetric information and tradable permit markets (Laffont and Tirole, 1996b). For example, Caswell et al. (1990) discuss the effects of environmental regulation (such as a drainage effluent fee) on the adoption of irrigation technologies. They find that such economic considerations may encourage the adoption of water-conserving technologies. Shah et al. (1995) find that it may be optimal to increase water prices to encourage more quickly the adoption of water conserving technologies such as drip-irrigation used with ground water (i.e. exhaustible resource). This will also retard excessive resource depletion caused by open access, market failure.

4. WATER INSTITUTIONS

There is a renewed interest regarding the evolution of economic institutions for managing natural resources (Ostrom, 1990; Easter and Tsur, 1993; Ostrom, Gardner and Walker, 1994; Merrey, 1996; and Saleth and Dinar, 1998). The term "water institution" broadly refers to the legal institutions of water distribution (water law and water rights systems), to water management and allocation institutions or water administration (as defined by water laws and water rights), and water policies (the practical implementation of water laws by water administration). These interrelated dimensions of water institutions characterize the water sector. Along these lines this section will discuss the various water institutions in turn. Important considerations derived from the inherent water institutions in place or from the changes occurring in these institutions (as in the case with the movement to decentralized water policies) are regarded as the political economy of water institutions and are discussed in Section 5.

4.1 Legal Institutions

The laws and rules that define water distribution will naturally affect the performance of the system (e.g., Asia – Small and Rimal, 1996; Spain - Garrido, 1997; Tamil Nadu - Brewer et al., 1997). The evolution of water law and property rights is intrinsically linked to political economies and changing climate of water regulation. It is therefore, difficult to separate out specific water laws that are applicable to the variety of global irrigation systems. I have provided several references that review water law and continue with a discussion of water rights. How well water rights are defined in a country will reflect its degree of decentralization in water regulation and the appropriateness of water markets to price irrigation water.

4.1.1 Water Law

It is important to integrate conscience design of institutional rules and economic incentives (e.g., water laws and property rights) to address social concerns of efficiency, equity and externalities. Anderson (1983) provides an extensive discussion of the roots and developments in water law and property rights for the American West. Several specific cases from the 19th Century and their importance in determining current practices can be found in Kanawa (2000). A similar discussion of international water law and literature can be found in McCaffrey (1993). Dinar and Loehman (1993) address the use of water law to resolve water provision problems (quality and quantity). Included are case studies and applications to current water issues (e.g., Colorado, California, Taiwan, India, Ontario, and Australia).

Unclear definitions and uncertainties in water laws are cited as the limiting factor regarding the sustainability and efficiency of irrigation system management. Brewer et al. (1997) review studies linking system performance to water rules. They separate these studies into four areas: those that use simulation models to investigate optimal distribution rules (e.g., Anderson and Maass, 1987; Chaudhry and Young, 1990; Howe, 1990; Kelley and Johnson, 1990; Small and Rimal, 1996); those that evaluate distribution performance for particular irrigation systems (e.g., the *warabandi* system in Haryana – Malhotra, 1982; Bandaragoda, 1998); those that discuss whether distribution rules are followed (e.g., Wade, 1988; Vermillion, 1991); and those that treat irrigation management as an open-access resource (e.g., Ostrom, 1992). They detail these effects for the Tambraparani Irrigation System (India) and note resulting inefficient performance and inequitable water distributions. Similar deficiencies have been noted in recent legislation accompanying the movement towards decentralized water regulation in Mexico (Johnson, 1997). Spulber and Sabbaghi (1998) review water regulations and compatibility with recent privatization efforts.

4.1.2 Water Rights

For the free market to determine fully the development and allocation of irrigation water, there would have to be a system of pure private property rights. Property rights based on long-term contracts may also be sufficient for efficient markets. Anderson, Burt and Tractor (1983) contend that the key to market allocation of groundwater is a well-defined, enforceable system of transferable property rights. The existence of this type of system necessitates: (1) certainty (specific definition of the right including such aspects as quantity, quality, location, and time of use); (2) transferability (ease of right transference via purchase and sale); (3) absence of externalities; and (4) existence of market competition in both the demand and supply sides of the market. In the absence of such rights, government intervention will be required to enforce private rights or to allocate scarce water resources using another mechanism[20].

Once markets begin to informally facilitate the transfer of water among users it is necessary to determine how water rights will be defined. Rights for water use have evolved through custom or bodies of law and regulation in most countries. Zilberman et al. (1997) trace the transition from water rights to water markets. The Western notion of privately defined property rights has

[20] Several authors have addressed the effects of ill-defined or enforced property rights (Hunt, 1990; Ghosh and Lahiri, 1992; Tang, 1994; Anderson and Synder, 1997), of uncertain property rights (Feder and Noronha, 1987; Feder and Feeny, 1991), and of open-access water resource management (Easter, Becker, and Tsur, 1997).

evolved over the centuries combining economic, and political changes (North, 1981). Water rights specify how water will be divided between sectors (industrial, domestic, and agricultural consumption) and also within sectors, as might be the case between individual farmers (Holden and Thobani, 1996). In most countries water rights are based on one of three current systems (Sampath, 1992; Holden and Thobani, 1996): riparian rights link ownership to adjacent land ownership[21], public allocation based on priorities of use determined by government, and prior allocation determined by actual historical use.

The limitations of prior allocation and riparian rights and the movement towards state administration of water rights are described in Anderson and Snyder (1997b). Rights can be defined in terms of a share of streamflow, aquifer, or reservoir. These can be in actual quantity terms or for given time periods. When rights are defined by quantity there are two methods typically used to address scarcity: by priority basis (e.g., senior water-rights holders in California) or a proportional division based on expected shortages (Easter, Becker, and Tsur, 1997). Anderson, Burt, and Fractor (1983) trace the evolution of groundwater rights and describe the similarities to surface water rights. As noted in Kanawa (2000), by clearly defining water property rights in the courts, legal uncertainty for market applications will result also reducing the amount of litigation.

Studies that examine water rights generally extend their analysis to the corresponding water markets associated with those systems. The movement from water rights to water markets is not always optimal, but depends on the associated political and economic costs (Saliba and Bush, 1987; Shah and Zilberman, 1995). As in the case of Mexico, there is often considerable tension between market transferability and highly regulated trading. Rosegrant and Schleyer (1996) note several trends that will continue to encourage the transition from water law and rights to market trades in Mexico, which are also applicable to other countries: continuing macroeconomic reform will require further market development at the micro level, growing nonagricultural demand will push for increasingly open water markets, farmers will continue to lobby for easily transferable water rights, and as mentioned the general climate of decentralization favors continued development of water markets.

Many of the same market and regulatory failures that are found with water provision in general are also relevant when defining water rights. Gisser and Johnson (1983) develop a model to explain water rights and externalities. They conclude that efficiency requires the transferability of these rights when well defined to account for third-party effects. Empirical extensions are provided for the Middle Rio Grande Conservancy District. The open-access problem with respect to instream water rights is examined for several western states in Huffman (1983). Tregarthen (1983) discusses how the informational and transaction costs associated with water right transfers in Colorado can generate perverse conservancy incentives. These incentives are difficult to legislate against due to public distrust of purely private markets. Anderson, Burt, and Fractor (1983) discuss groundwater rights and apply their model of optimal groundwater extraction to privatization efforts in the Tehachapi Basin, California.

[21] This system is generally found with abundant water (e.g., France and Eastern, USA).

4.2 Water Administration

The primary role of a water administration is to facilitate irrigation water management by reducing implementation costs and to promote an efficient, equitable, and sustainable allocation of water resources. The type of administration ranges from governmental water agencies to water user and supplier associations. This component of the water sector includes the following administration-related institutional aspects: spatial organization, organization features, functional capacity, pricing and finance, regulatory and accountability mechanisms, and information, research and technological capabilities (Saleth and Dinar, 1999). Roumasset (1988) outlines necessary incentive-compatible relationships between the different units in an irrigation system (manager, supplier, and user) to insure sustainable irrigation service provision.

The prevailing water administration and the performance of the different pricing methods are intrinsically related. What ties these two together is the task of implementation. Hurwicz (1998) examines institutional arrangements and the theory of implementation as applied to correcting market failure. Different institutional arrangements are more conducive to certain pricing methods and less so to others[22]. For example, volumetric pricing is inappropriate in a riparian system requiring metered water facilities. The existence or lack of water user associations of different forms bears important implications for information asymmetries and for the cost of extracting water fees. Where water rights (permits or entitlements) exist, the feasibility of trading them requires well-defined trading rules and appropriate institutions to enforce these rules and resolve conflicts as they arise. Moreover, as a society matures its socio-economic objectives and its institutional framework is subject to pressures. A nation's ability to cope with these pressures directly affects the management of its natural resources. This ability to cope gains increased importance as the quantity of uncommitted resources diminishes (Frederiksen, 1997). This section will provide a summary background of the evolution of water institutions in the context of irrigation beginning with centralized government control and following with decentralized supplier and user organizations.

4.2.1 Government Institutions

Livingstone (1998) notes that water organizations have had a pervasive role in the allocation of water. Historically, governments have provided defacto subsidies to the agricultural sector by not fully recovering capital costs and achieving partial recovery of O&M costs (Wichelns, 1998). Anderson and Snyder (1997b) trace the evolution of water administration in the US from the 17th Century to modern times. They note that well-defined, exclusive land and water rights provided the necessary tenure security to stimulate private irrigation investments. For a background on the evolution of government control of water resources see Fredriksen (1997) and Spulber and Sabbaghi (1998).

Reform efforts targeted at the government provision of irrigation water services have been hinted at in earlier sections, are largely due to the realization of government failures. Easter and Feder (1998) note that these failures are more pronounced in LDCs, but are also apparent in developed economies. These include: misallocated project investments, overextended government agencies,

[22] See Water Policy Section: .

inadequate service delivery to the poor, neglect of water quality and environmental concerns, and the underpricing of water resources.

That is not to say there are not examples of relatively efficient government water organizations that have adequately addressed the market failures associated with irrigation water provision. These include the management of the Mahaweli in Sri Lanka and the Bhakhra Beas Management Board, India (Livingstone, 1998). Both include basin-wide management strategies to evaluate the impacts of policies on most users. Characteristics distinguishing water organizations that encourage efficient water use are: unbiased allocation, providing water brokerage to lower trade transaction costs, floating water price, and enforcement of third party rights. Livingstone (1998) provides a good discussion of these requirements. Easter (1993) illustrates how four essential characteristics of government management can affect the efficiency of irrigation services. These include assurances that water fees will be used for O&M (both of other farmers and of government agencies), commitment to efficient water allocation, and fairness of setting water fees.

Government involvement in the allocation of water resources has increasingly become decentralized in recent years (Parker and Tsur, 1997; Spulber and Sabbaghi, 1998). For example, recent reform in Pakistan aimed at increasing irrigation water use efficiency is based on shifting strategic decision-making responsibilities to decentralized public utilities and water user associations (WUAs). These reforms would facilitate greater use of market mechanisms and greater role for the private sector in farm capital investments. However, in the development of water markets, the government is responsible for creating a supportive institutional environment. As mentioned earlier, water markets can achieve first-best allocations, but to be successful they require several components from the local, regional, or national government. Government intervention is often necessary to define and enforce water rights in order for the successful functioning of water markets. Governments assist in monitoring and regulating externalities and third-party effects of irrigation (Meinzen-Dick, 1997).

4.2.2 Water Supply Organizations

Although faced with limited physical, financial, and ecological resources to potential water supplies, countries try their best to set the right institutional foundation of their water sector. These efforts are reflected in terms of legal and policy reforms and administrative reorientation. Water supply reform is mainly due to three reasons (Vermillion, 1997): (1) CWAs lack incentives and responsiveness to optimize management performance – farmers have direct interests in enhancing system quality, efficiency, and sustainability; (2) management transfers coupled with supportive social and technical support will result in improved system quality and efficiency; and (3) management transfer will save the government money in terms of reduced O&M responsibilities.

While reform efforts differ across countries in terms of actual coverage and effectiveness, the currently observed water sector institutional changes at the international level are remarkable for their commonality of focus and direction. These include a shift from source development (supply management) to allocation (demand management), wide acceptance of privatization and the decentralization of control, adoption of integrated approaches to sector-wide management, and an increased focus on economic viability and physical sustainability. The first of these, the paradigmatic shift from water development to water allocation, cannot be affected overnight (e.g., in Turkey – Bilen, 1995; Svendsen and Nott, 1997). Fundamental changes are needed to reorient all the water institution components. While it is easier to have allocation-oriented water laws and policies, it is difficult to build an allocation-oriented organizational structure needed to translate the legislative provisions out of an organization with an entrenched experience and tradition in water development. Realignment of existing water administration with new skills and information along with the creation of additional inter-sectoral and inter-regional organizations are critical to face the challenges of an allocation paradigm. Unlike the development era characterized by bureaucracy and dominated by political and engineering considerations, the allocation era requires open and participatory decision processes with the primacy of economic and ecological information.

Countries have begun to recognize the functional distinction between centralized mechanisms needed for coordination and enforcement and decentralized mechanisms needed for user participation and decision-making (Winchelns, 1998; Vermillion, 1997). Often these reforms face much bureaucratic resistance (Wilson, 1997). Some examples of recent reform include: Uzbekistan (Djalalov, 1998); Turkey (Bilen, 1995; Sevendsen and Nott, 1997); Mexico (Rosegrant and Schleyer, 1996; Johnson, 1997); New Zealand (Farley and Simon, 1996); Vietnam (Small, 1996); and Australia (Pigram, 1999).

The key features of this ongoing decentralization are river basin organizations, privatization programs in the irrigation sub-sector, and utility agencies in the urban water sub-sector. Many countries have realized the importance of basin level organizations both as a planning and operational mechanism. Although they are called differently in different countries with considerable variation in their organizational structures, they have a common conceptual basis. Such organizations, designed primarily on hydro-geological rather than administrative boundaries, could provide the basis for pursuing an integrated approach to water management and for resolving regional and sectoral conflicts. Recent reviews of the basin-wide approach to reform with case studies can be found in Vermillion (1997) and Easter (1999).

4.2.3 Water User Organizations

These farmer-managed associations, better known as Water User Associations (WUAs), are examples of organizations that allocate the water shared by a group of farmers. These organizations are responsible for a wide range of management activities. Some have more responsibilities than others (Martin and Yoder, 1987). For example, Meinzen-Dick (1997) identifies two broad categories of WUAs: the Asian model and the Americas Model. The Asian model incorporates farmers in smaller organization units allowing direct participation of all farmers based on social boundaries. The American model relies on specialized, formal irrigation organizations based on hydraulic boundaries. The Americas model contains specific provisions regarding farmers' water rights (e.g., Columbia Basin and Mexico), whereas the Asian model focuses do a greater degree on the formation of social capital.

Since WUAs are managed by and operated with the interests of water users in mind, they tend to substantially reduce the costs of implementing water pricing, such as monitoring and enforcement costs (Easter and Welsch, 1986b; Wade, 1987; Zilberman, 1997). For example, volumetric wholesaling is the practice by which the CWA sells water to a WUA at some point in the delivery system where volumetric measurement is possible. This practice can achieve a high degree of efficiency in the collection of water costs by the WUA (Small, 1989; Meinzen-Dick and Rosegrant, 1997). This type of distribution would require strong leadership and organization of the WUA to be responsible for delivering water in the branch canal(s) and collecting fees from each user (Easter and Welsch, 1986b). WUAs can also provide important brokering services for water trades as found in water transfers in the western U.S. (Cummings and Nercissiantz, 1989).

Many factors affect the viability of WUAs; property rights are a crucial factor[23]. The creation and ownership of irrigation property (water, conveyance structures, and pumping equipment) form the basis for relationships among the irrigators, which form the, "... social basis for collective action by irrigators in performing various irrigation tasks," (Coward, 1986). Well-defined water rights give farmers incentives to participate in the operation and maintenance of their water supply system. These rights can be assigned to individuals or to groups of farmers, such as WUAs (Wade, 1987; Feder and Noronha, 1987). The individuals or associations will have economic incentives to maximize net benefits generated by their activities (Winchelns, 1998), which include both increasing supply efficiency and production efficiency (Kloezen et al., 1997). For example, public irrigation in Mexico has undergone substantial decentralization. The resulting transfer of control to WUAs has resulted in increased O&M fee collection and provision of irrigation services (Mexico - Johnson, 1997; Pakistan – Svendsen and Nott, 1997). This property-induced cohesion is important in many aspects of water management, but it is especially critical for water allocation. Another example concerns small-scale irrigation and its link to land tenure in Niger (Norman, 1998). Niger law requires that irrigated land within "state-developed" systems belong to the state. However official policy requires all systems to be organized as cooperatives with autonomy as the goal. This has encouraged a gradual reduction in state management and correspondingly complex rules regulating system operation. As a result farmers can now pass parcel titles on to family members and subdivide individual parcels increasing user efficiency. Obviously, user groups cannot make decisions regarding water if they have no rights over that water (Meinzen-Dick and Mendoza, 1996; Johnson, 1997).

In addition user-based allocation requires collective action institutions with the authority to influence water rights. While empirical studies of water resource management have shown that such institutions can be developed spontaneously or through an external catalyst, institutions are not always in place or strong enough to make an impact (Meinzen-Dick et al., 1997). Easter and Welsch (1986b) note that the strength of these collective action institutions is directly related to water scarcity. Water must be sufficiently scarce as to provide the incentive to organize. Also affecting the viability of WUAs are the size and location of irrigation system (smaller systems within bounded areas lend themselves to farmer cooperation), relatively equal income distributions (wide economic disparities may lead to conflicting interests), and freely available information on irrigation technology (Easter and Welsch, 1986b).

The effect of user-based allocation on water conservation depends on the content of local norms and strength of local institutions (Easter, 1999). It is easier for users to organize collectively for increasing water supply (a positive-sum activity for membership) than for water distribution (at best a zero-sum activity). If the WUA does not actively promote efficient use, this allocation

[23] Feder and Noronha (1987) provide a discussion of the positive effects of secure, legal ownership of property (water rights).

mechanism will have little effect in demand management. However, social norms can provide a strong incentive for conservation, particularly if they are backed by rules against excessive consumption, monitoring of compliance, and sanctions against water waste. Where members of WUAs are conscious of the need to conserve, monitor, and trust other members to do the same such that all are contributing to the common good, WUAs can achieve high efficiency in water use (Feder and Noronha, 1987).

The practical functioning of WUAs is not without problems. In many cases the WUA organization replaces former state-controlled water agencies and adopts many of their inefficiencies. Marre et al. (1998) examines the case of low farmer participation in Mendoza, Argentina. They describe the problematic issue of low collection levels for irrigation services (average 64%) and consequent degrading of irrigation infrastructure, which leads to increased levels of farmer dissatisfaction with the system. As a result most fees are used to pay for recurrent costs (such as salaries) and a vicious circle in management results. Marre et al. (1998) advocate improvement of irrigation services and simultaneously discontinuing flows to non-payers. Similarly, Easter (1999) reviews the successes (failures) of WUAs in several Asian countries. As a percent of cost-recovery WUAs collect 65% of fees in the Philippine, 70 % in Andra Pradesh (India), 50% in Nepal, 79% in Indonesia, and 68% - 100% in Pakistan (Easter, 1999). There are several indicators used to compare irrigation system efficiencies. These are divided into crop output based measures and system. These indicators are described and illustrated in Molden et al. (1998) and Kloezen and Garcés-Restrepo (1998).

