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The Role of Technology and Institutions in the Cost Recovery of Irrigation and Drainage Projects

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Executive Summary

The cost recovery of investment, operation, and maintenance of irrigation and drainage (I&D) water systems is an important policy intervention that improves water productivity and financial sustainability of irrigation and drainage systems. While many in the water policy circles recognizes that cost recovery is an important aspect of water management systems, it is not yet a common practice among farmers in many countries. Many mechanisms and good practices can strengthen cost recovery in I&D projects, with user participation amongst the most effective factor to improve the collection rate. Technology and institutions also form the basis for improving cost recovery in I&D projects. Although there are varying degrees of success in the employment of technology and institutions in cost recovery, identifying the right approaches to achieve the most effective cost recovery in the sector still presents a challenge.

This publication offers four carefully analyzed case studies in various countries that together may offer a reasonable framework to learn from. Moreover, the case studies will present important indicators and demonstrate the inherent potential that technology and institutions have to improve cost recovery implementation.

The first chapter, "Cost Recovery of Irrigation and Drainage Projects: Wishful Thinking or Difficult Reality?" provides information collected in various agencies about the range of cost recovery collection strategies and introduces discussion that will take place. The chapter argues that water-charging (pricing and cost recovery) policies in most countries often fail to perform because of incoherent approaches and inappropriate institutions that have been enrooted in a complicated political economy and environment. Both developed and developing countries face this dismal reality. Thus, the current situation of cost recovery of irrigation and drainage projects around the world presents a good forum that lends into the purpose of this paper, which strives to present and advocate for undertaking non-traditional approaches to cost recover.

Chapter two, "Canal Automation and Cost Recovery – Australian Experience Using Rubicon Total Channel Control™," provides an overview of the Total Channel Control™ (TCC™) canal automation system. Since Australia has irrigation districts that already have well-established frameworks for cost recovery and active water markets, the TCC™ system has recently been implemented in its irrigation districts. The chapter describes how TCC™ automation is one of the key infrastructure solutions in Australia for improved water-use efficiency in canal irrigation schemes. It also explains how these irrigation districts use a range of methods to recover the investment cost in the TCC™ system, including the sale of water savings to irrigators and government environmental agencies, as well as recovering costs conventionally through

infrastructure charges. Such institutional arrangements, in turn, are leading to increased investment in irrigation water-use efficiency. Lastly, the chapter briefly assesses the staged implementation of TCC™ in irrigation systems in less developed countries and explains how this can be successfully implemented to promote cost recovery.

The third chapter, "Satellite Measurements to Assess and Charge for Groundwater Abstraction," focuses on a relatively new method that computes evapotranspiration (ET), net groundwater-use, and groundwater abstractions in irrigated areas using satellite-based measurements of land surface temperature and surface reflectance with a minimum of field data. The chapter departs from the argument that information is lacking on the accurate size of extracted groundwater volumes for irrigation. Assessments, if they exist, are often inaccurate, inconsistent, expensive, and subject to fraud, which present obstacles for volumetric charging to recover costs and jeopardize sustainable aquifer exploitation. Instead, the chapter argues that volumetric charges can be implemented on the basis of crop consumptive-use, net groundwater-use, or abstractions, which are viable alternatives to the conventional irrigated and crop acreage–based charges. Such a method requires a high level of expertise, but requires only a short testing session for results to be achieved.

The fourth chapter, "Cost Recovery in the Irrigation and Drainage Sector: User's Participation as a Mechanism for Its Promotion," focuses on an approach that charges for irrigation and drainage in Egypt, such as funding dams, barrages, pumping stations, levees, main canals, and drains. Egyptian water law requires cost recovery from beneficiaries for the construction of *mesqa* improvements and from users of the construction improvements to the field pipe drainage system. The chapter demonstrates that the use of community participation in water supply and small irrigation systems can improve the performance of irrigation schemes. Since the study shows that public participation provides the basis for promoting cost recovery of I&D projects in Egypt, community participation should be oriented toward developing and enhancing a sense of ownership and responsibility within the communities. Furthermore, the chapter analyzes several types of service charge implementation schemes that have been used, and evaluates their strengths and weaknesses.

Chapter five, "Advancing Irrigation Cost Recovery in the Republic of Yemen: A Community Cost-sharing Approach," presents an approach applied in Yemen, a poor water-scarce country. The government's budget-strapped reform in the water sector called for improved cost-sharing initiatives to replace chronic patronage and supply-driven approaches, particularly in spate irrigation. The chapter presents success stories and lessons learned from the cost-sharing and water-user participation activities of the spate irrigation, which is the dominant Irrigation Improvement Project in Yemen. The chapter also presents comparable experiences from other groundwater conservation projects in Yemen. The chapter concludes that fostering proper awareness and incentives can ensure that cost-sharing and water-user participation results are obtained. This includes enhancing interfarm and interbeneficiary equity, improving on-farm productivity, and enabling the irrigators to participate in the design, contracting, implementation, supervision, operation, and maintenance of irrigation works.