4.3 Water Policy

The water policy component of water institution includes the following policy-related institutional aspects: project selection criteria, pricing and cost recovery, inter-regional/sectoral water transfer, private sector participation, user participation, and linkages with other economic policies (Saleth and Dinar, 1999). Water provision and management policy can be characterized mainly according to levels of (de)centralization. On the one extreme lie command and control methods, in which quantities and prices are determined at the outset by some CWA (e.g., Wanjiazhai Water Transfer Project, China - Qingtao et al., 1999). The opposite extreme consists of decentralized methods based solely on market mechanisms (e.g., spot and options markets in California - Howitt, 1998). In between lies an entire policy spectrum, however, as more irrigation systems adopt market mechanisms, water policy is increasingly being driven by the necessity to define water rights and establish water markets to facilitate inter-regional and sectoral water transfers.

4.3.1 Centralized Policies

It is desirable to base prices on the marginal cost of acquiring more water or on its opportunity cost. However, prices based on marginal costs often are too high for low farm incomes. For example, farmers in India and Pakistan paid full costs of irrigation supply prior to WWII. The financial burdens incurred building huge irrigation projects during the 1950's were too large for farmers to cover. However, national policies of food security resulted in large subsidy schemes for the irrigated water systems. These trends have reversed in recent years, and users are being asked to once again fully cover costs (Dinar and Subramanian, 1997). This movement in India is not consistent and irrigation pricing varies substantially from state to state as determined by the provincial water authority: in West Bengal water rates vary by season, in Kerala rates are bases solely on area cropped, in other states water prices vary by crop, season, and irrigation project, irrigation type, category of water user, etc. (Saleth, 1997).

Several pricing alternatives have arisen to cater to farmers' ability to pay and to promote efficiency. One alternative system of dual fees would use a low initial fee for quotas plus higher marginal charges for water consumed in excess of the quota. If these quotas were traded between users, economic efficiency would be enhanced. The basic idea is that marginal prices need to be flexible enough to ration available water supplies (Seagraves and Easter, 1983). There are a variety of pricing policies that attempt to approach marginal cost pricing while balancing other considerations (such as informational, structural, and environmental concerns). Several empirical examinations of these policies are noted below.

Renzetti and Dupont (1999) evaluate a two-part water use charge. The first is annual permit fee; the second is a volumetric charge based on consumption. The use of a permit fee will enhance efficiency, improve water quality, increase government revenue, and improve the government's knowledge base regarding water use. Algeria has recently adopted a two-part tariff similar to this in order to reflect the full cost of service. However, many costs (e.g., capital equipment) continue to be subsidized by the government (Salem, 1997). Wichelns et al. (1996) evaluate a California incentive program to improve on farm management efficiencies via farm-specific water allotments, tiered water pricing, and low-interest loans for irrigation equipment. Results confirm that economic incentives can be effective in generating improvements in water quality. Recent reforms of water institutions are often coupled with new infrastructure investment. In Morocco, new infrastructure investments for the irrigated agriculture sector will be accompanied by institutional reforms aimed at improving water use efficiency. One such reform is water pricing that covers true O&M costs and that reflects the scarcity value of water in Morocco (Dinar et al., 1998).

4.3.2 Transition Policies

The transition to market-based irrigation pricing as mentioned earlier depends on the sets of rules and institutions surrounding the agricultural systems already in place. This inertia is difficult to overcome due to a variety of constraints: transaction costs (see Section 3.1.2.2), technological constraints (see Section 3.3.2), and political constraints (see Section 5). Zilberman et al. (1992) posit that the availability of new technology or institutional design may not suffice and that these obstacles may require large random shocks to overcome (e.g., the California drought of the late 1980's). Roumasset (1997) provides an overview of the literature and theory concerning the institutional aspects of water pricing and derives optimal decentralization rules depending on the policy environment. Dinar and Subramanian (1997) identify several factors that encourage and hinder policy reform: level of development (GDP per capita), per capita water availability, and the size of the budget deficit to GDP. An example lying between central regulation and market systems is Israeli differential pricing, which varies by sector and type of use (Just, Netanyahu, and Horowitz, 1997). The Israeli government sets water prices for users according to increasing block-rate structure where different users face different marginal prices. The block rate facing agriculture is not the same for all users, but is determined by farm-specific quotas.

4.3.3 Market-Based Policies

As mentioned, attributes such as external effects across users, temporal interdependencies, large fixed investments costs, and uncertain supplies, all tend to hamper the operation of water markets, hence the prospect to attain efficient allocations via markets alone (e.g., tubewell market monopolies in Bangladesh – Ahmed and Sampath, 1988). Yet this is a weak argument against water markets and in favor of centralized regulation, as the latter has its own shortcomings, including information asymmetries, large implementation costs, and susceptibility to the influence of pressure group and corruption.

The scope for water markets in allocating irrigation water is, therefore, far from negligible, and the desired level of decentralization in any allocation mechanism is of prime importance. For example, Brill, Hockman, and Zilberman (1997) compare the efficiency gains under several water policies to allocate water under reduced supply. They show that the aforementioned, tiered pricing schemes (e.g., Israel and California) result in second-best allocations. Pareto efficient allocations can be obtained via transferable water rights. They argue that even when there does not exist well-defined property rights, it is possible to avoid prohibitive transactions costs involved with trades via a "passive trading" policy, which allows a Pareto efficient allocation. Observations such as these have lead to increased interest in the use of water markets for allocating irrigation water (Dinar and Loehman, 1993; Brill, Hochman and Zilberman, 1997; Parker and Tsur, 1997; Spulber and Sabbaghi, 1998; Easter et al., 1998).

Saliba and Bush (1987) and more recently Anderson and Snyder (1997) describe the trend towards water markets in the American Southwest and West. Examples include: intra-farm trading of annual federal water entitlements (Fort Collins, CO); water banks (Idaho and California); between agriculture and urban users (Utah, Arizona, Colorado, and Nevada); between agriculture and environmental concerns (Oregon); interbasin transfers (Southwestern, USA; Australia, North America). Wilson (1997) notes reluctance to move from centralized water pricing in Arizona to water market pricing.

Water Permits and Trades

Roumasset (1997) examines water trading schemes and their dependence on top-down or bottom-up regulation. The optimal approach (whether top-down or bottom-up) is shown to depend on such variables as transaction costs, asymmetric information, intertemporal and spatial water supply. Becker et al. (1997) discuss the potential for tradable water claims in the Middle East. Empirical analysis suggests that all parties benefit from either buying or selling water. However, farmers may be reluctant to trade their water entitlements (or rights) in the short-run if they fear that they may lose them in the future. Water trading also requires a well-developed conveyance system (Zilberman et al., 1997) and the existence of appropriate institutions to overlook transactions and resolve conflicts that may arise. When these do not exist the existence of tradable water rights may lead to further inefficiencies (Rosegrant and Schleyer, 1996). Anderson and Snyder (1997b) note three arguments against market-based allocations: monopoly power, imperfect capital markets, and externalities.

Benefits of transferable water entitlements and the establishment of formal water markets have been noted in Australia (Musgrave, 1997), Chile (Hearne and Easter, 1998), Mexico (Hearne, 1998), Pakistan (Meinzen-Dick, 1998), India (Saleth, 1998), Spain (Garrido, 1998), and Canda (Horbulyk and Lo, 1998). Due to legal and institutional restrictions entitlement trading has not been as active as expected. However, increased acceptance of trades to improve delivery certainty and efficiency should lead to increased trading and diversification of available market contracts (e.g., entitlements to storage space, groundwater, and pollution dilution capacity of streams). Dudley and Scott (1998) simulate the potential of water markets using dynamic optimization. These simulations are used to derive short-run demand functions for reservoir water and marginal opportunity costs for a variety of decisions. Once these opportunity costs are determined, it is possible to derive optimal short-run water allocations.

Recently transfers of water rights have occurred for environmental amelioration (Anderson and Snyder, 1997). Huffman (1983) details how the Nature Conservancy has purchased private rights to instream flows in Colorado and private individuals have purchased instream rights in Montana in order to charge for fishing access. Similar arrangements can be found in Oregon and Arizona. Willis et al. (1998) discuss farmer costs of contingent water contracts requiring the agricultural release of stored irrigation supplies during low flow years during critical flow periods to improve salmon migration conditions. Sunding et al. (1994) illustrate that environmental legislation in California aimed at reducing agricultural irrigation diversions will lead to dramatic revenue and labor losses in the Central Valley. Using a combination of models (see Section 3.2.2.4) it is shown that water trading can reduce these losses substantially. Isè and Sunding (1997) examine the reallocation of agricultural water to provide for environmental restoration in Nevada's Lahontan Valley.

International trading agreements, few in number, have recently gained exposure. The treatments of cross-border water trading in North America are reviewed in Anderson (1994). Frisvold and Caswell (1997) note the beneficial role aid agencies may have when negotiating international water agreements. A recent example of this is the Mekong River agreement and international water allocation agreements (Browder and Ortolano, 1999). An important caveat of this agreement was that international donors agreed to subsidize the Mekong operations and water negotiations.

Water Banks

Water banks are a special case of water trading and have been promoted as a means to allocate water in a more flexible manner, subject to the limitation of large quantity transfers. Comprehensive discussion of arrangements for these specialized water rights for several states and in general framework for setting up a water bank can be found in MacDonnell et al. (1994). These are described as "institutionalized mechanism[s] specifically designed to facilitate the transfer of water use entitlements". They review the water recharge programs in 19 states and examine 5 actual banking programs in terms of legislation, logistics, and effects.

Archibald and Renwick (1998) model gains from water trades and look at the transaction costs and incentives inherent in the California State Water Bank. They find that despite significant welfare gains possible from increased traffic in water trades, there are policy-induced transaction costs that retard the California system.

Market Extensions
The need to stabilize stochastic supply may require the development of spot and options markets, whereas the permanent shifts in demand may be best realized via a system of tradable water rights. Spot and option prices are examined for new emerging markets in California (Howitt, 1998). He notes that the evolution from spot to options markets may mitigate the costs of developing alternative trading systems for permanent water rights in LDCs. These market developments are simulated using experimental economics for the San Joaquin Valley and then extended to other countries (Dinar, Howitt, Rassenti, and Smith, 1998). They show that experimental simulations based on a sample Central Valley scenario can generate competitive outcomes.

5. THE POLITICAL ECONOMIES OF WATER PRICING

The role of politics in reform, setting utility charges, tariffs and other prices that are subject to policy influence has long attracted the attention of economists. In some places the provision of free irrigation water is viewed as a human rights issue and pricing water is considered politically unacceptable. In such cases, indirect pricing (via output/input or per area pricing) might be considered. The observation that agricultural sectors in developed economies tend to be highly subsidized in contrast to those in LDCs is often attributed to political forces (de Gorter and Tsur, 1991). For example, land cultivation may serve the purpose of self-sustained food production, even though it is more economical to import some of the food. In places where water is scarce, this subsidy often includes water directly.

These issues have been discussed in Section 3, yet there remains to be a more detailed examination of the issue of political economies in water allocation and its literature. Increased water scarcity and quality concerns have generated new approaches to water management and reform. Water pricing reform among them, has been noted recently in quite a few countries[24]. However, pricing reform in practice often does not adhere to first-best allocations as prescribed by the classical economic framework. Second-best or third-best outcomes often result from special interest group pressures, or political economies. For example, when examining the provision of water, political constraints can be interpreted as part of implementation costs (e.g., San Joaquin Valley – Shah and Zilberman, 1995). In this section I will review the literature surrounding the theory of political economy of water pricing and reform.

5.1 Theory

Rent seeking occurs when decision-makers use the government to increase their personal wealth at the expense of others. Roumasset (1987) states, "... heavily subsidized irrigation design, construction, operation and maintenance invites pork-barrel politics and rent-seeking motives, that overcome the incentives for efficient provision of irrigation services." Anderson and Snyder (1997b) posit that government regulation is inherently inefficient due to public choice for the

[24] See for recent OECD water pricing reforms, OECD (1999) and Jones (1999); see for the Near East, Ahmed (1999), and for an additional 22 select countries, Dinar and Subramanian (1997).

following reasons: voters have imperfect information, special interest groups will lobby for those interests, politicians are short-sighted with respect to policy, and there are few incentives for candidates to account for individual preferences. Similarly, reform efforts, which result in a redistribution of economic benefits, will generate significant political opposition. Interest groups will form to impact the reform process so that the end results best serve their constituents. These political groups may slow, divert, or stop desirable reforms (e.g., Morocco – Dinar et al., 1998). In his book, *Cadillac Dessert*, Marc Reisner aptly describes the result of rent-seeking in irrigation projects. He details the history of "pork-barrel politics and rent-seeking motives" in the American West from the time of early Mormon settlers in Utah to current intrigues with the water lobbyists.

The literature in this vein is quite dispersed, but it is possible to identify three main approaches. The first is the interest group approach (Backer, 1983). Here political decisions are viewed as the outcome of a struggle between pressure groups (also Panagariya and Rodrik, 1993). Second is the politician-voter interaction approach where the interaction between voters and support-maximizing politicians result in policy (Peltzman, 1976; Hillman, 1989; de Gortner and Tsur, 1991). Lastly are the bargaining process models (Zusman, 1976), where policies are determined via a bargaining process with players of different power (also Scarpa, 1994; Jordon, 1995, Finkelshtein and Kislev, 1997; Zusman, 1997, Ruasser and Zusman, 1991, 1998).

Grossman and Helpman (1994) offer a synthesis approach that incorporates principal-agent theory with pressure group activity. In addition there have been recent extensions to these approaches incorporating environmental aspects of water management. These include cooperative game studies looking at incentives for individuals to participate in group management schemes (Bardhan, 1993; Hurwicz, 1998); in the exploitation of common property resources (Ligon and Narain, 1997; Becker and Easter, 1998); and the literature surrounding environmental regulation (Laffont and Tirole, 1996; Chen et al., 1998; Loehman, 1998).

5.2 Applications to Irrigation Water

Recent studies looking at irrigation water reform often will employ one or more of these approaches to model the political economy involved. For example, lobbying efforts for irrigation in the American West have possibly provided the greatest source of material for political economy water studies. Already mentioned, Reisner (1993) traces the history of U.S. land reclamation in the West, taking pains to highlight the highly subsidized, inefficient, and inequitable nature of the irrigation water provided by Congress to western states. He hypothesizes that a significant reason behind President Carter's resounding election defeat in 1980 was due to his opposition to funding "a couple dozen" extremely questionable and expensive irrigation projects. Rucker and Fishback (1983) examine the early activities of the Bureau of Reclamation following the Reclamation Act of 1902 using a simple rent-seeking model. Gardner (1983) discusses how in the irrigation economy of California, water is a constraining input and is often priced below the value of its use. Both of these studies use the difference between optimal prices and actual prices as evidence of rent seeking and describe how these rents eventually dissipate with further rent-seeking behavior. Another early California study illustrates how the interest group model, the politician-voter model, and the bargaining approach can all be found in water pricing (Cuzán, 1983).

However, as a framework for describing this literature, it is useful to understand the reasons for reform, the institutions undergoing reform, who is supporting/opposing the reform and compensation mechanisms, and possible international influences on the reform process (Dinar, 2000). This framework traces reform efforts from its initial stages to post-reform effects, and resembles similar examinations of reform found in White (1990), Krueger (1991), Williamson (1994) and Haggard and Webb (1996).

5.2.1 Reasons for Reform

In many cases reform efforts directed at water pricing are simply the results of financial crisis, low cost recovery percentages, deteriorating facilities, and increasing water demand (e.g., for Asia - Easter, 1987; for Egypt – Wichelns, 1998; for Pakistan – Wambia, 2000). However, there are often other motives such as linking water sector reform to other macroeconomic reforms that are indirectly related (e.g., for Morocco – Diao and Roe, 2000; for Yemen – Ward, 2000). Just et al. (1997) observe that standard economic analyses contend that economic efficiency is improved by equating prices and that current deviations are the result of political power. A different interpretation for Israel and Jordan are concerns for food security, infant-industry motivations, settlement policies (national security), and equity issues. It may be more efficient to partially equalize water prices when new water supplies are developed. Such political power framework incorporating lobbying has been used to evaluate optimal environmental regulation mechanisms. The mechanism of environmental regulation will depend on the weights society places on laborers and capitalists (Chen et al. 1998).

5.2.2 Institutions and Reform

As previously mentioned, the institutional framework and its changing nature are intrinsically lined to political economy considerations. These considerations include existing institutions, the power system, and the electoral system.

Existing Institutions

Decentralization of existing water institutions often comes with some reluctance (Wilson, 1997), which may impair the effectiveness of reform. It is often necessary to actively engage existing bureaucracies in the reform process (de Azevedo and Asad, 2000) or to induce farmers to view water management as a public good (Bromley, 2000) in order to overcome political transaction costs in reform. Garrido (1998) compares allocations between conventional profit maximization for an individual farm, an intra-community water market, and to an inter-community water market. Empirical estimates were generated using EPIC (see appendix) as well as on site experimental research. The resulting allocations were shown to be sensitive to transaction costs, but that decentralization generates a range of short-run probable gains.

Rausser and Zusman (1991) examine the political history of collective action in Western US water resource systems. Their model includes a (n+2) player game: the CWA seeks to maximize cost efficiencies and political recognition, n-districts seek to maximize profit, and the government pursues both selfish and unselfish "public interest" goals. The resulting model determines water prices in what Rausser and Zusman term as the "Hydrological-Political-

Economic Equilibrium. They note that for equilibrium prices to be efficient two conditions must be met: a uniform distribution of power and that all districts account for ground-water level effects. Building on this model, Zusman (1997) incorporates asymmetric information into the optimal regulation regime. The optimal regulator size should be controlled to minimize the political power distortions caused by rent seeking. This will also minimize operating and transaction costs in the system.

The Political Establishment

The political establishment includes political parties, electoral systems, and interest groups. These groups form a dynamic atmosphere in which the reform process occurs. Rausser (2000) provides a game theoretic and a bargaining approach to evaluating this dynamic interaction for water policy reform. The strengths of the various groups depend on such things as informational power, which can lead to second-best allocations, and are thus important when planning and implementing water pricing reform. Tsur (2000) illustrates how asymmetric information can lead to second-best allocations in pricing reform. Cueva and Lauria (2000) and Renzetti (2000) illustrate how such second-best allocations can arise from ignoring the power system and how to incorporate them into third-best reform efforts.

The electoral system that determines how laws are changed and what direction reform efforts will take are encompassed in the political establishment. McCann and Zilberman (2000) examine the results of water district voting in California. They note that resulting allocation depend on the electoral rules. In some instances (property-weighted voting) district managers will not seek to maximize consumer welfare. In Dinar, Balakrishnan, and Wambia (1998) the actions of politicians in the water sector are endogenized to estimate the political risks associated with reform. They develop a two-tiered approach to first assess power distribution among groups interested in reform effects, and then to incorporate a Delphi process (summary of expert opinions) to determine the risks associated with reform. This approach is used to examine the National Drainage Program Project in Pakistan. An extension of the politician-voter literature to include the trade-offs between environmental policy and rent producing firms that pollute can be found in Boyer and Laffont (1996). They show that the thinner the majority of environmentally conscious voters and the larger the informational rents, the more the politician's objectives are biased away from social welfare. These incentives are subject to change when reelection considerations affect reputation and social control.