Chapter 6, "What is Common and What is Specific in Initiatives Aiming to Improve Cost Recovery? A Synthesis of Case Studies" integrates the set of experiences and analyzes the common issues and themes in technical and institutional approaches to improve cost recovery. Such approaches include the potential to increase water-use efficiency, equity, reliability, and accountability. A key factor in success is the extent to which these approaches make services to users more reliable and agencies more accountable. Studies show that farmers are willing to pay water charges when water supplies are reliable. The issue of cost recovery, however, cannot be narrowly considered from a single angle. The initiatives to upscale cost recovery so that it is financially sustainable depend on a broader set of factors, which should then be included within a larger reform framework. Full cost recovery could be wishful thinking, but the natural, cultural, economic, and political conditions determine the level of cost recovery that is acceptable and affordable by users in a specific situation. If full cost recovery cannot be achieved, good policy analyses of the prevailing situation could determine the best alternative and employ the appropriate technology and institutional arrangement to use the opportunity to its full extent. The World Bank and other development agencies have an important role to play in working with governments to promote initiatives that improve and enable the environment and introduce higher levels of cost recovery. In collaboration, research centers and the private sector can contribute to developing and adapting technology for the varying situations in developing countries.

1. Cost Recovery of Irrigation and Drainage Projects: Wishful Thinking or Difficult Reality?

Ariel Dinar[1]

Abstract: Cost recovery of investment and operation and maintenance costs of irrigation and drainage water systems are in the center of a public debate that spans over many years. Although great ideas and so-called magic solutions to determine appropriate ways to charge for and collect cost recovery fees have been designed and implemented, the reality is that it is the exception rather than the rule that farmers pay the imposed cost recovery fees or even mutually agreed on them. This chapter provides the information collected in various agencies about the range of cost recovery collection strategies and introduces the discussion that will take place in this report.

1.0 Role of Cost Recovery

Policy makers are probing for and debating about ways to close the gap between the soaring usage of water and its limited availability. Much has been discussed and written about the importance of ensuring that water users in all sectors appreciate the relative and absolute scarcity of the resource they use.

Charging for water is considered to be one of many policy interventions that could mitigate quantity and quality dimensions of water scarcity and enhance productivity of water. Charging for water has two key roles: (1) a financial role as a mechanism for recovering the investment and operation and maintenance (O&M) cost of the water system, and (2) an economic role of signaling the scarcity value and opportunity cost of water to guide allocation decisions both within and across water subsectors.

As defined by Barakat, irrigation cost recovery is the "process of directly or indirectly capturing and directing to public agencies some portion of revenue resulting from government actions to provide irrigation services, regardless of whether or not these funds are used to pay for any construction or operation or maintenance costs" (Barakat 2002).

Water-charging (pricing and cost recovery) policies in most countries fail to perform successfully most likely because of incoherent approaches and inappropriate institutions that have their roots in complicated political economy environment. Development agencies, such as the World Bank, maintain a policy that cost recovery should be sufficient to pay for O&M and for fair return on capital investment. Implementation on the ground, however, is unsatisfactory for most of the cases. Use of prices to ration scarce water is almost nonexistent. Examples in which pricing for water rationing has been

attempted include Israel—in the irrigation and urban sectors (Yaron 1997), the United Kingdom (Scott and Eakins 2002), and the Broadview water district in California (Wichelns 1991). In the latter example, block rate pricing was implemented and is still in existence to reduce water quality–related problems. A common problem in such cases is that the intent is to ration water, but the design of the rate structures is a compromise of political pressure by interest groups and, thus, falls short of its intent. The most extreme example can be found in Ireland (Scott 2003), where a water rate structure that was agreed on in one administration for rationing water in Ireland was abolished after the elections by the incoming administration.

Irrigation and drainage projects in particular face multiple challenges, among which are achieving and securing financial sustainability and their derived equity and poverty aspects. Cost sharing between users and governments in the form of cost recovery of investment and O&M costs of irrigation projects is one of the most used methods, but also one of the most controversial. Experience with the application of various cost recovery mechanisms is mixed. In recent years, however, with technological and institutional advancements, there are indications of successful experiences in various countries. In addition to the irrigation and drainage sectors, attempts to implement cost recovery have been documented in other sectors.

Past experiences with cost recovery implementation primarily have been poor, but the need to provide the necessary financial resources to sustain the irrigation system and its services is acknowledged by irrigation and drainage water providers and users. In this report, we introduce several approaches to achieve cost recovery that have been implemented in various countries in recent years. Technology and institutions play an important role in the four cases to be presented in the report. Two technology-based cases are (1) the use of Total Canal Control™ (TCC™) in Australia (Nayar and Aughton 2007), and (2) the application of remote sensing for charging for groundwater abstraction in Mexico, Pakistan, and Saudi Arabia (Bastiaanssen and Hellegers 2007). The two institution-based cases are (1) promoting user participation as mechanism for cost recovery of drainage water systems in the Arab Republic of Egypt (Attia 2007) and (2) experiencing community cost sharing of irrigation water in the Republic of Yemen (Hatim and Shawky 2007).