5.2.3 Support and Opposition

As touched on earlier, water pricing and reform creates a dynamic interaction between existing institutions and the political establishment. Dinar (2000) contains reviews of reform efforts in 5 countries (see appendix), which document the supporting and opposing groups in these case studies. In most cases (Musgrave, 2000; de Azevedo and Asad, 2000; Kemper and Olson, 2000; Ward, 2000) the reform efforts stemmed from existing inefficiencies in pricing policy (i.e., subsidized irrigation water). However, environmental quality can also be a motivating factor (waterlogging and salinity - Wambia, 2000).

5.2.4 Compensation Mechanisms

Opposition to water sector reform is often subverted via payoff mechanisms that reimburse negatively affected parties. For example, the optimal regulation model developed in Zusman

(1997) seeks to maximize the sum of utilities of all water users in a system subject to the constraint that system costs should be fully covered by system revenues. In addition, I have mentioned earlier the need to include affected interest groups in the reform process (de Azevedo and Asad, 2000). In addition to including existing institutions, it is also necessary to weigh equity and environmental concerns when planning and implementing water pricing reform. Boland and Whittington (2000) conclude that often reform in LDC water pricing policy comes with unaccounted adverse effects on poor households. It may be necessary to balance the need to increase efficiency with that of enhancing equity.

Other payoff mechanisms include sharing of reform benefits or compensation of reform costs. For example, Diao and Roe (1999, 2000) show how water reform can be coupled with trade reform to generate a win-win situation for Moroccan agriculture. They employ a general equilibrium treatment of trade and water reform in the Moroccan agricultural sector to estimate investment and economic growth responses. They note that there will most likely be reallocations of resources from import competing crops to the production of fruits and vegetables. The resulting change in return to sector-specific assets will likely cause interest group conflict opposing the trade reforms. This tension may provide an opening to reform the irrigation pricing policies, and reimburse the import competing agricultural sector with consequential efficiency gains.

5.2.5 International Influence

Barrett (1994) includes a discussion of the management of conflict with international water resources. He examines previous water laws and treaties in the simple Nash-game viewpoint. Cases include the Columbia River Treaty (Canada and the US) and the Indus River Treaty (India and Pakistan). He then goes on to describe Coase's Theorm and its implications for a Nash-game type of scenario. This ignores the equity aspect of water resource issues as between two countries and possible externalities imposed (Diao and Roe, 1995). Hurwicz (1998) extends a Coasian economy / Nash equilibrium to include market mechanisms to achieve the optimal allocations.

Howitt and Vaux (1995) describe the formation of water coalitions in California as a cooperative game driven by rents accruing to economies of scale in sharing costs. A similar cooperative outcome for international water resource exploitation is modeled in Becker and Easter (1998) depending on the number of participants and the degree of cooperation induced by economic incentives. Frisvold and Caswell (1997) develop a game-theoretic approach to describe the Nash-like scenario facing countries involved in transboundary water transfers and pollution abatement agreements. They conclude that international development assistance can encourage joint water quality projects. This carrot-approach to encouraging international water agreements may be an effective way for the international donor community to deal with water conflicts (e.g., Mekong River agreement - Browder and Ortolano, 1999). The opposite (stick) approach to encourage cooperative bargaining agreements for environmental regulation is described in Loehman (1998). Here cost sharing among polluters and sufferers is required for Pareto improvements via cooperative bargaining.

Roe and Diao (1997) use a general equilibrium treatment of a shared water aquifer to evaluate one country's water policy on another country. Various water tax, subsidy, and technology structures are simulated to estimate effects on GDP. An externality is introduced into the basic Heckscher-Olin framework to represent extraction effects of one country on another country's water endowment. Results imply each country has an incentive to subsidize water use and, thus, lessen water availability to the other country. The optimal solution is for a cooperative tax on water use in each country. This simple model (similar to a Nash-game) can be used to represent in a stylized manner the case of Israel and Jordan. Other international influences on water reform include loan conditionalities (Krueger et al., 1991) and trade agreements (Dinar, 2000).

6. CONCLUDING COMMENTS

As indicated in the executive summary, there is quite a range of issues the touch directly and indirectly on irrigation water pricing. I have attempted to include and synthesize the most relevant literature under the seven broad section headings. Rather than provide a summary and reference list at the end of each of those sections I do so here. However, for those that do not have unfettered access to these studies, it is hoped that the discussion provided under the broad section headings will prove useful and relevant to current pricing policy questions.

I would like to first focus on several literature sources essential for this review. Above all, the Natural Resource Management and Policy Series published by Kluwer Academic Publishers[25] as edited by Ariel Dinar and David Zilberman is an excellent source of information for irrigation practitioners and policy makers. They review a vast array of recent research and often contain empirical applications and case studies. In this series I have drawn heavily from:

- *Conflict and Cooperation on Trans-Boundary Water Resources*, edited by Richard Just and Sinaia Netanyahu.
- *Markets for Water: Potential and Performance*, edited by K. William Easter, Mark W. Rosegrant, and Ariel Dinar.
- *Decentralization and Coordination of Water Resource Management*, edited by Douglas D. Parker and Yacov Tsur.
- *Economics of Water Resources. From Regulation to Privatization*, edited by Nicolas Spulber and Asghar Sabbaghi.
- *The Economics and Management of Water and Drainage in Agriculture*, edited by Ariel Dinar and David Zilberman.

In addition to these, the IIMI[26] research report series and the review by Dinar and Subramanian (1997) provide a current overview of the prevailing irrigation systems found around the world. Other reviews used extensively in this survey are:

- *Designing Institutions for Environmental and Resource Management*, edited by Edna Tusak Loehman and D. Marc Kilgour.

[25] Kluwer Academic Publishers: 101 Philip Drive / Assinippi Park / Norwell, MA 02061 / USA or Distribution Centre / Post Office Box 322 / 3300 AH Dordrecht / The Netherlands.
[26] International Irrigation Management Institute / P.O. Box 2075 / Colombo, Sri Lanka.

- *Water Quantity/Quality Management and Conflict Resolution*, edited by Ariel Dinar and Edna Tusak Loehman.
- *Sustainability, Growth, and Poverty Alleviation*, edited by Stephen A. Vosti and Thomas Reardon.
- *The Political Economy of Water Pricing Reforms*, edited by Ariel Dinar.

These and the many other studies, case studies, and research articles that I have outlined in the survey indicate that the methods surrounding irrigation water pricing have many dimensions, both theoretical and practical. That these issues will become increasingly important, as future water and food demands increase, is not in question. Efficiently pricing water will help meet these increasing demand, but what is the best way to increase pricing efficiency? Many argue that water markets offer one solution, however, under which circumstances are water markets viable? What effect will decentralization have on farm production and the rest of the economy? What are the forces that are moving towards decentralization or (re)centralization? The answers to these questions are complex and often site specific, which is why the list of case studies in the appendix may assist in locating useful comparisons to other sites. In the following section I will summarize the main points found earlier in the survey.

Water Pricing Methods

A variety of pricing methods and various studies aimed at determining the efficiency and equity of those methods have been outlined. A brief summary of these methods is found below (see also Tsur and Dinar 1995, 1997). To reflect the different means of evaluating pricing efficiency and equity, these methods have been compared across several broad categories: difficulty of implementation, potential efficiency, time horizon of efficiency, ability to control demand, affect on income distribution and on water quality (see Table 2).

Volumetric Pricing (Marginal Cost Pricing)

A volumetric pricing policy in which the price of water is equal to the marginal cost of supply achieves first-best efficiency. A departure from marginal cost pricing may be required if the pricing mechanism seeks to recover capital depreciation and other fixed costs. In this situation, volumetric pricing can achieve a second-best efficient allocation. As (homogenous) farmers will face the same price, income inequality is due solely to land endowments and is not affected by pricing[27]. Marginal costs of supply will increase as water quality erodes and therefore volumetrically charged prices will increase as well to reveal the real value of water. Countries employing volumetric pricing include[28]: India (OM-CD), Jordan (OM), Mexico OM), Morocco (OM), England OM-CD), France (OM-CD), Australia (OM), U.S.A. (OM-CD), and Israel (OM-CD).

Output and Input Pricing

Because output taxes and zero price of water may distort input/output decisions the equilibrium allocation is second best. Any measure of income equality will likewise be affected by land endowments and not by the pricing mechanism. As output taxes are not assessed until the crop is

[27] Rhodes and Sampath (1987) illustrate how the optimal pricing mechanism depends heavily on the relative capital intensities between small and large farmers.

[28] OM = seeks to at least partly recover operation and management costs; CD = seeks to at least partly recovery capital depreciation (Tsur and Dinar, 1995).

marketed this method of pricing does not allow flexibility of water quality conditions. Similarly, input taxes will be assessed at the beginning of the growing season and are not flexible to changing water quality conditions in the short-run.

Per Area Pricing

Demand under this pricing mechanism is larger than that under marginal cost pricing rule, hence the resulting allocations will be inefficient. It is possible to influence water demand directly via differential fee schemes. As before, income inequality is linked to land endowments and is unchanged by the pricing scheme. Similarly to output pricing, per area pricing is not flexible to changing water quality conditions in the short-run. Countries employing per area pricing include[29]: China (OM), India (groundwater), Iraq, Mexico (OM), Nigeria (OM), Pakistan (OM), Peru (OM-CD), Philippines (OM), and Zimbabwe (OM).

Tiered Pricing

This pricing method is common when water demand has period variations: during low demand periods (supply > demand) marginal cost pricing achieves (short-run) efficiency; during peak demand periods (demand ≥ supply) pricing accounts for the scarcity value of water (marginal supply costs plus shadow price of water availability). This method does not affect the income inequality of homogenous farmers and allows some flexibility in dealing with changing water quality. Another tiered pricing method (increasing blocks) discounts prices in favor of irrigators (relative to domestic or industry), which may in the long run negatively affect measures of efficiency, equity, and water quality. If this second tiered method is coupled with water quotas allocated on an equal basis between farms (independent of size) the resulting allocations will redistribute rent from larger farms to smaller farms. Tiered pricing systems can be found in Israel (coupled with a multi-rate volumetric method) and in California (also coupled with a multi-rate volumetric method).

Two-part Tariff

By introducing the admission fixed charge to balance the budget of the CWA, the short-run efficiency of marginal cost pricing is extended to account for long-run fixed cost considerations. An annual *Pigouvian* tax avoids distortionary affects of other taxing forms and is therefore capable of achieving long-run efficiency. Two-part water tariffs used to recover total operating costs may discriminate against farmers as many argue social benefits of irrigation accrue not only to farmers, but also to consumers of farm products. As with volumetric pricing, this pricing mechanism will reflect increasing marginal costs of supply and is flexible to water quality changes.

Water Markets

Water markets will achieve first-best allocations under specialized conditions. Water markets rarely exhibit all these conditions, but the resulting second-best allocations may be more efficient than those achieved under the preceding methods. This is due to the internalization of information collection and absence of strong CWA to administer water allocations. Water markets in noncompetitive environments can lead to monopoly pressures on water prices, which

[29] As above.

are likely to adversely affect income distributions. They do allow the greatest flexibility in responding to changing water quality and will reflect the real value of water.

Table 1: Comparison of Pricing Methods with Efficiency / Equity / Water Quality Management

Pricing Scheme	Implementation	Potential Efficiency Achieved	Time Horizon of Efficiency	Ability to Control Demand	*Affect on Intra-Sectoral Income Distribution	Adaptability to Water Quality Conditions
Single-rate Volumetric	Complicated	First-best	Short-run	Easy	Small / None	Easy
Output / Input	Less Complicated	Second-best	Short-run	Relatively Easy	Small / None	Difficult
Per Area	Easy	None	N/A	Through Variable Cropping Restrictions/ Fees	Small / None	Difficult
Tiered	Relatively Complicated	First-best	Short-run	Easy	Moderate	Relatively Easy
Two-Part	Relatively Complicated	First-best	Long-run	Relatively Easy	Moderate	Relatively Easy
Water Markets	Difficult	First-best	Short-run / Long-run	Depends on Type of Market	Depends on Type of Market	Easy

Source: Adapted from Tsur and Dinar (1995).

* The potential for redistribution depends on the assumption of homogenous farmers. In cases where farmers are employing different technologies and are growing different crops, pricing mechanisms can target certain agricultural sectors to pay more or less than other sectors.

Pricing Theory

There are various means by which one could outline and summarize the broad swath of literature surrounding the theory of irrigation water pricing. I have separated these articles into three broad headings: partial equilibrium, general equilibrium, and water quality management. The majority of studies on irrigation water pricing are partial equilibrium in nature and attempt to explain deviations from first-best allocations. Examples are: Vermillion (1997) and Easter, Becker, and Tsur (1997) regarding the public good nature of irrigation services; Rosegrant and Binswanger (1994) Tsur and Dinar (1997), and Barrett and Sinclair (1999) regarding implementation costs; Loehman and Dinar (1994) and Smith and Tsur (1997) concerning asymmetric information; MacDonnell et al. (1994) and Willis et al. (1998) on third party effects; Tsur (1990, 1997), Tsur and Graham-Tomasi (1991), and Moreno et al. (1999) on supply scarcity; and Spulber and Spagghati (1998) on returns-to-scale. There is a significant literature concerning the equity of irrigation pricing. The main works include Rhodes and Sampath (1988), Sampath (1991, 1992), and Tsur and Dinar (1995).

Smaller in size, but not in importance, are the general equilibrium and water quality management studies. These studies investigate not necessarily deviations from first-best equilibrium, but the effects of implementing pricing or environmental policies on the agricultural sector and the economy as a whole. Key among the general equilibrium studies are Robinson et al. (1993), Roe and Diao (1995, 1997), Goulder et al. (1999), and Diao and Roe (1998). The water quality literature can be divided into those studies examining water pollution and that examining water conservation. Key pollution studies include the review by Dinar and Zilberman (1991), Biswas (1997), Segerson (1988), Kim et al. (1997), and Goetz and Zilberman (1998). Notable in the conservation literature are several recent economic reviews of the management for groundwater systems (Gisser, 1983; Tsur and Zemel, 1995; Zilberman, 1997) and for conjunctive management with surface water (Tsur, 1990; Boggess et al., 1993; Zilberman, 1997).

Water Law and Property Rights

Water law and property rights highlight the effects of already linked legal aspects of conflict resolution and accountability. It influences water policy via effects on water pricing, cost recovery, management decentralization, and private sector participation. Water law and rights effect water administration because of implementation mechanisms, user participation, and management decentralization. Saleth and Dinar (1999) have determined that there are four critical variables that effect performance of water law: integrated treatment of water sources, effectiveness of conflict resolution, degree of integration within water law, and legal scope for private sector participation. As mentioned the water law component of water institutions incorporates other factors as well. These include the following law-related institutional aspects: provisions for conflict resolution (Dinar and Loehman, 1995), provisions for accountability, scope for private sector participation, centralization tendency, and degree of legal integration within water law (Saleth and Dinar, 1999).

Water Administration

Reform efforts targeted at government provision of irrigation water services hinted at in earlier sections, are largely due to the realization of government failures. These failures include: misallocated project investments, overextended government agencies, inadequate service delivery to the poor, neglect of water quality and environmental concerns, and the underpricing of water resources.

Consequently, reform efforts targeted at water supply have been increasing. This reform is linked to the aforementioned government failure, but is mainly due to three reasons: lack incentives and responsiveness to optimize management performance, management transfers coupled with supportive social and technical support will result in improved system quality and efficiency, and management transfers will save the government money in terms of reduced O&M responsibilities.

To address other market failures associated with the provision of irrigation water, other reform efforts have been targeted at the implementation of Water User Associations. It has been shown that WUAs tend to substantially reduce the costs of implementing water pricing (Easter and Welsch, 1986b; Wade, 1987). The associations have economic incentives to maximize net benefits generated by their activities (Winchelns, 1998), which include both increasing supply efficiency and production efficiency (Kloezen et al., 1997). However, the impact of WUAs on irrigation performance requires evaluation to determine whether these new the gains from farmer participation are not outweighed by increased costs in other areas. For example, an important indicator measuring the successes of new management regimes are levels of transaction costs (Feeny, 1998).

Note that this process of decentralization of O&M and of farmer participation is far from complete. Ruttan (1998) notes that institutional design remains problematic and those capable of balancing efficiency and equity must "... proceed on an ad hoc, trial-and-error basis, and errors continue to be expensive." Meinzen-Dick (1997) points out that long-run farmer participation in the system may be the most important performance indicator of WUAs, which has yet to be measured for most countries.

Water Policies

The movement from centralized water pricing to decentralized market-based mechanisms is occurring globally. Recent examples from a variety of countries (Dinar and Subramanian, 1997) confirm that, even in countries with centralized water structures, there is an increasing realization that water subsidies to the agricultural sector and government inefficiencies require higher water prices and better marketing institutions to meet increasing scarcity. To meet this need, a large interdisciplinary body of literature has emerged to address different aspects of water management under various conditions. The wide range of policies currently being promoted to price and market irrigation water can be loosely grouped from centralized policies to decentralized, market-based policies. Some of these have been described above (see also appendix). Easter et al. (1998) discuss the potential future of water markets. They note the potential economic benefits from water markets are likely to be very large in the future subject to transaction costs. To keep these costs low requires appropriate institutional and organizational structures as well as flexible infrastructure and management. Spot markets for water combined with options markets may provide sufficient security to farmers for these efficiency gains and low transaction costs, even if legally enforceable water rights are difficult to establish.

An alternative categorization of policies addressing water scarcity is supply management vs. demand management. Supply management seeks to increase the available water supply. Some examples are extracting from local aquifers, bringing in more water from water-abundant regions, or decreasing water outflow (by a system of dams). Exploitation of ground water sources is one potential area of increased supply (Rosegrant and Perez, 1997). The future of supply management policies is becoming limited, as most of the diversion projects, dams, and aquifers that pass a cost-benefit test have already been exploited and the remaining sites are either too costly or involve international disagreements. Technological advances may increase the feasibility of future irrigation projects, but as mentioned most recent efforts are directed towards existing system modernization. As a consequence nontraditional sources are likely to be a major component of new water supplies: desalinization, recycling, water catchment systems (Rosegrant, 1997; Rosegrant and Meinzen-Dick, 1996).

Demand management seeks to encourage more efficient use of available water. These have historically been ignored for the most part, and hence convey a large potential for managing scarcity. A demand management policy of irrigation water consists of a combination of quotas, and prices. It may be centralized, operating in a command-and-control fashion, or decentralized to various degrees, allowing certain market mechanisms in which water users are free to decide on their water intake. Potential efficiencies in water use resulting from demand strategies will serve to extend scarce water resources (e.g., the development and adoption of resource-augmenting techniques had been well documented: Caswell et al., 1993; Shah et al, 1995). Policies that rely on quotas are typically more centralized, while pricing policies can be either centralized or decentralized. These policies have been already touched on earlier, but also are evident in the case studies mentioned in the appendix.