1.1 The Technology- and Institution-Based Cases

Nayar and Aughton (2007) describe the Total Channel Control™ (TCC™) canal automation system and its recent implementation in a number of irrigation districts in Australia. The chapter also describes the range of methods used to recover the investment cost in the TCC™ system, including the sale of water saved to other irrigators and government environmental agencies as well as conventional cost recovery through infrastructure charges.

Bastiaanssen and Hellegers (2007) focus on a methodology that computes evapotranspiration, net groundwater use, and groundwater abstractions in irrigated areas using satellite-based measurements of land surface temperature and surface reflectance with a minimum of field data. The actual

application of volumetric charging to recover costs in several countries is described and discussed.

Attia (2007) asserts that it is unlikely that cost recovery of irrigation and drainage projects will be achieved without formal and effective user participation in projects management. User participation may include a wide range of activities at different levels as well as the development of district water boards and the enhancement of Water Users Associations (WUAs).

Hatim and Shawky (2007) introduce cost-sharing initiatives that replace chronic patronage and supply-driven approaches, particularly in spate irrigation, using experience from the (Groundwater) Irrigation Improvement Project in Yemen and from other groundwater conservation projects in the Republic of Yemen. The main message is that cost-sharing and water user participation results can be obtained when proper awareness-raising and incentives are fostered, including enhancing interfarm and interbeneficiary equity.

1.2 The Structure of This Chapter

The remainder of this chapter reviews cost recovery approaches and implementation experiences and attempts to synthesize the experience into a window of options. These options are discussed in the subsequent chapters, which detail the individual case studies, and in the synthesis chapter. The next section provides a short menu of cost recovery approaches and their relative effectiveness. Section 3 is dedicated to review of World Bank project experiences with cost recovery. Sections 4 and 5 focus on cost recovery implementation experiences in developing and industrial countries, respectively. Section 6 introduces the inevitable conclusion that a fresh look at cost recovery implementation—taking advantage of technology breakthrough and institutional progress—will expand more promising approaches and widen success.

2.0 Pricing Effectiveness and Cost Recovery Alternatives

A vocal debate exists regarding the effectiveness and relevance of charging for water and water services, especially as it relates to irrigation water. With all the deficiencies of the volumetric water pricing methods that have been addressed in the literature (Easter and Liu 2005; Johansson et al. 2002), some argue that a distinction between pricing and charging of water has to be made. Critics of volumetric water pricing assert that a minimal response by users is a common phenomenon. In trying to understand the economic rational for such a low response, Moore and Dinar (1995) and Moore (1999) investigate the behavioral reasoning that could affect irrigators' behavior in response to water price increases. Moore and Dinar (1995) find for the case of California that farmers will respond differently to regulations, depending on the binding resource. If land is relatively scarcer than water, then water quotas will be more effective in sending the water scarcity signal rather than prices. A similar finding, with more general implications is suggested by Finkelstein and Kislev (1997). Moore (1999) goes further to check what price increase would affect the demand for water by the Bureau of Reclamation districts' farmers in Western United States. Not surprisingly, as baseline prices are unrealistically low, the

answer is that in most districts the increase in the price of water that will affect farmers' decisions (that is, equate the shadow price of their water supply) is so big that it is politically infeasible to achieve.

A recently published survey (Bosworth et al. 2002) draws lessons from the literature and concludes that because prices have to be increased dramatically to affect the demand by farmers, and much higher than the cost of service provision, the likelihood of that to happen is nil. Thus, to be practical and effective, emphasis should be put on cost recovery to allow at least a proper O&M of the irrigation system, and secure efficient water delivery to fields. Despite practical experience with cost recovery in developing (Bosworth et al. 2002) as well as in industrial countries (Massarutto 2002), cost recovery schemes are malfunctioning and do not provide the expected results. Massarutto extends his analysis of the role of cost recovery for long-run sustainability of irrigation systems in light of the new European Water Directive (Massarutto 2004). Using an accounting approach, Massarutto offers alternative arrangements to allocate the cost of irrigation water provision, asserting that as an instrument aimed at the efficient allocation of water resources among users and as an instrument of environmental policy, water pricing can be (moderately) effective, but it will hardly be sufficient, calling on additional tools and cost allocation arrangements. But a more in-depth discussion on the various aspects of the political economy of water pricing is beyond the scope of this paper.

One would hypothesize that good cost recovery experiences are more likely in societies with greater ability to pay than poor societies. However, bad cost recovery experiences are observed in developed as well as in developing countries, among rich and poor, and among big and small irrigators. A review of cost recovery performance data from various sources supports the previous statement.[2]

3.0 Cost Recovery Experiences in and Implications for World Bank Projects

The 1993 World Bank Water Resources Policy provided a framework to improve water resources management. The framework included two important components: (1) incentives and (2) poverty (alleviation) reduction with a focus on water pricing and demand management. The 1993 policy opened the road for the possibility to implement cost recovery and charging. Did the implementation of cost recovery occur as expected? Three evaluations of the application of cost recovery experiences in World Bank Projects have been conducted.

3.1 A 10-Year Portfolio Review, 1991–2000

A 1991–2000 irrigation and drainage (I&D) portfolio review conducted in the Agriculture and Rural Development Department indicated that the Bank uses water pricing, cost recovery, and other volumetric measures to varying degrees as mechanisms to charge for water use. Mechanisms used include the following:

- Increasing cost-sharing charges over time
- Full O&M and partial investment

- Full O&M, full investment
- Volumetric mechanisms, mainly by measuring head in lateral canals

A review of the 67 active I&D projects of the World Bank portfolio (as of September 2000) suggest several charging practices (table 1.1).

As shown in table 1.1, 52 of the 67 projects had water charging implemented and 15 had no water charging at all. Table 1.1 also shows that the majority (63 percent) of the projects with water charging have nonincentive (cost recovery) water pricing mechanisms, 20 percent include volumetric measures of water that allow incentive-based pricing, and 17 percent do not identify the pricing mechanism. Although the majority of the projects include cost recovery pricing, 25 percent also allow for a gradual increase to reach full cost recovery toward the end of the project.

Several projects are worth mentioning because the features they implemented could be applied to related projects (see table 1.2).

Table 1.1 Distribution of Pricing Incentives in World Bank's Irrigation and Drainage Projects (1991–2000)

Type of Water Pricing	Number of Projects (%)
Volumetric, targeting O&M and investment	6 (12)
Volumetric, targeting O&M	4 (8)
Annual fixed fee for O&M and/or capital	13 (25)
Fee, gradually increasing to cover O&M and/or capital	11 (21)
Land-based fixed fee, targeting O&M	9 (17)
Mechanism not determined	9 (17)
Total	52 (100)

Source: Author.
Note: O&M = operation and maintenance.

Table 1.2 Examples of Irrigation and Drainage Projects That Introduce New Cost Recovery Features

Project Name	Features
Philippines 2nd Irrigation Operations Support Project	Monetary bonus to agency staff (percent of fee collection)
Turkey Privatization of Irrigation Project	Purchase of O&M equipment and its operation by users
Nepal Irrigation Sector Project	The "No-Payment, No-Project" Principle
Pakistan National Drainage Program	Up-front cost sharing for capital investment

Source: Author.
Note: O&M = operation and maintenance.

Two projects (Pakistan and Nepal) were identified to have interesting features of cost recovery that, if appropriately designed, could motivate users. By involving users in the project from the first stage, and by acknowledging their responsibility, users can become more responsible and efficient:

The first project is the "No-Payment No-Project" Principle that was implemented in the Nepal Irrigation Sector Project (NISP), which is part of the Irrigation Policy (IP) of Nepal. In accordance with IP principles, private and public systems would be considered eligible for funding under NISP upon written application of beneficiary farmers. These applications must be backed up by the farmers' financial contribution to investment costs. The No-Payment No-Project Principle would be applied.

Up-front cost sharing in Pakistan's National Drainage Program (NDP) is the second example. The NDP will progressively ensure that all O&M costs are covered. Provincial Irrigation and Drainage Agencies (PIDAs) and Area Water Boards (AWBs) would become financially self-sustained for O&M costs within 10 years and Farmer Organizations (FOs) would become self-sufficient within 7 years. Up-front cost sharing for capital investment (compared with back-end cost recovery in many other projects) will prevail. This cost-sharing agreement will be stipulated in the participation agreements between the provinces and PIDAs, AWBs, and FOs.

3.2 The Operations Evaluation Department Report, 2004

An Operations Evaluation Department (OED) report titled "Bridging Troubled Water" (OED 2004) assessed the implementation of the 1993 Water Resources Policy and found that water pricing is considered to be a key component of the Bank's water strategy and effective water allocation. Efficient water pricing combined with appropriate fee collection and good management ensures water service delivery and thus meets the Bank's poverty objectives. In practice, however, water resources have only a nominal price set by a small license fee because of economic, cultural, and political difficulties. Overall, most Bank projects pay lip service to cost recovery, and only two-thirds of Bank projects have addressed it substantially.

3.3 Review of Project Appraisal Documents, 2002–05

A review of recent project appraisal documents (PADs) shows that although cost sharing is more dominant in project investment charging, cost recovery of O&M is absent in most Bank I&D projects.