Political Economies of Pricing Irrigation Water

Merrey (1997) at IIMI comments, "*Everyone involved in irrigation and water resource issues claims to recognize that institutional, policy, and political issues are central causes of poor performance. But it has proven difficult to focus governments' and donors' attention on these matters, and develop long-term solutions that can be implemented.*" However, compared to other aspect of irrigation water pricing, studies both theoretic and empirical of the political economies of pricing are relatively unexplored. These concerns are extremely important when trying to balance optimal allocations and pricing policies with equity concerns.

Several promising avenues for this research include extensions of rent-seeking models to water management case studies, game theory extensions to dynamic and non-cooperative games in water pricing, and further use of computable general equilibrium models to explore the effects macroeconomic policies on the irrigated agricultural sector. Examples of these include Zusman (1997), Frisvold and Caswell (1997), and Diao and Roe (1999) respectively.

Another channel for productive analysis in this area is the application of endogenous growth theory to decentralization in irrigation management, to technology adoption and innovation, and to growth effects of income distribution. Aghion and Howitt (1998) discuss these issues in their comprehensive text, *Endogenous Growth Theory.* They note that redistributive policies in the form of transferred resources may enhance aggregate incentives. This has important implications for the projected impacts of pricing reform in terms of agriculture sector growth. Vosti and Reardon (1997) address these concerns in their review: *Sustainability, Growth and Poverty Alleviation.* They focus on the links between the adverse affects of rural poverty on development, political stability, and the environment.

It should be noted that water scarcity has often led to a history of disputes and conflicts. These have generated enormous costs and adversely affected populations of people. One example is the displaced population problem associated with large dam projects (e.g., Shuikou, China - Thayer, 1997). Postel (1999) reviews the history of irrigation-based societies and argues that disruptions in the orderly working of irrigation water supplies were main reasons for the downfall of many ancient societies (Sumeria, Babylon, and Assyria). Recent conflicts over water are detailed for the Middle East and Asian subcontinent (Gleick, 1993, 1997; McCaffrey, 1993; Postel, 1999) and for the American West (Colby, 1997; Gleick, 1997). The resolution of these conflicts often follows strictly political lines. Dinar and Loehman (1993) review case studies in water conflicts and theoretical approaches to their resolution.

Summary

Water scarcity is an ever-growing global problem. Increased population pressures, improved living standards and growing demands for environmental quality, have all prompted governments to find better ways to manage their available water resources. Most economists agree that if water users pay the marginal cost of supplying that water, significant movements towards increasing our water management efficiency would be made. Section 3 discusses the many peculiarities associated with irrigation systems make it difficult to quantify and charge via marginal cost pricing. This would increase the cost of irrigation water for most farmers globally. The equity of marginal cost pricing is also in question as many small farmers would not be able to continue farming under such a pricing mechanism. There is continued debate as to the role of irrigation and farming as a development tool and as a means to redistribute wealth to both producers and consumers via cheaper staple food prices. As the general equilibrium section illustrates, one means to enhance water management efficiency is to allow inter-regional or international trading of water. The caveat to this argument as with marginal cost pricing, is whether these trades or pricing mechanisms are long-run solutions, when environmental concerns are incorporated.

Necessary for implementing any pricing policies are the various water institutions discussed in Section 4. These are also undergoing significant changes stemming from increased water demand. There are quite a number of case studies mentioned that trace the movement in countries' irrigation management from centralized water authorities to decentralized water supplier and water user organizations. The policies associated with these changes reflect the aforementioned movement towards market-based means to price water. The reason for these changes is not only increased water scarcity, but also political pressures. These pressures can be traced historically (as in the aforementioned case studies) and can also be understood in a fundamental sense via various political economy mechanisms. This last section of the survey is a logical place to end (excepting annotation of case studies). With any change in environment, whether it is physical in the case of increasing water scarcity or whether it is political in the case of changing water institutions, there are groups who will be better off and those who will be worse off. When examining the potential of an irrigation pricing mechanisms to better manage existing water supplies, it is essential to evaluate these groups in order to successfully implement the pricing policy.

REFERENCES

Aghion, P. and P. Howitt. 1998. *Endogenous Growth Theory*, MIT Press, Cambridge, MA.

Ahmed, A.U. and R.K. Sampath. 1988. "Welfare Implications of Tubewell Irrigation in Bangladesh," *Water Resources Bulletin*, 24(5): 1057-1063.

Ahmed, A.U. and R.K. Sampath. 1992. "Effects of Irrigation-Induced Technological Change in Bangladesh Rice Production," *Amer. J. Agr. Econ.*, 74(1): 144-157.

Anderson, R.L. and A. Maass. 1987. *A Simulation of Irrigation Systems: The Effects of Operating Rules on Production and Income on Irrigated Farms*, Krieger Publishing, Malabar, FL.

Anderson, T. (ed.) 1993. *Water Rights: Scarce Resource Allocation, Bureaucracy, and the Environment*, Pacific Institute for Public Policy Research, San Francisco.

Anderson, T., O.R. Burt, and D.T. Fractor. 1983. "Privatizing Groundwater Basins: A Model and Its Application," in T. Anderson (ed.) *Water Rights: Scarce Resource Allocation, Bureaucracy, and the Environment*, PIPPR, San Francisco.

Anderson, T. 1994. "[Introduction:] From Political Water to Private Water," in Terry Anderson(Ed.) *Continental Water Marketing*, Pacific Research Institute for Public Policy, San Francisco.

Anderson, T. (Ed). 1994. *Continental Water Marketing*, Pacific Research Institute for Public Policy, San Francisco.

Anderson, T. and P.S. Snyder. 1997a. "Priming the Invisible Pump," *PERC*, Issue Number PS-9.

Anderson, T. and P.S. Synder. 1997b. *Water Markets: Priming the Invisible Pump*, Cato Institute, Washington, D.C.

Archibald, S.O. and M.E. Renwick. 1998. "Expected Transaction Costs and Incentives for Water Market Development," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Asano, Takashi. 1997. "Wastewater Reuse." In Asit K. Biswas (Ed.) *Water Resources: Environmental Planning, Management and Development*, McGraw-Hill, New York.

Bandaragoda, D.J. 1998. *Design and Practice of Water Allocation Rules: Lessons from Warabandi in Pakistan's Punjab*, IIMI, Research Report #17, Colombo, Sri Lanka.

Bandaragoda, D.J. 1998. *Need for Institutional Impact Assessment in Planning Irrigation System Modernization*, IIMI, Research Report #21, Colombo, Sri Lanka.

Bardhan, P. 1993. "Analytics of the Institutions of Informal Cooperation in Rural Development," *World Development*, 24(4): 633-639.

Barrett, R. and P. Sinclair. 1999. "Water Charges and the Cost of Metering," Paper Presentation, 6th Conference of the International Water and Resource Economics Consortium, Hawaii.

Barrett, Scott. 1994. "Conflict and Cooperation in Managing International Water Resources," World Bank, Policy Research Working Paper #1303.

Baumol, W.J. and D.F. Bradford. 1970. "Optimal Departure from Marginal Cost Pricing." *American Economic Review*, 60: 265-283.

Baumol, W.J. and W.E. Oates. 1989. *Theory of Environmental Policy*, Cambridge University Press, New York.

Becker, N., N. Zeitouni, and M. Shechter. 1997. "Employing Market Mechanisms to Encourage Efficient Use of Water in the Middle East," in Parker and Tsur (Eds.) *Decentralization and Coordination in Water Resource Management*, Kluwer Academic Publisher, Boston.

Becker, N. and K.W. Easter. 1998. "Conflict and Cooperation in Utilizing a Common Property Resource," *Natural Resource Modeling*, 11(3): 173-198.

Berk, Peter, Sherman Robinson, and George Goldman. 1991. "The Use of Computable General Equilibrium Models to Assess Water Policies," in Arial Dinar and David Zilberman (Eds.) *The Economics and Management of Water and Drainage in Agriculture*, Kluwer Academic Publishers, Boston.

Bhat, M.G., R.R. Alexander, B.C. English. 1998. "Toward Controlling Nonpoint Source Pollution of Groundwater: A Hierarchical Policy Formulation Game," *Natural Resource Modeling*, 11(4): 379-403.

Bilen, O. 1995. "Setting Up a National Water Policy Through an Integrated Water Resources Management Strategy: the Turkish Case," in *Methodology for Water Policy Review and Reform*, FAO, Rome.

Binswanger, Hans P., Klaus Deininger, and Gershon Feder. 1993. "Agricultural Land Relations in the Developing World," *Amer. J. Agri. Econ.*, 75: 1242-1248.

Biswas, Asit (ed.) 1997. *Water Resources: Environmental Planning, Management and Development*, McGraw-Hill, New York.

Biswas, Asit K. 1997, "Water Development and Environment." In Biswas (ed.) *Water Resources: Environmental Planning, Management and Development*, McGraw-Hill, New York.

Bjornlund, H. and J. McKay. 1999. "Do Water Markets Promote a Socially Equitable Reallocation of Water? A Case Study of a Rural Water Market in Victoria, Australia," Paper Presentation, 6th Conference of the International Water and Resources Consortium, Hawaii.

Blomquist, S. and V. Christiansen. 1999. "The Political Economy of Publicly Provided Private Goods," *Journal of Public Econ*, 79: 31-54.

Boggess, W., R. Lacewell, and D. Zilberman. 1993. "Economics of Water Use in Agriculture," in Carlson, Zilberman, and Miranowski (eds.) *Agricultural and Environmental Resource Economics*, Oxford University Press, London.

Boland, J.J. and D. Whittington. 2000. "The Political Economy of Water Tariff Design in Developing Countries: Increasing Block Tariffs vs. Uniform Price with Rebate Designs," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Bos, M.G. and W. Walters. 1990. "Water Charges and Irrigation Efficiencies." *Irrigation and Drainage Systems*, 4: 267-278.

Bos, M. G., J. Vos, and R.A. Feddes. 1996. *CRIWAR 2.0: A Simulation Model on Crop Irrigation Water Requirements*, ILRI, Netherlands, Publication 46.

Bovenberg, A.L. and R.A. de Mooij. 1997. "Environmental Tax Reform and Endogenous Growth," *Journal of Public Economics*, 63: 207-237.

Boyer, M. and J. Laffont. 1996. "Toward a Political Theory of Environmental Policy," *Economics Energy Environment*, Fondazione Eni Enrico Mattei (October).

Brewer, J.D., R. Skathivadivel, and K.V. Raju. 1997. *Water Distribution Rules and Water Distribution Performance: A Case Study in the Tambraparani Irrigation System*, IIMI, Research Report #12, Colombo, Sri Lanka.

Brill, E., E. Hochman and D. Zilberman. 1997. "Allocating and Pricing at the Water District Level." *American Journal of Agricultural Economics*, 79: 952-963.

Bromley, D.W. (ed.) 1995. *The Handbook of Environmental Economics*, Blackwell Publishers Ltd., Cambridge, MA.

Bromley, D.W. 2000. "Property Regimes and Pricing Regimes in Water Resource Management," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Browder, G. and L. Ortolano. 1999. "An Analysis of the Negotiations for the 1995 Mekong Agreement," Paper Presentation: 6th Conference of the International Water and Resource Economics Consortium, Hawaii (June 29 – July 3).
Brown, G. and C. B. McGuire. 1967. "A socially Optimal Pricing Policy for a Public Water Agency." *Water Resources Research*, 1: 33-43.
Carruthers, Ian. 1996. "Economics of Irrigation," in *Sustainability of Irrigated Agriculture*, (ed.) L.S. Pereira et al., Kluwer Academic Publishers, Netherlands.
Carruthers, I., M.W. Rosegrant, and D. Seckler. 1997. "Irrigation and Food Security in the 21st Century," *Irrigation and Drainage Systems*, 11: 83-101.
Caswell, M. and D. Zilberman. 1985. "The Choices of Irrigation Technologies in California," *Amer. J. Agri. Econ.*, 67: 224-234.
Casswell, M. and D. Zilberman. 1986. "The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology," *Amer. J. Agr. Econ.*, 68: 798-811.
Caswell, M., E. Lichtenberg and D. Zilberman. 1990. "The Effects of Pricing Policies on Water Conservation and Drainage." *American Journal of Agricultural Economics*, November: 883-890.
Caswell, M., D. Zilberman, and G. Casterline. 1993. "The Diffusion of Resource-Quality-Augmenting Technologies: Output Supply and Input Demand Effects," *Natural Resource Modeling*, 7(4): 305-329.
Chaudry, M.A. and R.A. Young. 1990. "Economic Impacts of Alternative Irrigation Water Allocation Institutions: Pakistan's Warabandi System," in Sampath and Young (eds.) *Social, Economic, and Institutional Issues in Third World Irrigation Management*, Westview Press, Boulder, Co.
Chen, K, T.Tomasi, and T. Roe. 1998. "Pollution Regulation in a Political Economy," in Loehman and Kilgour (eds.) *Designing Institutions for Environmental and Resource Management*, Edward Elgar, Northampton, MA.
Chiang, A.C. 1992. *Elements of Dynamic Optimization*, McGraw-Hill Inc., New York.
Clark, C.W. 1990. *Mathematical Bioeconomics*, John Wiley & Sons, Inc., New York.
Coase, R. 1970. "The Theory of Public Utility Pricing and its Application." *Bell Journal of Economics*, 1: 113-128.
Colby, B. 1989. "Estimating the Value of Water in Alternative Uses," *Natural Resources Journal*, 29: 511-527.
Coward, E.W. 1986. "Direct or indirect alternatives for irrigation investment and the creation of property," in K.W. Easter (ed.) *Irrigation investment, technology and management strategies for development*, Westview Press, Boulder.
Cueva, A.H. and D.T. Lauria. 2000. "Assessing Consequences of Political Constraints on Rate Making in Dakar: A Monte Carlo Approach," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).
Cummings, R. G., and V. Nercissiantz. 1992. "The Use of Water Pricing as a Means for Enhancing Water Use Efficiency in Irrigation: Case Studies in Mexico and the United States," *Natural Resources Journal*, 32, 731-755.
Cuzán, A.G. 1983. "Appropriators Versus Expropriators," in T.Anderson (ed.) *Water Rights*, PIPPR, San Francisco.
Dahwan, B.D. 1988. *Irrigation in India's Agricultural Development*, Sage Publications, New Delhi.
Das Gupta, P.S. and G.M. Heal. 1979. *Economic Theory of Exhaustible Resources*, Cambridge University Press, New York.

de Azevedo, L.G. and M. Asad. 2000. "Political Process Behind the Implementation of Bulk Water Pricing in Brazil," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

de Gorter, H. and Y. Tsur, 1991, "Explaining Policy Bias in Agriculture: the Calculus of Support Maximizing Politicians," *American Journal of Agricultural Economics*, 73, 1244-1254.

De Vries, F.W.T., R. Rabbinge, and J.J.R. Groot.. 1997. "Potential and Attainable Food Production and Food Security in Different Regions," *Phil. Trans. R. Soc. London, Series B*, 352: 917-928.

Diao, X. and T. Roe. 1995. "Environment, Welfare and Gains from Trade: A North-South Model in General Equilibrium," University of Minnesota, Economic Development Center, Bulletin #95-4.

Diao, X., E.H. Elbasha, T. Roe, and E. Yeldan. 1996. "A Dynamic DGE Model: An Application of R&D-Based Endogenous Growth Model Theory," University of Minnesota, Economic Development Center, Bulletin #96-1.

Diao, X. and T. Roe. 1998. "The Effect of Sequencing Trade and Water Market Reform on Interest Groups in Irrigated Agriculture: An Intertemporal Economy-Wide Analysis of the Moroccan Case," University of Minnesota, Economic Development Center, Bulletin Number 98-5.

Diao, X. and T. Roe. 2000. "The Win-Win Effect of Joint Water Market and Trade Reform on Interest Groups in Irrigated Agriculture in Morocco," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Dinar, A., K.C. Knapp, and J. Letey. 1989. "Irrigation Water Pricing to Reduce and Finance Subsurface Drainage Disposal," *Agricultural Water Management*, 16: 155-171.

Dinar, A. and D. Yaron. 1990. "Influence of Quality and Scarcity of Inputs on the Adoption of Modern Agricultural Technologies," *Western Journal of Agricultural Economics*, 15(2): 224-233.

Dinar, A. and D. Zilberman. 1991. "The Economics of Resource-Conservation, Pollution-Reduction Technology Selection," *Resources and Energy*, 13: 323-348.

Dinar, A. and D. Zilberman (eds.) 1991. *The Economics and Management of Water and Drainage in Agriculture*, New York, Kluwer Academic Publishers.

Dinar, A. and E. T. Loehman (eds.) 1993. *Water Quantity/Quality Management and Conflict Resolution: Institutions, Processes, and Economic Analysis*, Praeger, London.

Dinar, A. and J. Letey. 1996. *Modeling Economic Management and Policy Issues of Water in Irrigated Agriculture*, Praeger, London.

Dinar, A., M.W. Rosegrant, and R. Meinzen-Dick. 1997. "Water Allocation Mechanisms: Principles and Examples," World Bank: Policy Research Working Paper #1779, Washington, D.C.

Dinar, A. and A. Subramanian, 1997, "Water Pricing Experience: An International Perspective," World Bank Technical Paper #386.

Dinar, A., T.K. Balakrishnan, and J. Wambia. 1998. "Political Economy and Political Risks of Institutional Reform in the Water Sector," Policy Research Working Paper #1987, Washington, D.C.