As shown in table 3, there is a steady decline in projects with water pricing or cost recovery for O&M between 2002 and 2005. However, the data in table 1.3 suggest an increased trend between 2002 and 2005 of projects with investment cost sharing.

3.4 Interim Remarks

Evidence suggests that cost recovery has been attempted more often in non-Bank projects. Following are explanations for some of the difficulties in implementing cost recovery?

Table 1.3 Extent of Cost Sharing and Cost Recovery in PADs, 2002–05

Year	Number of Projects	With Pricing/Cost Recovery (%)	With Cost Sharing (%)
2002	6	3 (50)	5 (83)
2003	8	3 (37)	5 (62)
2004	11	1 (9)	7 (64)
2005	11	1 (9)	6 (55)
Total	**36**	**8 (22)**	**23 (64)**

Source: Based on Gambarelli 2006.

Certain country conditions, irrigation practices, and other factors appear to enhance cost recovery and fee collection rates in Bank projects. The country conditions include the following: (1) physical conditions (common water scarcity and drought and poor-condition infrastructure); (2) economic and political conditions and policies (economic liberalization, decentralization, and serious financial constraints); and (3) legal and institutional arrangements (definition of water rights, effective local system for enforcing water use rules, and rights to establish WUAs). Good irrigation practices that favor water fee collection include the following: (1) pricing structure or technology that encourages water savings, (2) assurance and transparency in water delivery, (3) public education and technical assistance, (4) water market, and (5) management transfer (financial autonomy and user participation). Other factors include monetary bonuses to agency staff or incentives to collect (percentage fee collection); purchase of O&M equipment and its operation by users (user participation and transparency); the no-Payment No-Project Principle (penalty for nonpayment); up-front cost sharing for capital investment; financial autonomy; and improved irrigation services.

4.0 Cost Recovery in Developing Countries

Cost recovery becomes highly emotional in developing countries where the economy is usually subsidized and thus recovering the cost of water delivery is much more complicated and difficult. The famous vicious circle is frequently mentioned, giving rise to equity issues and linking payment for service with quality of service. Because O&M costs lag substantially over years of operation, water is not usually delivered effectively and therefore produces inequities along the irrigation system.

As suggested by Abu-Zeid (2002) methods of assessment and collection of fees must be considered in light of the country's economic and technical environment. Developing countries find themselves in a difficult situation. On one hand, multilateral and bilateral donors with the objective to improve the efficiency of irrigation systems put pressure on host governments to discontinue the subsidy of O&M of the system and push them to increase the share of the investment or the O&M to be born by the users. Conflicts exist between the government and the private sector and between the government

and the users and their representatives (Abu-Zeid, 2002). Some cases do exist, however, that can highlight useful examples. They are tallied below.

In the Loskop Irrigation Scheme in South Africa, farmers pay an area-based fee of about South African rand (R) 24 per hectare (ha) and a water tariff, depending on the crop, to cover variable costs. The irrigators' surplus is R 90.5 per ha when water price is R 0.07 per cubic meter (m^3) for tobacco, citrus, table grapes, and peas. The joint surplus is R 55.9 million because farmers are transferring R 34.6 million (for 2000/01) to suppliers, which are the fixed costs for that year. Therefore, when applying volumetric pricing, price differentiation among crops only serves to encourage some crops relative to others by subsidizing them (Tsur et al. 2004).

Based on the South African experience, Schur (2000) warns that previous conditions regarding access to irrigation water and pricing policy can set powerful limits on the possibility of cost recovery, for example, cost recovery strategies must be sensitive to historical inequities (Schur 2000). Within such historical limits, an overview of the cost recovery experiences in a sample of countries leads to two principal findings: (1) cost recovery is becoming more prevalent and (2) success requires buy-in by farmers.

The idea that the cost of irrigation water supply must be recovered by charging for water is gradually being institutionalized through legal and legislative means. Some countries like Cyprus (Bazza and Ahmad 2002; Tsiourtis 2002) and Vietnam (Fontenelle and Molle 2002) have had a long history of cost recovery. Others, however, such as Egypt and the Republic of Yemen (Barakat 2002; Bazza and Ahmad 2002), do not have a formal water pricing policy, and even in those countries an understanding exists that the provision of water implies a significant cost as reflected in expensive groundwater extraction, strategic crop choices, and informal trading. In most cases, charging is aimed at recovering some or all of the O&M costs, but capital costs are addressed to a lesser extent (Aguilar 2000; Bazza and Ahmad 2002; Ben Abderrazik 2000; Yaozhou and Bingcai 2000). Most fees do not cover costs of rehabilitation, which are either subsidized by the state, or borrowed directly from foreign sources. Otherwise, systems are simply left to deteriorate.

Several examples suggest the importance of buy-in by farmers. Collection rates are generally better within WUAs than directly from individual farmers, especially when estimated fees are collected ahead of the irrigation season or the agricultural year (Aguilar 2000). Farmers pay for services received, so they prefer to see their taxes used for improvements in water delivery services instead of being dropped into the same pot along with other taxes in treasury departments (Bazza and Ahmad 2002; Fontenelle and Molle 2002). Liberalization of prices of irrigated crops and subsidies for modern equipment may be needed to make water tariff increases more acceptable to farmers, for example, as in Tunisia (Bazza and Ahmad 2002). In Morocco, the prices of strategic crops such as sugar beet and sugarcane need to be liberalized if farmers are to accept higher prices for water in large irrigation schemes (Ait-Kadi 2002). Transparency in accounting and management is necessary to encourage farmers to pay for services and to induce them to save water (Fontenelle and Molle 2002). A summary of these experiences is presented in table 4.

Table 1.4 Cost Recovery Strategies and Collection Rates in a Sample of Developing Countries

Country	Charging Scheme	Strategy for Cost Recovery	Cost Recovery Rate	Comments and Key Issues
Morocco	US$0.02/m^3 for gravity irrigation; US$0.02–0.04/m^3 for pumped water; US$0.04–0.053/m^3 for sprinkler schemes (depending on the ORMVA)	40% of investment cost from beneficiaries and 60% from budget; energy tax indexed to electricity tariff; 100% of O&M to be covered by water tariffs. Small farmers (<2.5 ha) have a different cost recovery scheme.	Recovery of water tariffs was 70–73% from 1990–97 and 52–58% from 1997–2000	Current decrease in recovery rate is believed to be due to droughts. Allocation of water occurs through planning and not pricing. Costs of extension services and rehabilitation are not included in fees.
Syria	US$40 to 120/ha for investment costs; flat fee of US$70/ha for permanent irrigation; and US$12/ha for winter crops	Direct fee for part of investment costs amortized over 30 years; flat fee represents average actual O&M costs in the main irrigation networks.	90% of O&M costs	Collection rate is impressive but only applies to government-irrigated networks. At the same time, 59% of irrigated area depends on well water (with costs covered by farmers) and lowering of groundwater levels is a problem.
Pakistan	Per area fee by crop, US$0.6 per acre-inch for fodder and US$3 per acre-inch for sugarcane; other crops in between	Government subsidies cover cost of rehabilitation of watercourses. Cultivation intensity and farm size determine water charge.	30–70% of O&M costs	Water charges not related to quantity of actual canal water applied so rate increases have little effect on economic efficiency. Also water revenues are pooled with other taxes and lose relation to O&M.

Table 1.4 (continued)

Country	Charging Scheme	Strategy for Cost Recovery	Cost Recovery Rate	Comments and Key Issues
Tunisia	US$0.066/m^3 at the national level; US$0.025–0.08/m^3 across regions	Policy aims to cover O&M costs in first phase. Preferential tariffs for cereals and for reuse of treated wastewater in agriculture; 16% of wastewater treatment is covered by tariff.	Recovery of O&M costs: 70% in 1991 to 115% in 2002	Water prices are to be increased at 15% per year in nominal terms. Policy has been resisted by farmers but assisted by liberalization of prices of most irrigated crops and subsidies for modern irrigation equipment.
Cyprus	Volumetric pricing; US$0.1078/m^3	The goal is to recover 38% of weighted average unit cost of irrigation water.	Charge since 1992 has been 34% of weighted average unit cost of irrigation water	Sum of annual costs of all existing projects divided by all irrigation water from the projects is the weighted average unit cost of irrigation water
China	Average national irrigation water tariff is 0.026 yuan/m^3 in 1997	Water tariff accounts for 36% of supply cost on average; water supply costs and a profit are to be recovered for cash crops but only water supply costs for grain crops.	———	Costs are higher in the north than in the south because of greater rainfall in the south. Pricing is highly centralized and only meant to recover costs.
Mexico	Charges set by WUA; estimated annual O&M budget divided by the water allocated to the module is the tariff for the year; average water cost is US$40 per ha	Users pay more than 70% of O&M costs and the government subsidizes around 15%.	In most irrigation districts, users pay the WUA before the irrigation cycle; otherwise a flat rate per season per ha is charged; recovery is 90–100%.	Transfer programs to WUAs have raised user payments from 39% of the irrigation districts in 1990 to almost 80% in late 1990s.