Dinar, A., R.E. Howitt, S.J. Rassenti, and V.L. Smith. 1998. "Development of Water Markets using Experimental Economics," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Dinar, A. (ed.) 2000. *The Political Economy of Water Pricing Reforms*, Oxford

University Press (forthcoming).
Dinar, A. 2000. "Political Economy of Water Pricing Reforms – Introduction," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).
Djalalov, S. 1998. "The Current Situation of Water Resources in irrigated Agriculture of Uzbekistan," Texas A&M, Faculty Paper Series, FP 98-14.
Dudley, Norman and Bradley Scott. 1997. "Deriving Short-Run Multistage Demand Curves and Simulating Market Prices for Reservoir Water Under Weather Uncertainty," in Parker and Tsur (Eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers, Boston.
Easter, K.W. 1980. "Capturing the Economic Surplus Created by Irrigation," *Dept. Agr. & Applied Econ.*, University of Minnesota, Staff Paper P80-14.
Easter, K.W. (Ed.). 1986. *Irrigation Investment, Technology, and Management Strategies for Development*, Westview Press, Boulder.
Easter, K.W. and D.E. Welsch. 1986a. "Priorities for Irrigation Planning and Investment," in K.W. Easter (Ed.) *Irrigation Investment, Technology, and Management Strategies for Development*, Westview Press, Boulder.
Easter, K.W. and D.E. Welsch. 1986b. "Implementing Irrigation Projects: Operational and Institutional Problems," in K.W. Easter (Ed.) *Irrigation Investment, Technology, and Management Strategies for Development*, Westview Press, Boulder.
Easter, K.W. 1987. "Inadequate Management and Declining Infrastructure: The Critical Recurring Cost Problem Facing Irrigation in Asia," *Institute of Agriculture, Forestry and Home Economics*, University of Minnesota, Economics Report ER87-2.
Easter, K.W. 1993. "Economic Failures Plagues Developing Countries' Public Irrigation: An Assurance Problem," *Water Resources Research*, 29(7): 1913-1922.
Easter, K.W., N. Becker, and Y. Tsur. 1997. "Economic Mechanisms for Managing Water Resources: Pricing, Permits, and Markets," in A. K. Biswas (ed.) *Water Resources: Environmental Planning, Management and Development,* McGraw-Hill, New York.
Easter, K.W. and G. Feder. 1998. "Water Institutions, Incentives, and Markets," in Parker and Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers, Boston.
Easter, K.W., M.W. Rosegrant, and A. Dinar (Eds.). 1998. *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.
Easter, K.W., M.W. Rosegrant, and A. Dinar. 1998. "The Future of Water Markets: A Realistic Perspective," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.
Easter, K.W. 1999. "The Transition of Irrigation Management in Asia: Have We Turned the Corner Yet?" Paper Presentation, 6th Conference of the International Water and Resource Economics Consortium, Hawaii.
Elbasha, E.H. and T. Roe. 1995a. "On Endogenous Growth: The Implications of Environmental Externalities," University of Minnesota, Economic Development Center, Bulletin #95-1.
Elbasha, E.H. and T. Roe. 1995b. "Environment in Three Classes of Endogenous Growth Models," University of Minnesota, Economic Development Center, Bulletin #95-6.
Evers, A.J.M., R.L. Elliott, E.W. Stevens. 1998. "Integrated Decision Making for Reservoir, Irrigation, and Crop Management," *Agricultural Systems*, 58(4): 529-554.
Falkenmark, Malin. "Meeting Water Requirements of an Expanding World Population," *Phil. Trans. R. Soc. Lond.: Series B Biological Science*, V. 352 (1997): 929-936.

Farley, P.J. and B.M. Simon. 1996. "Privatizing Government Irrigation Projects in New Zealand," *Water Resources Bulletin*, 32(3): 585-594.

Feder, G. and R. Noronha. 1987. "Land Rights Systems and Agricultural Development in Sub-Saharan Africa," *World Bank Research Observer*, 2(2): 143-169.

Feder, G. and D.Feeny.1991. "Land Tenure and Property Rights: Theory and Implications for Development Policy," *World Bank Economic Review*, 5(1): 135-153.

Feinerman, E., K.C. Knapp, and J. Letey. 1984. "Salinity and Uniformity of Water Infiltration as Factors in Yield and Economically Optimal Water Application," *Soil Science Society of America Journal*, 48(3): 477-481.

Finkelshtein, I. and Y. Kislev, 1997, Prices Versus Quantities: The Political Perspective, *Journal of Political Economy*, 105: 83-100.

Fisher, G. and G.K. Heilig. 1997. "Population Momentum and the Demand on Land and Water Resources," *Phil. Trans. R. Soc. London, Series B*, 352: 869-669.

Feeny, D. 1998. "Suboptimality and Transaction Costs on the Commons," in Loehman and Kilgour (eds.) *Designing Institutions for Environmental and Resource Management*, Edward Elgar, Northampton, MA.

Fleming, R.A. and R.M. Adams. 1997. "The Importance of Site-Specific Information in the Design of Policies to Control Pollution," *JEEM*, 33: 347-358.

Frederick, K.D. and D.C. Major. 1997. "Climate Change and Water Resources," *Climatic Change*, 37: 7-23.

Frederiksen, H.D. 1997. "Institutional Principles for Sound Management of Water and Related Environmental Resources," in A.K. Biswas (ed.) *Water Resources: Environmental Planning, Management, and Development*, McGraw-Hill, New York.

Frisvold, G.B. and M.F. Caswell. 1997. "Transboundary Water Agreements and Development Assistance," in D.D. Parker and Y. Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers, Boston.

Gardner, B.D. 1983. "Water Pricing and Rent Seeking in California Agriculture," in T. Anderson (ed.) *Water Rights*, PIPPR, San Francisco.

Garrido, A. 1998. "Economic Analysis of Water Markets in the Spanish Agricultural Sector: Can They Provide Substantial Benefits?" in Easter, Rosegrant and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Ghosh, S. and D. Lahiri. 1992. "Social Conflicts and Their Remedies in the Distribution of Canal Water: Case Study of the Damodar Valley Irrigation Project, India," *Water Resources Development*, 8(1): 65-72.

Gibbons, D. 1986. *The Economic Value Of Water*, Resources For the Future, Washington, DC.

Gill, Z.A. and R.K. Sampath. 1992. "Inequality in Irrigation Distribution in Pakistan," *The Pakistan Development Review*, 31(1): 75-100.

Gisser, M. 1983. "Groundwater: Focusing on the Real Issue," *Journal of Political Economy*, 91(6).

Gisser, M. and R.N. Johnson. 1983. "Institutional Restrictions on the Transfer of Water Rights and the Survival of an Agency," in T. Anderson (ed.) *Water Rights*, PIPPR, San Francisco.

Gleick, P. 1993. "Water in the 21st Century," in P. Gleick (ed.) *Water in Crisis: A Guide to the World's Fresh Water Resources*, Pacific Institute for Studies in Development, Environment, and Security & the Stockholm Environmental Institute, Oxford University Press, New York.

Gleick, P. (ed.) 1993. *Water in Crisis: A Guide to the World's Fresh Water Resources*, Pacific Institute for Studies in Development, Environment, and Security & the Stockholm Environmental Institute, Oxford University Press, New York.

Gleick, P. 1997. "Water and Conflict in the 21st Century," in D.D. Parker and Y. Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers, Boston.

Goetz, R.U. and D.Zilberman. 1998. "The Dynamics of Spatial Pollution: The Case of Phosphorous Runoff from Agricultural Land," University of Girona, Spain Working Paper

Goulder, L. H., I. W.H. Parry, R. C. Williams III, and D. Burtraw. 1999. "The Cost-Effectiveness of Alternative Instruments for Environmental Protection in a Second-best Setting," *Journal of Public Econ*, 72: 329-360.

Green, G.P. and D.L. Sunding. 1997. "Land Allocation, Soil Quality, and the Demand for Irrigation Technology," *Journal of Agr. & Resource Econ.*, 22(2): 367-375.

Graham-Tomasi, T., K. Segerson and J. Braden, 1992, Issues in the Design of Incentive Schemes for Nonpoint Source Pollution Control, Workshop on Nonpoint Pollution Control, Foundation Mattei, Milan.

Griffen, R.C. and G.M. Perry. 1985. "Volumetric Pricing of Agricultural Water Supplies: A Case Study," *Water Resources Research*, 21(7): 944-950.

Groupement Agroconcept/CID/SCET Maroc. 1997. Etude de la Tarifiction de L'Eau D'Irrigation au Maroc, Analyse des Couts Previsionnels, submitted to Royaume du Maroc, Ministere de L'Agriculture, et de la Mise en Valeur Agricole, Administration du Genie Rural.

Groves, T. 1973. "Incentive in Teams," *Econometrica*, 41: 617-632.

Haggard, S. and S.B. Webb. 1996. *Voting for Reform*, Oxford University Press, NY.

Hall, D.C. 2000. "Public Choice and Water Rate Design," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Hardin, G. 1968. "The Tragedy of the Commons," *Science*, 162: 1243-1248.

Heady, E.O. and R.W. Hexem. 1978. *Water Production Functions for Irrigated Agriculture*, Iowa State University Press, Ames, Iowa.

Hearne, R.R., and K.W. Easter. 1995. *Water Allocation and Water Markets: An Analysis of Gains-from-Trade in Chile*, World Bank Technical Paper #315, Washington, D.C.

Hearne, R.R. 1998. "Opportunities and Constraints to Improved Water Markets in Mexico," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Hearne, R.R. and K.W. Easter. 1998. "Economic and Financial Returns from Chile's Water Markets," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Hewitt, J.A. 2000. "Water Utilities' Choice of Residential Rate Structure," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Hillman, A. I., 1989, *The Political Economy of Protection* Harwood Academic Publisher, Chur, Switzerland.

Holden, P. and M. Thobani. 1996. "Tradable Water Rights: A Property Rights Approach to Resolving Water Shortages and Promoting Investment," Policy Research Dissemination Center, Working Paper 1627.

Horbulyk, T.M and L.J. Lo. 1998. "Welfare Gains from Potential Water Markets in Alberta, Canada," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Hotelling, H. 1938. The General Welfare in Relation to Problems of Taxation and of Railway and Utility Rates, *Econometrica*, 6, 242-269.

Howe, C. 1990. "Equity versus Efficiency in Indonesian Irrigation," in Sampath and Young (eds.) *Social, Economic, and Institutional Issues in Third World Irrigation Management*, Westview Press, Boulder, CO.

Howitt, R.E. and H. Vaux. 1995. "Competing Demands for California's Scarce Water," in Dinar and Loehman (eds.) *Water Quantity/Quality Management and Conflict Resolution*, Praeger, Westport, CT.

Howitt, R.E. 1998. "Spot Prices, Option Prices, and Water Markets: An Analysis of Emerging Markets in California," in Easter, Rosegrant, and Dinar (Eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Huffman, J.L. 1983. "Instream Water Use: Public and Private Alternatives," in T. Anderson (ed.) *Water Rights*, PIPPR, San Francisco.

Huffman, J.L. 1994. "A Brief History of North American Water Diplomacy," in T. Anderson (ed.) *Continental Water Marketing*, PIPPR, San Francisco.

Hunt, R.C. 1990. "Organizational Control Over Water: the Positive Identification of a Social Constraint on Farmer Participation," in R.K. Sampath and R.A. Young (eds.) *Social, Economic, and Institutional issues in Third World Irrigation Management.* Westview Press, Boulder.

Hurwicz, L. 1973. "On Informationally Decentralized Systems," in C. McGuire and R. Radner (eds), *Decision and Organization*, North Hollows, 297-336.

Hurwicz, L. 1973. "The Design of Mechanisms for Resource Allocation," *AER*, 63: 1-30.

Hurwicz, L. 1998. "Issues in the Design of Mechanisms and Institutions," in Loehman and Kilgour (eds.) *Designing Institutions for Environmental and Resource Management*, Edward Elgar, Northampton, MA.

Innes, R. 1999. "Remediation and Self-Reporting in Optimal Law Enforcement," *Journal of Public Econ*, 72: 379-393.

International Water Management Institute. 1999. *Collaborative Research on the Improvement of Irrigation Operation and Management: Water Quality Investigations*, Report, Colombo, Sri Lanka.

Isè, S. and D.L. Sunding. 1997. "Reallocating Water from Agriculture to the Environment under a Voluntary Purchase Program," *Review of Agr. Econ.*, 20(1): 214-226.

Johansson, R.C. 1999. "Minnesota Valley Phosphorous: A Case for Permit Banking," Paper Presentation, USDA-ERS (November 2).

Johnson, S. H. 1997. "Irrigation Management Transfer: Decentralizing Public Irrigation in Mexico," *Water International*, 22(3): 159-167.

Johnson, S.H., M. Svendsen, and X. Zhang. 1998. "Changes in System Performance in Two Chinese Irrigation Systems as a Result of Organizational Reform," *Irrigation and Drainage Systems*, 12: 289-309.

Jones, T. 1999. "Recent Developments in the Pricing of Water Services in OECD Countries," *Water Policy* (forthcoming).

Jordan, J.L. 1995. "Resolving Intergovernmental Water Disputes Through Negotiation," in Dinar and Loehman (eds.) *Water Quantity/Quality Management and Conflict Resolution*, Praeger, Westport, CT.

Just, E.R., S. Netanyahu, and J.K. Horowitz. 1997. "The Political Economy of Domestic Water Allocation: The Cases of Israel and Jordan," in Parker and Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers, Boston.

Kamien, M.I. and N.L. Schwartz. 1981. *Dynamic Optimization: The Calculus of Variations and Optimal Control in Economics and Management*, Elsevier Science Publishing Co. Inc., New York.

Kelley, T. and S.H. Johnson. 1990. "Evaluation of the PASTEN Irrigation Water Allocation System in Indonesia," in Sampath and Young (eds.) *Social, Economic, and Institutional Issues in Third World Irrigation Management*, Westview Press, Boulder, CO.

Kemper, K.E. and D. Olson. 2000. "Water Pricing – The Economics of Institutional Change in Mexico and Ceará, Brazil," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Kim, C.S., and C. Sandretto, R.A. Fleming, and R.A. Adams. 1997. "An Alternative Specification for Modeling Groundwater Dynamics," *Natural Resources Modeling*, 10(3): 173-182.

Kim, C.S., C. Sandretto, and D. Lee. 1999. "Controlling Groundwater Quality with Endogenously Regulatory Instruments," *Natural Resource Modeling*, 12(2): 249-272.

Kirda, C. and R. Kanber. 1999. "Water, No Longer a Plentiful Resource, Should Be Used Sparingly in Irrigated Agriculture," in (eds.) C. Kirda, P. Moutonnet, C. Hera, and D.R. Nielsen, *Crop Yield Responses to Deficit Irrigation*, Kluwer Academic Publishers.

Kloezen, W.H., C. Garcés-Restrepo, and S.J. Johnson. 1997. *Impact Assessment of Irrigation Management Transfer in the Alto Rio Lerma Irrigation District, Mexico*, IIMI, Research Report #15, Colombo, Sri Lanka.

Kloezen, W.H. and C. Garcés-Restrepo. 1998. *Assessing Irrigation Performance with Comparative Indicators: The Case of Alto Rio Lerma Irrigation District, Mexico*, IIMI, Research Report #22, Colombo, Sri Lanka.

Knapp, K.C., A. Dinar, and P. Nash. 1990. "Economic Policies for Regulating Agricultural Drainage Water," *Water Resources Bulletin*, 26(2): 289-298.

Krueger, A.O., M. Schiff, and A. Valdés (Eds.). 1991. *The Political Economy of Agricultural Pricing Policy*, A World Bank Comparative Study, Johns Hopkins University Press, Baltimore.

Laffont, J. J. and J. Tirole. 1993. *A Theory of Incentives in Procurement and Regulation*, MIT press, Cambridge.

Laffont, J. J. and J. Tirole. 1996a. "Pollution Permits and Compliance Strategies," *Journal of Public Economics*, 62: 85-125.

Laffont, J. J. and J. Tirole. 1996b. "Pollution Permits and Environmental Innovation," *Journal of Public Economics*, 62: 127-140.

Langworth, M.W. and T.J. Finan. 1996. "Insititutional Innovation in Small-Scale Irrigation Networks: A Cape Verdean Case," in J.B. Mabry (ed) *Canals and Communties*, University of Arizona Press, Tuscon.

Le Moigne, G., S. Barghouti, G. Feder, L. Garbus, and M. Xie (eds.) 1992. "Country Experiences with Water Resources Management: Economic, Institutional, Technological and Environmental Issues," World Bank Technical Paper No. 175.

Leiby, P and J. Rubin. 1998. "Efficient Greenhouse Gas Emission Banking and Borrowing Systems," Western Economic Association Int'l Conference (May 31).

Lety, J., A. Dinar, and K. Knapp. 1985. "Crop-water Production Function Model for Saline Irrigation Waters," *Soil Science Society America Journal*, 49: 1005-1009.

Lety, J. and A. Dinar. 1986. "Simulated Crop-water Production Functions for Several Crops when Irrigated with Saline Waters," *Hilgardia*, 54(1): 1-32.

Lety, J., K. Knapp, and K. Solomon. 1990. "Crop-water Production Functions," in K.K. Tanji (Ed) *Agricultural Salinity Assessment and Management*, American Society of Civil Engineers, New York.

Ligon, E. and U. Narain. 1997. "Computing the Equilibria of Dynamic Common Property Games," *Natural Resource Modeling*, 10(4): 345-369.

Llewelyn, R. V. and A.M. Featherstone. 1997. "A Comparison of Crop Production Functions using Simulated Data for Irrigated Corn in Western Kansas," *Agricultural Systems*, 54(4): 521-538.

Loehman, E.T. and A. Dinar, 1994, Cooperative Solution of Local Externality Problem: A Case of Mechanism Design Applied to Irrigation, *Journal of Environmental Economics and Management*, 26, 235-256.

Loehman, E.T. 1998. "Cooperation in Pollution Reduction," in Loehman and Kilgour (eds.) *Designing Institutions for Environmental and Resource Management*, Edward Elgar, Northampton, MA.

Loehman, E.T. and D.M. Kilgour. 1998. *Designing Institutions for Environmental and Resource Management*, Edward Elgar, Northamption, MA.

Ma, Q.L., J.E. Hook, R.D. Wauchope. 1999. "Evapotranspiration predictions: A Comparison among GLEAMS, Opus, PRZM-2, and RZWQM Models in a Humid and Thermic Climate," *Agricultural Systems*, 59(1): 41-55.

MacDonnell, L.J., C.W. Howe, K.A. Miller, T.A. Rice, and S.F. Bates. 1994. "Water Banks in the West," *Natural Resources Law Center*, University of Colorado, USGS Report #1434-92-G-2253.

Maloney, M.T. and B. Yandle. 1983. "Building Markets for Tradable Pollution Rights," in T. Anderson (ed.) *Water Rights*, PIPPR, San Francisco.

Marikar, F., J. Wilkin-Wells, S. Smolnik, and R.K. Sampath. 1992. "Irrigation System Performance and its Impact on Crop Productivity in Sri Lanka," *Water Resources Development*, 8(4): 226-234.

Mariño, M. and K.E. Kemper. 1999. "Institutional Frameworks in Successful Water Markets," World Bank Technical Paper #427, Washington, D.C.

Martin, E.D. and R. Yoder. 1987. *Institutions for Irrigation Management in Farmer Managed Systems: Examples for the Hills of Nepal*, IIMI, Research Paper #5, Colombo, Sri Lanka.

Marre, M., R. Bustos, J. Chambouleyron, and M.G. Bos. 1998. "Irrigation Water Rates in Mendoza's Decentralized Irrigation Administration," *Irrigation and Drainage Systems*, 12: 67-83.

Mas-Collel, A., M.D. Whinston, J. R. Green. 1995. *Microeconomic Theory*, New York, Oxford University Press.

McCaffrey, S.C. 1993. "Water, Politics and International Law," in P. Gleick (Ed.) *Water in Crisis: A Guide to the World's Fresh Water Resources*, Oxford University Press, New York.

McCann, R.J. and D. Zilberman. 2000. "Governance Rules and Management in California's Agricultural Water Districts," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Meinzen-Dick, R., and M. Mendoza. 1996. Alternative Water Allocation Mechanisms Indian and International Experiences. *Economic and Political Weekly*, XXXI: A25-A30, March 30.

Meinzen-Dick, R. 1997. "Farmer Participation in Irrigation: 20 Years of Experience and Lessons for the Future," *Irrigation and Drainage Systems*, 11: 103-118.