Table 1.4 (continued)

Country	Charging Scheme	Strategy for Cost Recovery	Cost Recovery Rate	Comments and Key Issues
Turkey	Capital cost was US$0.3–0.7 per ha in 1998 across regions. Examples of O&M fees from a region: wheat US$22 per ha, cotton US$76 per ha (for gravity irrigation; pump irrigation is more expensive), US$56 per ha for wheat	Annual area-based fee consists of capital cost and O&M costs. Capital cost recovery not to be charged for 10 years after project completion; O&M costs collected for the previous year.	Collection rates were 32% in 1991 and 37% in 1998; highest rate was 50% in 1985. WUAs collect annual fees for O&M and investment before irrigation for the year. In 1998, nearly 76% of the planned budget was collected.	Annual area-based fee for DSI operated schemes; capital cost varies by region; O&M costs vary by region and crop; no volumetric system and very low capital cost recovery; no inflation adjustment despite 70% inflation rate.
Vietnam	Fee expressed in kilos of paddy and converted to cash based on official rate for a kilo of paddy (for example, water fees in the BHH polder are 5.8% to 7.7% of annual paddy production; 464 kg and 639 kg per ha per year for single pumping and double pumping, respectively)	Area-based water fee calculated for crop and irrigation type. Fees include water diversion and drainage and O&M costs. Fees are paid along with taxes such as land tax and road maintenance tax so farmers do not know what they pay for water.	Water fee recovery from cooperatives has exceeded 92%; but IDMSC collection rates for water diversion fees from the IDMSCs were 55% and 72% in 1998 and 1999 respectively.	Polders may be served by partly by cooperatives and partly by IDMSCs. A water diversion fee has to be paid to the cum. Pricing mechanism aims at financial stability and not at water saving. Transparency in management is main issue.

Source: Dinar and Mody 2004.
Note: BHH = boc hung hoi polder in Viet Nam; DSI = state hydraulic works in Turkey; ha = hectare; IDMSC = irrigation and drainage management companies; ORMVA = Offices Régionaux de Mise en Valeur Agricole; US$ = U.S. dollar; WUA = Water Users Association.

Table 1.5 Irrigation Water Prices and Cost Recovery Performance in Selected European Union Countries

	Irrigation surface (he)	Actual water price (€/m³)	Dominant farming systems	Water-related governance issues	Trands/ options	Actual recovery of costs*
1	27800	0.015	Continental (maize)	Excess abstraction from watercourse Absolute scarcity in dry years	Transform gravity to spray irrigation Set aside/ reforestation	Nearly achieved (70–80%)
2	8200	0.04–0.1	Mediterranean (horticulture)	Excess abstraction from watercourse Conflict with PWS in the summer	Introduce drip irrigation Eliminate continental crops	Substantially achieved (60–70%)
3	180000	0.08–0.1	Mediterranean (fruit, vegetables, durum wheat)	Severe scarcity in the case of drought; need to avoid individual abstractions	Invest for improving productivity of water; use recycled/ brackish water	Achieved for operational cost only (50%)
4	5000	0.01	Continental (cereals, oilseeds)	Available water for irrigation is less than theoretical demand	Some opportunity to change cropping mix	Nearly achieved (90%)
5	20000	0.18	Continental (cereals, oilseeds)	Available water for irrigation is less than theoretical demand	Little opportunity to change cropping mix	Nearly achieved (90%)
6	206000	0.02–0.04	Continental (cereals, oilseeds)	Competition with other uses for the water transfer schemes	Improve tradability of water rights	Very low (10–20%)
7	46000	0.1	Mediterranean (fruit, vegetables), greenhouses	Depletion of aquifer due to excess abstractions	Purchase more surface water	Achieved

Table 1.5 (continued)

	Irrigation surface (he)	Actual water price (€ / m³)	Dominant farming systems	Water-related governance issues	Trands/ options	Actual recovery of costs*
8	244000	0.08 (S) 0.63 (GW)	Mixed	Competition with PWS Contested new water transfers	Allocate water water to the more productive crops	Achieved for GW. low for S (30–40%)

Source: Massarutto 2003.
Note: The numbers on the left-hand side of the table correspond to the following countries: 1 = France; 2 = Italy; 3 = Greece; 4 = Portugal; 5 = Spain; 6 = Germany; 7 = United Kingdom; and 8 = Netherlands. GW = ground water; PWS = power, water, and solicitation; S = surface water.

Although it is too early to detect clear patterns, trends indicate that resource-intensive irrigation systems, such as those supplying pumped water or sprinkler schemes, tend to pass on higher costs to users. Evidence also suggests that reliability of water services is associated with high cost recovery. In the first instance, broader economic efficiency considerations of allocating water to the most productive end use may be less salient than just reducing wastage of water. To reduce waste, the use of metering is a key element of the cost recovery strategy. Such technical measures and accompanying organizational innovations needed to effectively implement cost recovery are addressed in the following chapters in this report.

5.0 Cost Recovery in Industrial Countries

The European Water Framework Directive (WFD) calls for full cost recovery. Although the words "full" and "cost" are frequently used, such words do not always mean the same thing to everyone. We learn from Massarutto's study (Massarutto 2003) of several European Union countries, that the O&M cost recovery rate in these countries varies between 20 percent and 100 percent and the machinery and infrastructure cost recovery rate varies between 15 percent and 100 percent; however, the cost is typically at the lower end of the range. Moving from such an uneven distribution of cost recovery rates toward a target of full cost recovery (even without agreeing on what "full" is) can be an arduous process.