Meinzen-Dick, R. and M.W. Rosegrant. 1997. "Water as an Economic Good: Incentives, Institutions, and Infrastructure," in M. Kay, T. Franks, and L. Smith (eds.) *Water: Economics, Management, and Demand.* E and FN Spon., London.

Meinzen-Dick, R., M. Mendoza, L. Sadoulet, G. Abiad-Shields, and A. Subramanian. 1997. Sustainable Water User Associations: Lessons from a Literature Review. In: Subramanian, A., N. V. Jagannathan, and R. Meinzen-Dick, User Organization for Sustainable Water Services, World Bank Technical Paper No. 354, World Bank, Washington D.C.

Meinzen-Dick, R. 1998. "Groundwater Markets in Pakistan: Institutional Development and Productivity Impacts," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.

Meinzen-Dick, R. and M. Bakker. 1999. "Water Rights and Multiple Water Uses: Framework and Application to Kirindi Oya Irrigation System, Sri Lanka," Paper Presentation, 6th Conference of the International Water and Resource Economics Consortium, Hawaii.

Merrey, D.J. and J.M. Wolf. 1986. *Irrigation Management in Pakistan: Four Papers*, IIMI, Research Paper #4, Colombo, Sri Lanka.

Merrey, D.J. 1996. *Institutional Design Principles for Accountability in Large Irrigation Systems,* Research Report 8, IIMI, Colombo, Sri Lanka.

Merrey, D.J. 1997. *Expanding the Frontiers of Irrigation Management Research*, IIMI, Colombo, Sri Lanka.

Miller, K. A., S. L. Rhodes, and L. J. MacDonnell. 1997. "Water Allocation: Changing Climate: Institutions and Adaptation," *Climatic Change*, 35: 157-177.

Miranda, S. M. 1989. *Irrigation Management for Crop Diversification in Indonesia, The Philippines, and Sri Lanka: A Synthesis of IIMI's Research*, IIMI Technical Paper 1, Colombo, Sri Lanka.

Mohtadi, H. 1996. "Environment, Growth, and Optimal Policy Design," *Journal of Public Economics*, 63: 119-140.

Molden, D., R. Sakthivadivel, C.J. Perry, C, de Fraiture, and W.H. Kloezen. 1998. *Indicators for Comparing Performance of Irrigated Agricultural Systems*, IIMI, Research Report #20, Colombo, Sri Lanka.

Molhatra, S. 1982. "The Warabandi and its Infrastructure," New Delhi Central Board of Irrigation and Power, Publication #157.

Montgomery, W.E. 1972. "Markets in Licenses and Efficient Pollution Control Programs," *Journal of Economic Theory*, V: 395-418.

Moreno, G., D. Osgood, D. Sundling, and D. Zilberman. 1999. "Agricultural Valuation of Water Supply Reliability," Paper Presentation, 6th Conference for the International Water and Resource Economics Consortium, Hawaii.

Morgan, C. 1999. "Nitrate Abatement via Permits: Rochester," Department of Applied Economics, University of Minnesota, Ph.D. Thesis.

Munasinghe, M., 1990, "The Pricing of Water Services in Developing Countries," *Natural Resource Forum* (August 1990), 193-209.

Musgrave, W.F. 1997. "Australia," in Dinar and Subramanian (eds.) *Water Pricing Experiences: An International Perspective*, World Bank Technical Paper #386.

Musgrave, W.F. 2000. "The Political Economy of Water Price Reform in Australia," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Norman, W.R. 1998. "Changes in Land Tenure and Use During Thirty of Small Irrigation System Operation: A Case Study from the Sahel," *Irrigation and Drainage Systems*, 12: 161-183.
North, D. 1981. *Structure and Change in Economic History.* Norton, New York.
OECD. 1999. *The Price of Water, Trends in OECD Countries.* Organization for Economic Cooperation and Development, Paris.
O'Neil, W., M. David, C. Moore, and E. Joeres. 1983. "Transferable Discharge Permits And Economic Efficiency: The Fox River," *JEEM*, 10: 346-355.
Ostrom, E., 1990, *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge University Press, Boston.
Ostrom, E. 1992. *Crafting Institutions for Self-Governing Irrigation Systems*, ICS Press, San Francisco.
Ostrom, E., R. Gardnet, and J. Walker, 1994, *Rules, Games & Common-Pool Resources*, The University of Michigan Press: Ann Arbor.
O'Mara, G. T. (Ed) Efficiency in Irrigation: The conjunctive use of surface and groundwater resources, A World Bank symposium, Washington D.C., 1988.
Palanisami, K. 1984. *Irrigation Water Management: The Determinants of Canal Water Distribution in India*, Agricole Publishing Academy, New Delhi.
Palanisami, K. 1999. "Irrigation in Tamil Nadu," Tamil Nadu Agricultural University, India, *Water Technical Center*, Working Paper (Draft).
Panagariya, A. and D. Rodrik, 1993, Political Economy Arguments for a Uniform Tariff, International Economic Review, 34: 685-703.
Parker, D.D. and Y. Tsur (eds.) 1997. *Decentralization and Coordination of Water Resource Management.* Kluwer Academic Publishers: Boston.
Peltzman, S., 1976, Toward a More General Theory of Regulation, *Journal of Law and Economics*, 19: 211-40.
Pereira, L.S., R.A. Feddes, J.R. Gilley, and B. Lesaffre (eds.). 1996. *Sustainability of Irrigated Agriculture*. Kluwer Academic Publishers: Boston.
Perry, C.J. and S.G. Narayanamurthy. 1998. *Farmer Response to Rationed and Uncertain Irrigation Supplies*, IIMI, Research Report #24, Colombo, Sri Lanka.
Pigram, J.J. 1999. "Water Management in the Asia-Pacific Region: Projecting the Australian Experience in Water Reform," Paper Presentation, 6th Conference of the International Water and Resource Economics Consortium, Hawaii.
Plessner, Y. and E. Feinerman. 1995. "On the Economics of Irrigation with Saline Water: A Dynamic Analysis," *Natural Resource Modeling*, 9(3): 255-277.
Plusquellec, H., C. Burt, H. W. Wolter. 1994. "Modern Water Control in Irrigation: Concepts, Issues, and Applications," World Bank Technical Paper No. 246, Washington, D.C.
Postel, S. 1994. "Carrying Capacity: Earth's Bottom Line," In *State of the World 1994*, Worldwatch Institute Report on Progress Toward a Sustainable Society, W.W. Norton & Co. Ltd., New York.
Postel, S. 1999. *Pillars of Sand: Can the Irrigation Miracle Last?* W.W. Norton and Company, New York.
Provencher, B. 1995. "Issues in the Conjunctive Use of Surface Water and Groundwater," in D.W. Bromley (ed.) *The Handbook of Environmental Economics*, Blackwell Publishers Ltd., Cambridge, MA.
Qingtao, X., G. Xinan, and H.F. Ludwig. 1999. "The Wanjiazhai Water Transfer Project, China: A Environmentally Integrated Water Transfer System," *The Environmentalist*, 19: 39-60.

Ramsey, F., 1927, A Contribution to the Theory of Taxation, *Economic Journal*, 37: 47-61.
Rausser, G. C., and P. Zusman, 1998, *Political Power and Endogenous Policy Formation*, Cambridge University Press (forthcoming).
Rausser, G. C., and P. Zusman, 1991, Organizational Failure and the Political Economy of Water Resource Management, in Dinar and Zilberman (eds.) *The Economics and Management of Water and Drainage in Agriculture*, Kluwer Academic Publisher: Boston.
Rausser, G.C. 2000. "Collective Choice in Water Resource Systems," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).
Raymond, M. 1999. "Enforcement Leverage when Penalties are Restricted: a Reconsideration under Asymmetric Information," *Journal of Public Econ*, 73: 289-295.
Reisner, M. 1993, *Cadillac Dessert: The American West and Its Disappearing Water*, Penguin Books, New York.
Renfro, R.Z.H. and E.W. Sparling. 1986. "Private Tubewell and Canal Water Trade on Pakistan Punjab Watercourses," in *Irrigation Investment, Technology and Management Strategies for Development,* (ed) K. William Easter, Boulder, Westview Press, pp. 1923-210.
Renzetti, S. and D. Dupont. 1999. "An Assessment of the Impact of Charging for Provincial Water Use Permits," Paper Presentation, 6th Conference of the International Water and Resource Economics Consortium, Hawaii.
Renzetti, S. 2000. "An Empirical Perspective on Water Pricing Reforms," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).
Repetto, R.C. 1986. "Skimming the Water: Rent-Seeking and the Performance of Public Irrigation Systems," World Resources Instititute, Research Report 4, Washington, D.C.
Rhodes, G.F., and R.K. Sampath, 1988, "Efficiency, Equity and Cost Recovery Implications of Water Pricing and Allocation Schemes in Developing Countries," *Canadian Journal of Agricultural Economics*, 36: 103-117.
Rinaudo, J., P. Strosser, and T. Rieu. 1997. "Linking Water Market Functioning, Access To Water Resources and Farm Production Strategies: Examples from Pakistan," *Irrigation and Drainage Systems*, 11: 261-280.
Robinson, S., S. Subramanian, and J. Geoghegan. 1993. "A Regional, Environmental Computable General Equilibrium Model of the Los Angeles Basin," *Dept. of Agr. & Resource Econ.*, University of California, Berkeley, Working Paper #646.
Roe, T. and X. Diao, 1997, The Strategic Interdependence of a Shared Water Aquifer: A General Equilibrium Analysis. In Parker and Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publisher: Boston.
Rondeau, D., W.D. Schulze, and G.L. Poe. 1999. "Voluntary Revelation of the Demand for Public Goods using a Provision Point Mechanism," *Journal of Public Econ*, 72: 455-70.
Rogers, P. 1992. "Comprehensive Water Resources Management: A Concept Paper," World Bank Working Paper Series 879, Washington, D.C.
Rogers, P. 1993. *America's Water: Federal Roles and Responsibilities*, MIT Press, MA.
Rogers, P. 1997. "Engineering Design and Uncertainties Related to Climate Change," *Climatic Change*, 37: 229-242.
Rosegrant, M.W., and M. Svendsen. 1993. "Asian Food Production in the 1990s: Irrigation Investment and Management Scarcity," *Food Policy*, 19(2): 13-32.
Rosegrant, M.W., and H.P. Binswanger. 1994. "Markets in Tradable Water Rights: Potential for Efficiency Gains in Developing Country Water Resource Allocation," *World Development*, 22: 1613-1625.
Rosegrant, M.W., M.A. Sombilla, and N. D. Perez. 1995. "Global Food Projections to

2020: Implications for Investments, Food, Agriculture, and the Environment," *IFPRI*, Discussion Paper #5, Washington, D.C.
Rosegrant, M.W., and R.S. Meinzen-Dick. 1996. "Water Resources in the Asia- Pacific Region: Managing Scarcity," *Asia-Pacific Economic Literature,* 10: 32-53.
Rosegrant, M.W. and R.G. Schleyer. 1996. "Establishing Tradable Water Rights: Implementation of the Mexican Water Law," *Irrigation and Drainage Systems*, 10: 263-279.
Rosegrant, M.W. 1997. "Water Resources in the Twenty-First Century: Challenges and Implications for Action," Food, Agriculture, and the Environment Discussion Paper 20, *International Food Policy Research Institute,* Washington, D.C.
Rosegrant, M.W. and N.C. Perez. 1997. "Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials, and Strategies for the Future," IFPRI, EPTD Discussion Paper #28.
Rosegrant, M.W., C. Ringler, and R.V. Gerpacio. 1997. "Water and Land Resources and Global Food Supply," Paper prepared for the 23rd Int'l Conference of Agricultural Economics on "Food Security, Diversification, and Resource Management: Refocusing the Role of Agriculture," Sacramento, California, August 10-16.
Roumasset, J.A. 1987. *The Public Economics of Irrigation Management and Cost Recovery,* World Bank Mimeo.
Roumasset, J. 1997. "Designing Institutions for Water Management," in Parker and Tsur (Eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers, Boston.
Russel, C. S. and J. F. Shogren, 1993, Theory, Modeling and Experience in the Management of Nonpoint-Source Pollution, Kluwer: Boston.
Rucker, R.R. and P.V. Fishback. 1983. "The Federal Reclamation Program: An Analysis Of Rent-Seeking Behavior," in T. Anderson (ed.) *Water Rights*, PIPPR, San Francisco.
Ruttan, V.W. 1998. "Designing Institutions for Sustainability," in Loehman and Kilgour (eds.) *Designing Institutions for Environmental and Resource Management*, Edward Elgar, Northampton, MA.
Rydzewski, J.R. and C.F. Ward (eds.) 1989. *Irrigation: Theory and Practice*, Pentech Press, London.
Salem, A. 1997. "Algeria," in Dinar and Subramanian (eds.) *Water Pricing Experiences*, World Bank Technical Paper #386, Washington, D.C.
Saleth, M.R. 1996. *Water Institutions in India: Economics, Law and Policy*, Institute of Economic Growth, Commonwealth Publishers, New Delhi.
Saleth, M.R. 1997. "India," in Dinar and Subramanian (eds.) *Water Pricing Experiences: An International Perspective*, World Bank Technical Paper #386, Washington, D.C.
Saleth, M.R. 1998. "Water Markets in India: Economic and Institutional Aspects," in Easter, Rosegrant, and Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.
Saleth, M.R. and A. Dinar. 1998. "Institutional Response to water challenge: a cross-country perspective," World Bank Research Committee Report (April).
Saleth, M.R. and A. Dinar. 1999. "Evaluating Institutions and Water Sector Performance," World Bank Technical Paper #447, Washington, D.C.
Sampath, R.K. 1983. "Returns to Public Irrigation Development," *American Journal of Agricultural Economics*, 65(2): 337:339.

Sampath, R.K., 1990a, "On some aspects of Irrigation Distribution in India," *Land Economics*, 66: 448-463.
Sampath, R.K., 1990b, "Measures of Inequality for Distribution Analysis of Large Public Surface Irrigation Systems: A Welfare Theoretic Approach," in R. Sampath and R. Young (eds.) *Social, Economic and Institutional Issues in Third World Irrigation Management*, Westview Press, Boulder, CO, 75-108.
Sampath, R.K., 1991, "A Rawlsian Evaluation of Irrigation Distribution in India," *Water Resources Bulletin*, 27: 745-751.
Sampath, R.K., 1992, "Issues in Irrigation Pricing in Developing Countries," *World Development*, 20: 967-977.
Scheierling, S.M., G.E. Cardon, and R.A. Young. 1997. "Impact of Irrigation Timing on Simulated Water-crop Production Functions," *Irrigation Science*, 18: 23-31.
Scudder, T. 1997. "Resettlement" in *Environmental Planning, Management and Development*, (ed.) A.K. Biswas, McGraw-Hill, New York.
Seagraves, J. A. and K. W. Easter, 1983, Pricing Irrigation Water in Developing Countries, *Water Resources Bulletin*, 4, 663-671.
Seckler, D., R.K. Sampath and S.K. Raheja. 1988. "An Index for Measuring the Performance of Irrigation Management Systems with an Application," *Water Resources Bulletin*, 24: 855-860.
Seckler, D., U. Amarasinghe, D. Molden, R. de Silva, and R. Barker. 1998. *World Water Demand and Supply, 1990 – 2025: Scenarios and Issues*, IIMI, Research Report #19, Colombo, Sri Lanka.
Segerson, K. 1988. "Uncertainty and Incentives for Nonpoint Pollution Control," *JEEM*, 15: 87-98.
Shah, F. and D. Zilberman. 1991. "Government Policies to Improve Intertemporal Allocation of Water in Regions with Drainage Problems," in *The Economics and Management of Water and Drainage in Agriculture*, (eds.) Ariel Dinar and David Zilberman, Kluwer Academic Publishers, Boston: 637-660.
Shah, F. and D. Zilberman. 1995. "Political Economy of the Transition from Water Rights to Water Markets," in Dinar and Loehman (eds.) *Water Quantity/Quality Mangement and Conflict Resolution*, Praeger, Westport, CT.
Shah, F., D. Zilberman, and U. Chakravorty. 1995. "Technology Adoption in the Presence of an Exhaustible Resource: The Case of Groundwater Extraction," *Amer. J. Agri. Econ.*, 77: 291-299.
Shah, T., Groundwater markets and irrigation development: Political economy and practical policy, Oxford University Press, Bombay, 1993.
Shumba, E.M. and R. Maposa. 1996. "An Evaluation of the Performance of Six Smallholder Irrigation Schemes in Zimbabwe," *Irrigation and Drainage Systems*, 10: 355-366.
Saliba. B. and D. Bush. 1987. *Water Markets in Theory and Practice*, Westview Press, Boulder, CO.
Small, L.E. 1989. "User Charges in Irrigation: Potentials and Limitations," *Irrigation and Drainage Systems*, 3: 125-142.
Small, L.E. and I. Carruthers. 1991. *Farmer Financed Irrigation: The Economics of Reform*, Cambridge University Press, Cambridge.
Small, L.E. and A. Rimal. 1996. "Effects of Alternative Water Distribution Rules on Irrigation System Performance: A Simulation Analysis," *Irrigation & Drainage Systems*, 10: 25-45.
Small, L.E. 1996. "Irrigation Operation and Maintenance in Vietnam Under Economic Restructuring," *Irrigation and Drainage Systems*, 10: 245-262.

Smith, R.B.W. and Y. Tsur. 1997. "Asymmetric Information and the Pricing of Natural Resources: Understanding the Case of Unmetered Water, *Land Economics* (in press).
Smith, R.B.W. and J. Roumasset. 1998. "Constrained Conjunctive-Use for Endogenously Separable Water Markets: Managing the Waihole-Waikane Aqueduct," University of Minnesota, Working Paper (draft).
Sen, A.K. 1973. *On Economic Inequality*, Clarendon Press: Oxford.
Senauer, B. and T. Roe. 1997. "Food Security and the Household," Paper Presentation, IAAE Meetings, Sacremento.
Scarpa, C., 1994, Regulation as a Bargaining Process: Negotiation Over Price and Cost-Reducing Investments, *Oxford Economic Papers*, 46, 357-365.
Segerson, K., 1988, Uncertainty and Incentives for Nonpoint Pollution Control, *Journal of Environmental Economics and Management*, 15: 87-98.
Spulber, N. and A. Sabbaghi. 1998. *Economics of Water Resource: From Regulation to Privatization.* Kluwer Academic Publishers, Boston.
Strand, J. 2000. "A Political Economy Analysis of Water Pricing in Honduras's Capital Tegucigalpa," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).
Sunding, D., D. Zilberman, R. Howitt, A. Dinar, N. MacDougall. 1994. "Modeling the Impacts of Reducing Agricultural Water Supplies: Lessons from California's Bay/Delta Problem," UC Berkeley, Working Paper.
Sunding, D., D. Zilberman, G. Rausser, and A. Marco. 1995. "Flexible Technology and the Cost of Improving Groundwater Quality," *Natural Resource Modeling*, 9(2): 177-191.
Sutawan, N. 1989. "Farmer-Managed Irrigation Systems and the Impact of Government Assistance: A Note from Bali, Indonesia," in *Public Intervention in Farmer-Managed Irrigation Systems*, IIMI, Colombo, Sri Lanka.
Svendsen, M. and G. Nott. 1997. *Irrigation Management Transfer in Turkey: Early Experience with a National Program Under Rapid Implementation,"* IIMI, Report #17, Colombo, Sri Lanka.
Thiruvengadachari, S. and R. Sakthivadivel. 1997. *Satellite Remote Sensing for Assessment of Irrigation System Performance: A Case Study in India*, IIMI Research Report #9, Colombo, Sri Lanka.
Thobani, M. 1998. "Meeting Water Needs in Developing Countries: Resolving Issues in Establishing Tradable Water Rights," in K.W. Easter, M.W. Rosegrant, and A. Dinar (eds.) *Markets for Water: Potential and Performance*, Kluwer Academic Publishers, Boston.
Tregarthen, T.D. 1983. "Water in Colorado: Fear and Loathing in the Marketplace," in T. Anderson (ed.) *Water Markets*, PIPPR, San Francisco.
Tsur, Y. 1990. "The Stabilization Role of Groundwater When Surface Water Supplies Are Uncertain: The Implications for Groundwater Development," *Water Resources Research*, 26(5): 811-818.
Tsur, Y. and T. Graham-Tomasi. 1991. "The Buffer Value of Groundwater with Stochastic Surface Water Supplies," *JEEM*, 21: 811-818.
Tsur, Y. and A. Dinar, 1995. "Efficiency and Equity Considerations in Pricing and Allocating Irrigation Water." World Bank Policy Research Paper #1460, Washington, D.C.
Tsur, Y. and A. Zemel. 1995. "Uncertainty and Irreversibility in Groundwater Resource Management," *JEEM*, 29(2): 149-161.

Tsur, Y. and A. Dinar. 1996. "On the Relative Efficiency of Alternative Methods for Pricing Irrigation Water and Their Implementation," *The Center for Agricultural Economics Research*, Working Paper #9611, Rehovot, Israel.

Tsur, Y. 1997. "The Economics of Conjunctive Ground and Surface Water Irrigation Systems: Basic Principles and Empirical Evidence from Southern California," in D.D. Parker and Y. Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publisher: Boston: 339-361.

Tsur, Y. and A. Dinar. 1997. "On the Relative Efficiency of Alternative Methods for Pricing Irrigation Water and Their Implementation," *World Bank Economic Review*, 11: 243-262.

Tsur, Y. 2000. "Water Regulation Via Pricing: The Role of Implementation Costs and Asymmetric Information," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Van Humbeeck, P. 2000. "The Distributive Effects of the Wastewater Charge and Drinking-Water Tariff Reform on Households in the Flanders Region in Belgium," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Varela-Ortega, C., J.M. Sumpsi, A. Garrido, M. Blanco, and E. Iglesias. 1998. "Water Pricing Policies, Public Decision Making and Farmers' Response: Implications for Water Policy," *Agricultural Economics*, 19: 193-202.

Vaux, H.J. and W.O. Pruitt. 1983. "Crop-water Production Functions," *Advances in Irrigation*, 2: 61-97.

Vaux, H. J. and R.E. Howitt. 1984. "Managing Water Scarcity: An Evaluation of Inter-regional Transfers," *Water Resources Research*, 20: 785-792.

Ventura, F., D. Spano, P. Duce, and R.L. Snyder. 1999. "An Evaluation of Common Evapotranspiration Equations," *Irrigation Science*, 18: 163-170.

Vermillion, D.L. 1991. "Farmer-level Irrigation Management in Private and Public Systems in Indonesia," in *Farm-level Irrigation Water Management*, Asian Productivity Organization, Tokyo.

Vermillion, D.L. 1997. *Impacts of Irrigation Management Transfer: A Review of the Evidence*, IIMI, Research Report #11, Colombo, Sri Lanka.

Vosti, S.A. and T. Reardon (eds.) 1997. *Sustainability, Growth, and Poverty Alleviation*, IFPRI, The Johns Hopkins University Press, Baltimore.

Wade, R. 1987. "The Management of Common Property Resources: Collective Action as an Alternative to Privatization or State Regulation," *Cambridge Journal of Economics*, 11: 95-106.

Wade, R. 1988. *Village Republics: Economic Conditions for Collective Action in South India.* Cambridge University Press, Cambridge.

Wallace, J.S. and C.H. Batchelor. "Managing Water Resources for Crop Production," *Phil. Trans. R. Soc. London Series B*, 352 (1997): 937-947.

Wambia, J.M. 2000. "The Political Economy of Water Resources Institutional Reform in Pakistan," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Ward, C. 2000. "The Political Economy of Irrigation Water Pricing in Yemen," in A. Dinar (ed.) *The Political Economy of Water Pricing Reforms*, Oxford University Press (forthcoming).

Westra, J. 1999. "Agricultural Phosphorous Nonpoint Source Pollution in the Minnesota River," Paper Presentation, AAEA: Nashville, Tennessee (August).

White. L.G. 1990. *Implementing Policy Reforms in LDCs: A Strategy for Designing and Effecting Change*, Lynne Rienner Publishers, Boulder, CO.
Wichelns, D. 1998. "Economic Issues Regarding Tertiary Canal Improvement Programs, with an Example from Egypt," *Irrigation and Drainage Systems*, 12: 227-251.
Wichelns, D., L. Houston, and D. Cone. 1996. "Economic Incentives Reduce Irrigation Deliveries and Drain Water Volume," *Irrigation and Drainage Systems*, 10: 131-141.
Willardson, L.S., D. Boels, and L.K. Smedema. 1997, "Reuse of Drainage Water from Irrigated Areas," *Irrigation and Drainage Systems*, 11: 215-239.
Williamson, J. 1994. *The Political Economy of Policy Reform*, Institute for International Economics, Washington, DC.
Willis, D.B., J. Caldas, M. Frasier, N. K. Wittlesey, and J. R. Hamilton. 1998. "The Effects of Water Rights and Irrigation Technology on Streamflow Augmentation Cost in the Snake River Basin," *Journal of Agricultural and Resource Economics*, 23(1): 225-243.
Wilson, P.N. 1997. "Economic Discovery in Federally Supported Irrigation Districts: A Tribute to William E. Martin and Friends," *Journal of Agricultural and Resource Economics*, 22(1): 61-77.
World Bank. 1992. *World Development Report 1992*. Oxford University Press, New York.
World Bank. 1995. Kingdom of Morocco, Water Sector Review, Report No. 14750-MOR, Middle East and North Africa Region, Maghreb and Iran Department, Natural Resources and Environment Division, The World Bank, Washington D.C.
World Bank. 1998. Kingdom of Morocco Water Resource Management Project, Report No. 15760-MOR, Rural Development, Water and Environment Group, Middle East and North Africa Regional Office, The World Bank, Washington D.C.
World Bank. 1998. *World Development Indicators: 1998*, The World Bank, Washington, D.C.
World Resources. 1998. *A Guide to the Global Environment: 1998-1999*, Oxford University Press, New York.
Yaron, D., H. Bielorai, J. Shalhevet, and Y. Gavish. 1972. "Estimation Procedures for Response Functions of Crops to Soil Water Content and Salinity," *Water Resources Research*, 8: 291-300.
Yaron, D. 1997a. "Israel," in A. Dinar and A. Subramanian (eds.) *Water Pricing Experiences: An International Perspective*, World Bank Technical Paper #386, Washington, DC.
Yaron, D. 1997b. "The Israel Water Economy: An Overview," in D.D. Parker and Y. Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers, Boston.
Young, R.A. 1986. "Why are there so few transactions among water users?" *AJAE*, 68(5):1143-1151.
Young, R.A. and R. Haveman. 1985. *Economics of Water Resources: A survey, in Handbook of Resource and Energy Economics*, Vol. II, A.V. Kneese and J.L. Sweeny (eds), Elsevier.
Young, R.A. 1996. "Measuring Economic Benefits for Water Investment and Policies," World Bank Technical Paper #338.
Zilberman, D., A. Dinar, N. MacDougall, M. Khanna, C. Brown, F.Castillo. 1992. "Individual and Institutional Responses to the Drought: The Case of California Agriculture," UC Berkeley, Working Paper.
Zilberman, D., U. Chakroavorty, and F. Shah. 1997. "Efficient Management of Water in Agriculture," in Parker and Tsur (Eds.) *Decentralization and Coordination of Water Resources*, Kluwer Academic Publishers, Boston.
Zilberman, D. 1997. "Incentives and Economics in Water Resource Management," 2nd Toulouse Conference on Environment and Resource Economics, Toulouse, France (May 14-16).

Zilberman, D. and D. Sunding. "Climate Change Policy and the Agricultural Sector," *Dept. Agricultural and Resource Economics*, Paper Presentation: Girona, Spain (May 1999).

Zusman, P., 1976, The Incorporation and Measurement of Social Power in Economic Models, *International Economic Review*, 17, 447-762.

Zusman, P., 1997, Informational Imperfections in Water Resource Systems and the Political Economy of Water Supply and Pricing in Israel, in Parker and Tsur (eds.) *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers: Boston.

APPENDIX A: CASE STUDIES

It is the intention of this survey to categorize recent case studies on irrigation systems, building on the work by Dinar and Subramanian (1997). Due to the vast number of case studies concerning relevant aspects of irrigation, I have kept this summary to a brief description: author, country, year, subject, etc. The full reference for the studies will be found in the reference section under the first author's last name.

Table 2: Case Studies

Study and Country	Subject / Year	Pricing Policy(s) / Allocation Method	Key Findings
LDCs			
De Azevedo and Asad (2000) – Brazil	Political process behind water pricing reform and initiation of bulk water pricing	CWA	Full economic cost recovery via bulk water pricing is not practical due to information costs and hence water markets may be more sensible.
Kemper and Olson (2000) – Mexico and Ceará, Brazil	Institutional change in water pricing.	CWA	Development projects that incorporate institutional reform (e.g., water right definition and decentralized management) and supply/demand side management have to increase the timeframe for project evaluation.
Wambia (2000) – Pakistan	Political economy of water institution reform.	CWA	Evaluating reform success is difficult for policy makers as political parameter information is often missing. To minimize social implementation costs, it is necessary to choose reform sequences correctly.
Ward (2000) – Yemen	Political economy of irrigation water pricing.	CWA	Increasing irrigation water prices encourage use efficiency, but have often come with political and social unrest. The most benign government option lies in promoting irrigation efficiency via research, extension, and investment.
Qingtao et al. (1999) - China	Description of Chinese water transfer project: water price structure, clean technologies, improved waste treatment.	CWA	Environmental protection measures must be taken as part of an irrigation system. Inattention to these measures could lead to serious adverse effects in the Wanjiazhai Transfer Project.
Palanisami (1999) - Tamil Nadu	Irrigation strategies to meet increasing water demand.	CWA	To increase water-use efficiency the following short term measures are advisable: better management strategies with WUAs, irrigation technology adoption, and use of waste and salt water for irrigation. Long-term measures include identification

			of appropriate investments and diversion of water from west flowing rivers.
Johnson, Svendsen, and Zhang (1998) – China	System performance changes in response to organizational reform.	Decentralized CWA	Incentive management systems and financial autonomy for public irrigation districts have led to increases in irrigation fee collection rates and more efficient multi-part fee structures.
Perry and Narayanamurthy (1998) – Haryana, India	Farmer response to uncertain supplies.	Warabandi	Farmers aim to maximize returns to the scarce resource, but guard against risk by reducing areas planted when season water allocations are uncertain.
Wichelns (1998) - Egypt	Economic issues regarding tertiary canal improvements.	CWA/WUA	Public agencies have an important role in enforcing property rights and designating uses of water funds. Cost recovery can be implemented in cooperation with WUAs and enhanced by allowing trades to occur.
Diao and Roe (1998) - Morocco	Sequencing of trade and water market reform.	CWA	Welfare decreasing effects of water market reform on certain agricultural sectors can be ameliorated by reforming trade practices prior to the water reforms.
Marre et al. (1998) - Mendoza, Argentina	Differential charges and participation rates	WUAs	Due to low collection levels, much of WUA income is spent on fixed costs (e.g., salaries) and little on O&M. This causes further dissatisfaction with paying users.
Kloezen and Garcés-Restrepo (1998) – Mexico	Assessing irrigation performance.	WUAs	Comparative indicators used in Mexico's Lerma District for irrigation management show conditions of abundant water availability, irrigation depths that are high relative to crop requirements, economic outputs per unit of water and land that are favorable to other districts, full recovery of O&M, and overexploitation of the aquifers.
Bandaragoda (1998) – Pakistan	Water allocation rules.	Warabandi	Increasing inequity in water distribution indicates that the balance between infrastructure, water rights, and organizational responsibilities is failing. Adaptability of rules to changing conditions is therefore necessary.
Rosegrant and Perez (1997) – Select African Countries	Water resources development.	CWA	Water reform is needed in Africa to meet growing demands. The most important reforms require establishment of secure water rights, decentralization and privatization of water management, the use of market for trading water rights, pricing reforms and reductions in subsidies, and pollution charges.

Svendsen and Nott (1997) - Turkey	Management transfers.	WUAs	Falling public O&M costs, rising private costs, improved cost recovery, falling bureaucratic staff numbers, and improved system performance have been linked to rapid irrigation management decentralization in Turkey.
Brewer et al. (1997) – Tambraparani, India	Water distribution rules.	WUAs	Inconsistent water rules cause operational problems that may lead to poor efficiency and equity in water distribution. Therefore, water law needs to be flexible to adapt to new problems or demand changes.
Hearne and Easter (1997) – Chile	Economic and financial gains from water markets.	Water Trades	Market transfer of water-use rights does produce substantial economics gains-from-trade. Lack of trading in some regions reflects the costs of modifying fixed infrastructure to facilitate trades.
Johnson (1997) – Mexico	Decentralization o f public irrigation.	WUAs	WUAs have proven capable of operating and maintaining irrigation systems in Mexico. They have established an investment fund to cover emergencies and future investments. It is necessary, however, to insure long-run sustainability of the program to clarify water laws in order to protect agricultural water rights.
Kloezen, Restrepo, and Johnson (1997) – Mexico	Management transfers and performance indicators.	WUAs	Comparative indicators for system performance were developed to assess management decentralization strategies.
Rinaudo et al. (1997) - Pakistan	Private tubewells, surface water markets, and inadequate canal water supply.	Informal water market trades.	Groundwater sales form the bulk of total irrigation water transaction, although canal rights are also traded. Water markets are localized and so the spatial structure of the markets within a watercourse command area requires further examination.
Shumba and Mposa (1996) - Zimbabwe	Performance of 6 smallholder Schemes evaluated in yields of maize and beans.	CWA	Crop yields under small-scale farms are so low as to make irrigation investment questionable. Increased efficiencies can be achieved if farmers form coalitions.
Johnson (1997) - Mexico	Decentralization of public irrigation and management transfers.	WUAs	Efficiency increases have been realized in fee collection and O&M, however more funds for future investment needs to be put aside. Water law clarifications are necessary as well.

Plusquellec (1996) – Iran	Technology in small farm irrigation.		Advanced water control technologies are appropriate for small-scale farm projects.
Small (1996) – Vietnam	O&M under economic reform	Supply Co-ops	Financial autonomy of irrigation systems is enhanced by supply cooperatives that act as an intermediary between farmers and the central water authority.
Shumba and Maposa (1996) – Zimbabwe	Performance of small-scale irrigation schemes.	CWA	There are tremendous potential increases in small-scale farm yields possible by increasing irrigation water certainty and by fixing the road infrastructure.
Rosegrant and Schleyer (1996) - Mexico	Mexican water law reform	Water Trading	Tradable water rights raised cost of supplying water via inflexible conveyance system.
Bilen (1995) - Turkey	Water management plan for a basin should be fit into national plans and policies.	CWA	Inter-sectoral planning of several aspects of water resource management can augment system efficiency. Recommends a movement from project-oriented water resource planning toward broader national perspectives.
Marikar, Wilkin-Wells, Smolnik and Sampath (1992) – Sri Lanka	Measures to evaluate system performance and crop productivity.	WUAs	Using performance measures adapted from Thiel's mean-square forecast error concept, it was shown that fertilizer, labor and concentration of power positively affects yields, while poor management adversely affects yields.
Sampath (1991) – India	Evaluation of irrigation distribution and equity in India's states.	CWA	There is considerable inequality in irrigation distribution in India's states. Changing the current policy to a Rawlsian distribution policy would reduce this inequity in general and specifically in the canal irrigation areas.
Seckler, Sampath and Raheja (1988) - India	Measuring the performance of irrigation management systems.	Warabandi System	Farmers irrigate the designed amount of land, but show significant inter-farm irrigation levels. The operating efficiency of this system was found to be 80%.
Dhawan (1988) – India	Productivity, stability, and equity in India's agricultural development.	CWA	Factors such as credit availability for the purchase of fertilizer at low rates of interest adversely affect the chances of small farmers in India to fully realize benefits of irrigation. This compounds inequality problems inherent in this system. Land redistribution is cited as one possible solution.

Martin and Yoder (1987) – Nepal	Institutional structures / 1982 – 1983.	WUAs	Water allocation by purchasing shares in a continuous flow rotation provides efficient development of resources, while proportional irrigated area allocation does not.
Merrey and Wolf (1986) – Pakistan	O&M Finance / 1983 – 1984.		Irrigation planners must focus on the development of appropriate organizational capacities so that users can best make use of the system.

MDCs

Musgrave (2000) – Australia	Political economy of water price reform.	CWA	Decentralization and water price reforms are advanced in the urban sector, but there are many groups opposed to reform in the rural agricultural sector.
Pigram (1999) – Australia	Applicability of Australian water reforms to general conditions.		
Bjornlund and McKay (1999) - Victoria, Australia	Impact of Trade (water markets) on socially equitable water allocation.		Tradable Water Entitlements (TWE) are a tool to alleviate the influence of raising water prices and to facilitate a re-allocation of water resources to more efficient and sustainable uses from an economic, social and environmental perspective. Within the present legislative framework this does however not always direct water to the most sustainable users in an equitable manner.
Varela-Ortega et al. (1998) – Spain	Farmer response to alternative water pricing policies.	CWA	Policies are strongly dependent on the distinct regional institutions. Equivalent water charges would then create widespread effects on water savings, farm income, and government collections across regions.
Willis et al. (1998) – Snake River Basin	Effects of water rights and irrigation technology on streamflow augmentation	CWA / Water Bank	Contract costs are lower under an excess stored water contract than a total stored water contract, however there is less water for environmental protection.
Isè and Sunding (1997) - Nevada	Trades to the environment.	Water Markets	Personal characteristics such as short-term financial constraints, significantly affect trading decisions. This suggests that environmental agencies may wish to target marginal farmers to attain more efficient outcomes.

MacDonnell et al. (1994) – American West	• Kern Water Bank, CA • Arvin Edison / Metro, LA • Orange County, CA • Las Vegas Valley, NV • Arizona-California Colorado River	Water Banks	A comprehensive guide to issues surrounding the development of and movement towards water banking in the American West. These allow greater flexibility in marketing of water and reduce transactions costs.
Chang and Griffen (1992) – Texas	Water markets as a means to reallocate water.	Water Markets	For transactions involving representative cities, the estimated benefits from water marketing far exceed the agricultural cost of the transfer.
Cummings and Nercissiantz (1989) – U.S. and Mexico	Water pricing to enhance efficiency in irrigation.	Water Markets	The equity concerns related to third parties and water markets have been addressed in the western U.S., which may be applicable to recent Mexican reforms.

Reviews	**Included Studies/Countries**	**Subject**	**Key Findings**
Dinar (2000)	• Musgrave (2000) – Australia • De Azevedo and Asad (2000) – Brazil • Wambia (2000) – Pakistan • Kemper and Olson (2000) – Mexico and Brazil • Ward (2000) - Yemen	Political economy of water pricing reform.	Documents key reform efforts in these countries, noting the effects of political economies on success or failure.
Saleth and Dinar (1999) World Bank	• Australia • Brazil • Chile • India • Israel • Mexico	Evaluation of water institutions and water sector performance.	With an overall pro-reform climate, it is possible to minimize transaction costs and achieve more than proportionate improvement in water sector performance.

	• S. Africa • Spain • Sri Lanka • USA		Results indicate that a sequential strategy for institutional reform in general and water institutions in particular.
Marino and Kemper (1999) World Bank	• Brazil • Spain • Colorado	Institutional frameworks in successful water markets.	When theoretical models for water markets are being derived from industrialized countries for application to LDCs, it is essential to review the institutional frameworks that have contributed to successful water markets.
International Water Management Institute (1999)	• Matsuno (1999) - Sri Lanka • Scott, Zarazúa, and Levine (1999) – Mexico • Jensen (1999) - Pakistan	Nonagricultural uses of irrigation water.	Due to increasing water scarcity, nonagricultural uses of irrigation water have significant environmental, health, and other domestic consequences that need to be examined.
Easter et al. (1998) Kluwer Academic Publishers	• Griffin (1998) – Texas • Howe (1998) – Colorado • Colby (1998) – U.S. West • Howitt (1998) – California • Hearne (1998) – Chile • Hearne and Easter (1998) – Chile • Hearne (1998) – Mexico • Saleth (1998) – India • Meinzen-Dick (1998) – Pakistan • Garrido (1998) – Spain • Horbulyk and Lo (1998) – Canada	Water Markets	Water markets have worked and can be used efficiently to allocate water. Where water is scarce and large amounts of available water have already been committed to users, the economic benefits from water markets are likely to be the largest. For these markets to be effective, it is necessary to keep transaction costs low and to develop appropriate institutional and organizational

			arrangements.
Dinar and Subranian (1997) World Bank	• Salem (197) – Algeria • Musgrave (1997) – Australia • Thema (1997) – Botswana • de Azevedo (1997) – Brazil • Horbulyk (1997) – Canada • Montginoul (1997) – France • Saleth (1997) – India • Yaron (1997) – Israel • Destro (1997) – Italy • Rabemanambola (1997) – Madagascar • Heyns (1997) – Namibia • Scrimgeour (1997) – New Zealand • Mohtadullah (1997) – Pakistan • Maestu (1997) – Spain • Adam (1997) – Sudan • Hsiao and Luo (1997) – China • Mujwahuzi (1997) – Tanzania • Slim et al. (1997) – Tunisia • Onek (1997) – Uganda • Rees (1997) – United Kingdom • Wahl (1997) – United States	Pricing Policies	Most countries surveyed are decentralizing water management. Some are developing legal frameworks to decentralize and to encourage private investment through incentives. Many countries are implementing prices to recover a portion of O&M costs from users. This entails a movement away from uniform tariffs and minimum prices towards higher volumetric prices. The development of transferable water rights and water markets is crucial to consider for future water management.
Vermillion (1997) IIMI	• Oorthuizen and Kloezen (1995) – Philippines • Wijayarantna and Vermillion (1994) – Philippines • Badadion (1994) – Philippines • Svendsen (1992) – Philippines • Johnson and Reiss (1993) – Indonesia • Nguyen and Luong (1994) – Vietnam • Johnson et al. (1995) – China	Decentralization and Management Transfer	The impacts of management transfer are for the most part positive. These include reduction in the cost of irrigation to farmers and government, enhanced self-reliance of irrigation schemes, expansion of service areas, reduction in the amount of water delivered on a per

	• IIMI and BAU (1996) – Bangladesh • Rana et al. (1994) – Nepal • Olin (1994) – Nepal • Mishra and Molden (1996) – Nepal • Kloezen (1996) – Sri Lanka • Uphoff (1992) – Sri Lanka • Pant (1994) – India • Srivastava and Brewer (1994) – India • Rao (1994) – India • Shah et al. (1994) – India • Kalro and Naik (1995) – India • Azziz (1994) – Egypt • Samad and Dingle (1995) – Sudan • DSI, EDI, and IIMI (1996) – Turkey • Maurya and Musa (1993, 1994) – Nigeria • Wester et al. (1995) – Senegal • Yap-Salinas (1994) – Dominican Republic • Vermillion and Garcés-Restrepo (1996) – Colombia • Garcés-Restrepo and Vermillion (1994) – Colombia • Johnson (1996) – Mexico • Svednsen and Vermillion (1994) – Washington State, USA • Farley (1994) – New Zealand		hectare basis, and increases in cropping yields. Negative impacts reported include increased costs of irrigation services, failing financial viability, and deteriorating infrastructure.
Merrey (1997) – Summary of IIMI R&D: 1984-1995	• Indonesia • Pakistan • Sudan • West Africa • Malaysia	O&M Design of Irrigation Systems, Irrigation Management Transfers, Health and Environmental Aspects of Irrigation	Documents using case studies the actual performance of irrigation systems and potential efficiency gains. Documents the high degree of unreliability

	• Bihar, India • Gujarat, India • Sri Lanka • Egypt • USA • Colombia • Niger • Nigeria • Philippines • China • Nepal	Systems, Institutional Capacity Building,.	and inequity of surface water deliveries and its relationship to salinity. IIMIs research illustrates that negative trends in irrigation, such as soil degradation and erosion, are due primarily to institutional and political concerns. Financial viability of LDC irrigation systems is questionable and is also linked to institutional and political concerns. WUAs have poor organization and political strength and have no clear, enforceable water rights, and therefore suffer from inefficiencies. Increasing water competition from other sectors is leading to a decline in importance of irrigation agencies.
Johnson (1997) – Mexico Districts IIMI	Irrigation management transfers and decentralization in Mexican irrigation.	CWA/WUA	To insure the stability of WUAs and the sustainable management of Mexican irrigation, it will be necessary to establish an investment fund and to clarify water laws to protect agricultural rights.
Parker and Tsur (1997) Kluwer Academic Publishers	• Yaron (1997) – Israel • Kindler (1997) – Jordan River Basin • Cakmak (1997) – Turkey • Parker (1997) – California	Decentralization and Coordination	As water becomes scarcer it becomes more expensive via increasing scarcity prices. Hence, misuse is becoming

	• Boggess (1997) – Florida • Pigram (1997) – Australia • Just, Netanyahu, and Horowitz (1997) – Israel and Jordan • Zusman (1997) – Israel • Becker, Zeitouni, and Shechter (1997) – Middle East • Tsur (1997) – California • Just, Horowitz, and Netanyahu (1997) – Jordan-Yarmouk River Basin • Sunding, Zilberman, MacDougall, Howitt, and Dinar (1997) – California Bay/Delta • Gleick (1997) – Middle East and California • Musgrave (1997) - Australia		more costly and the need for more efficient use management has increased. As a result there has been a global movement away from centralized water management towards decentralized mechanisms to increase distributional efficiency.
Miranda (1989) IIMI	• Indonesia • Philippines • Sri Lanka	Irrigation Management for Crop Diversification	
Rydzewski and Ward (1989) Institute of Irrigation Studies	• Sampath (1989) – India • Ramamurthy (1989) – S. India • Farbrother (1989) – Sudan • Smith and Carruthers (1989) – Inus Valley • Chohan (1989) – Pakistan • Bybordi (1989) – Iran • Zhaoyi (1989) – China • Biswas (1989) – Sri Lanka • Tekinel et al. (1989) – Turkey • Satyanarayana et al. (1989) – India • Portch et al. (1989) – Sub-Saharan Africa	Performance Evaluation of Existing Irrigation Projects.	Text Book.

	• Stoutjesdijk (1989) – Southern Africa • McAnderson et al. (1989) – Ethiopia • Hewett et al. (1989) – Sudan • Van Bentam and Smout (1989) - Bhutan		
Easter (1987) University of Minnesota / USAID	• Philippines • Maharashtra, India • Nepal • Sri Lanka	Inadequate management and declining infrastructure.	Pricing policies in many Asian countries and/or the ability to collect fees is inadequate. There are 4 conditions necessary for increased collection rates: volumetric or yield-acreage data, dependable delivery systems, sufficiently staffed collection service, reallocation of increased collections to infrastructure improvement.

APPENDIX B: METHODOLOGIES AND DATABASES

Methodologies

There are several good sources describing generalized methodologies for estimating crop-water response functions (Heady and Hexem, 1978; Vaux and Pruitt, 1983; Letey, Knapp and Solomon, 1990; and Llewelyn and Fetherstone, 1997). These address economic, engineering, and biological aspects of the production process. They conclude that crop-water production relationships are very complicated and must include various management issues to adequately cater to specific situations. Consequently, these methodologies have been developed to incorporate salinity (Feinerman et al., 1984; Plessner and Feinerman, 1995; Kirda et al., 1999) and evapotranspiration[30] (Letey, Dinar, and Knapp, 1985), and deficit irrigation (Small and Rimal, 1996; Kirda, et al., 1999). Empirical verifications of this theory for several crops can be found in Letey and Dinar (1986) and Kirda et al. (1999)[31]. The use of production function technology to reduce drainage and salinity problems are developed in Dinar et al. (1989); Letey, Knapp, and Solomon (1990); Knapp et al, (1990); and Dinar and Letey (1996). Intertemporal aspects of crop-water production functions have been developed in Plessner and Feinerman (1995), Scheierling et al. (1997), and Kirda et al. (1999).

Comparative analysis of crop water requirements conducted for Zimbabwe, Egypt, Turkey, Scotland, Tamil Nadu, Indonesia, and New Zealand can be found in Rydzewski and Ward (1989). Perry and Narayanamurthy (1998) review theoretical responses of farmers to uncertain irrigation supplies and provide an empirical illustration for *warabandi* irrigation in Haryana State, India.

Programs to Calculate Crop-water Requirements[32]

- *FAO Methodologies* (see http://fao.org, 1999)
  Since the early 1970's FAO has been using CROPWAT[33] for calculating crop water requirements. This has been a widely accepted standard for irrigation studies over the past two decades. CROPWAT is intended as a practical tool for practitioners when calculating standard evapotranspiration and crop water uses. It is adapted for development or improvement of the management and design of irrigation schemes under varying water conditions: rainfed or deficit irrigation. CROPWAT calculations of crop water requirements utilize the CLIMWAT climatic and crop data (see below).

---

[30] Evapotranspiration is the amount of water actually used by the soil-plant system.

[31] Included in Kirda et al, (1999) are response functions for a variety of crops: cotton, maize, soybean, sugar beet, sunflower, wheat, winter wheat, common bean, groundnuts, sugarcane, and irish potato.

[32] A review of the evapotranspiration equations used in most computable crop-water programs recently appeared in *Irrigation Science* (Ventura et al., 1999).

[33] CROPWAT version 5.7 issued in 1992 is freely available from the FAO web site in English, French, and Spanish. It can also be found as a publication (FAO: Drainage and Irrigation Paper No. 46, 1992. Included is a manual and guidelines).

In 1990 a panel of experts recommended the adoption of the Penman-Monteith methodology[34] for evapotranspiration and parameter calculations necessary to determine crop water requirements around the globe. The FAO minutes from their discussion of methodology and current revisions can be found in Smith (1999)[35].

- *ILRI Methodology*
Another program for calculating crop irrigation requirements in CRIWAR, which was developed jointly between the Wageningen University of Agriculture (WUA), the Winand Staring Centre for Integrated Research on Rural Areas SC-DLO), and the International Institute for Land Reclamation and Improvement (ILRI). A copy of this program and operating manual can be found in the public domain (ILRI Publication 46). CRIWAR calculates the irrigation water requirements of cropping patterns in an irrigated area for various stages during the growing season. The irrigated water requirement is simply the difference between the potential evapotranspiration and the effective precipitation. Evapotranspiration values can be calculated using either the modified Penman Method or the Penman-Monteith Method. The effective precipitation values are estimated using the method developed by the U.S. Soil Conservation Service.

- *Other Commonly Encountered Programs*
There are many modeling programs available that predict evapotranspiration and crop responses to water availability, including irrigation water. Some of these include: GLEAMS, Opus, PRZM-2, RZMWQM, PRMS, EPIC, SIRS (rice) and CERES (maize). It is obviously beyond the scope of this work to review the literature surrounding the many simulation programs available. Several recent sources comparing the accuracy of forecasts for various crop conditions are: Small and Rimal (1996), Llewelyn and Featherstone (1997), Evers et al. (1998), and Ma et al. (1999). Dinar and Letey (1996) draw a distinction between holistic and specific simulation models. Holistic models simulate the production process of only one crop in a detailed manner, including several state and decision variables. Examples include COTMOD, GOSSYM, ARID CROP, and EPIC. Specific models focus on a single production input, such as yield responses to changes in soil moisture. Examples for soil moisture and salinity can be found in Yaron et al. (1972) and in Dinar and Letey (1996).

Databases

- The FAO maintains and extensive climate database, which includes standard crop information plus daily soil and water balances for 144 countries (CLIMWAT). This data can be accessed via the internet (as above) or as a publication (FAO: Irrigation and Drainage Paper No. 49,1993).

- There are several downloadable USDA databases available on the internet via Cornell University (see http://www.usda.mannlib.cornell.edu/). These include:

[34] FAO current guidelines for calculating crop water requirements can be found in FAO: Irrigation and Drainage Paper No. 56 (1998).
[35] See http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGL/aglw/Wcrop.html).

(1) Bureau of Reclamation Data – Agricultural Water Use [ERS]

Contains data on agricultural use of federally supplied irrigation water for bureau of reclamation lands receiving full and supplemental water service. This includes net water supply, water deliveries, and acres irrigated by drip, sprinkler, and gravity systems.

(2) Farm and Ranch Irrigation [ERS]

This includes the data from the 1984 Farm and Ranch Irrigation Survey, which supplements the basic irrigation data collected from all farm operators in the 1982 Census of Agriculture. The methodology is similar to those used in the 1979 Farm and Ranch Irrigation Survey.

(3) Irrigation Production Data System [ERS]

(4) World Food Aid Needs and Availability [ERS]

This is a full-text report that studies the world food aid needs, defined as the amount of grain needed to fill the gap between what a country can produce and its financial capacity to import, and a targeted consumption level including emergency needs. This factors in such a comprehensive set of considerations that include: supply and demand, prices and trade, food production, yields, fertilizer use, land constraints, water and irrigation, population growth, food consumption and nutrition, domestic policies and foreign exchange availabilities.

- Through the International Food Policy Research Institute (IFPRI) and associate organizations several irrigation resources can be accessed (see http://www.cgiar.org/). These include:

(1) IMPACT

This is a multi-sector model to examine global food security. One of the parameters is irrigation water supply and investment.

(2) IIMI Spreadsheet: World Water and Climate Atlas

This is a simulation model to simulate water supply and demand for major countries (by sector) in the world between 1990 and 2025.

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS2429	Corruption, Composition of Capital Flows, and Currency Crises	Shang-Jin Wei	August 2000	H. Sladovich 37698
WPS2430	Financial Structure and Bank Profitability	Asli Demirgüç-Kunt Harry Huizinga	August 2000	K. Labrie 31001
WPS2431	Inside the Crisis: An Empirical Analysis of Banking Systems in Distress	Asli Demirgüç-Kunt Enrica Detragiache Poonam Gupta	August 2000	K. Labrie 31001
WPS2432	Funding Growth in Bank-Based and Market-Based Financial Systems: Evidence from Firm-Level Data	Asli Demirgüç-Kunt Vojislav Maksimovic	August 2000	K. Labrie 31001
WPS2433	External Interventions and the Duration of Civil Wars	Ibrahim A. Elbadawi Nicholas Sambanis	September 2000	H. Sladovich 37698
WPS2434	Socioeconomic Inequalities in Child Malnutrition in the Developing World	Adam Wagstaff Naoko Watanabe	September 2000	A. Maranon 38009
WPS2435	The Evolution of Poverty during the Crisis in Indonesia, 1996–99	Asep Suryahadi Sudarno Sumarto Yusuf Suharso Lant Pritchett	September 2000	P. Sader 33902
WPS2436	Safety Nets and Safety Ropes: Who Benefited from Two Indonesian Crisis Programs—the "Poor" or the "Shocked?"	Sudarno Sumarto Asep Suryahadi Lant Pritchett	September 2000	P. Sader 33902
WPS2437	Quantifying Vulnerability to Poverty: A Proposed Measure, Applied to Indonesia	Lant Pritchett Asep Suryahadi Sudarno Sumarto	September 2000	P. Sader 33902
WPS2438	Measurements of Poverty in Indonesia: 1996, 1999, and Beyond	Menno Pradhan Asep Suryahadi Sudarno Sumarto Lant Pritchett	September 2000	P. Sader 33902
WPS2439	State-Community Synergies in Development: Laying the Basis for Collective Action	Monica Das Gupta Helene Grandvoinnet Mattia Romani	September 2000	M. Das Gupta 31983
WPS2440	Lessons from Uganda on Strategies to Fight Poverty	John Mackinnon Ritva Reinikka	September 2000	H. Sladovich 37698
WPS2441	Controlling the Fiscal Costs of Banking Crises	Patrick Honohan Daniela Klingebiel	September 2000	A. Yaptenco 38526

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS2442	A Firms's-Eye View of Policy and Fiscal Reforms in Cameroon	Bernard Gauthier Isidro Soloaga James Tybout	September 2000	L. Tabada 36896
WPS2443	The Politics of Economic Policy Reform in Developing Countries	Richard H. Adams Jr.	September 2000	M. Coleridge-Taylor 33704
WPS2444	Seize the State, Seize the Day: State Capture, Corruption, and Influence in Transition	Joel S. Hellman Geraint Jones Daniel Kaufmann	September 2000	D. Billups 35818
WPS2445	Subsidies in Chilean Public Utilities	Pablo Serra	September 2000	G. Chenet-Smith 36370
WPS2446	Forecasting the Demand for Privatized Transport: What Economic Regulators Should Know, and Why	Lourdes Trujillo Emile Quinet Antonio Estache	September 2000	G. Chenet-Smith 36370
WPS2447	Attrition in Longitudinal Household Survey Data: Some Tests for Three Developing-Country Samples	Harold Alderman Jere R. Behrman Hans-Peter Kohler John A. Maluccio Susan Cotts Watkins	September 2000	P. Sader 33902
WPS2448	On "Good" Politicians and "Bad" Policies: Social Cohesion, Institutions, and Growth	Jo Ritzen William Easterly Michael Woolcock	September 2000	A. Kibutu 34047

00|5