6.0 Conclusion and Looking Forward

Many mechanisms and good practices can strengthen cost recovery in I&D projects with user participation being the most effective factor to improve the collection rate. Technology and institutions appear to form the basis for improving cost recovery in I&D projects.

According to Dinar and Mody (2004) modern technologies are expected to reduce water withdrawals and increase crop yields through the more focused application of water. At the same time, institutional and organizational changes

are necessary to realize the benefits of applying the advanced technologies. These changes include steps to organize water delivery at the level of tertiary canals, streamline fee and tariff collection, maintain a constant flow of information among supply agencies and users, arrange rural credit mechanisms, provide extension services, institute legal codes to establish water rights when necessary, and resolve conflicts. Government responsibilities, and those of other agencies, must be clearly defined. Several examples illustrate the role of appropriate use of technology and institutional innovations to enhance the effectiveness of cost recovery. Modernization of the existing irrigation systems—along with appropriate changes in rules of operation—is often necessary to meet today's goals (Facon 2002).

For cost recovery policies to be effective, the idea of charging for the extraction and delivery of water has to be made acceptable to farmers. In addition to farm produce price decreases, the perception of decreased income as a result of increased fees is corroborated by many studies. Water users must feel that they are receiving a reliable service for the prices paid, and that the price is no more than the cost of services rendered (Abu-Zeid 2002). Country studies emphasize the need to address equity issues to enable farmers to conform to water pricing reform. In addition, the history of access to water must be taken into account in trying to gain farmer acceptance for irrigation water pricing.

Some experts suggest that WUAs may be used as an interface to collect revenues (for example, Hamdy 2002). By being able to represent farmers' needs and interests to the irrigation authority, WUAs can also aid in collecting revenues from farmers. The outcome is regarded as very successful in terms of measuring volume of water delivered and settlement of conflicts. However, it has not always been easy to establish sustainable WUAs. For example, in Turkey, the lack of a legal basis ensuring that irrigation associations were democratically constituted and that they could federate was an initial constraint that has still to be resolved (Vermillion 2006). Furthermore, as Vermillion explains,

> *studies by IWMI [the International Water Management Institute] have shown that both cost recovery and the performance level of O&M improve with granting of financial autonomy to WUAs. However, in cases in which WUAs are responsible for paying for O&M, but expect the government to make repairs and improvements periodically, they tend to defer maintenance (2006, p. 36).*

Although there are plenty of successful and less successful examples of technology and institutions employed in cost recovery, it is still difficult to identify the right approach to achieve effective cost recovery in the sector. The four case studies discussed in the following chapters are important indicators that demonstrate the potential embedded in technology and institutions for improved cost recovery implementation.

Notes

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[2] A comparison between various cost recovery cases may address different metrics. For example, it is important to define the agreed-on base of the cost recovery share. So, two cases that display a similar cost recovery rate of, say 20 percent, do not necessarily imply the same burden on the users, because each may refer to a different O&M or investment volume, and thus end up with different absolute values although the percentage rates are similar. Although this is a useful observation, it is less relevant for discussions in this paper. There is no basis for comparison of any two irrigation projects in different locations. What is of interest to us in this context is to realize the agreed-on final share of cost recovery and its implementation. Surprisingly, irrigation projects with a lower basis for cost recovery reflect lower cost recovery rates than those with higher O&M and investment costs.

References

Abu-Zeid, M. 2002. "Water Pricing in Irrigated Agriculture." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Aguilar, Enrique. 2000. "Pricing of Irrigation Water in Mexico." World Bank, Washington, DC (Unpublished).

Ait-Kadi, Mohammed. 2002. "Irrigation Water Pricing Policy in Morocco's Large Scale Irrigation Projects." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Attia, Bayoumi. 2007. Chapter 4: Cost Recovery in the Irrigation and Drainage Sector: User's Participation as a Mechanism for its Promotion. In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank.

Barakat, Essam. 2002. "Cost Recovery for Irrigated Agriculture: Egyptian Experience." *Options Mediterraneennes* Serie A(49): 73–90.

Bastiaanssen, Wim, and Petra Hellegers. 2007. Chapter 3: Satellite Measurements to Assess and Charge for Groundwater Abstraction. In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank.

Bazza, M., and M. Ahmad. 2002. "A Comparative Assessment of Links Between Irrigation Water Pricing and Irrigation Performance in the Near East." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Ben Abderrazik, Hassan. 2000. "Pricing of Irrigation Water in Morocco." World Bank, Washington, DC (Unpublished).

Bosworth, B., G. Cornish, C. Perry, and F. van Steenbergen. 2002. "Water Charging in Irrigated Agriculture: Lessons from the Literature." Report OD 145, HR Wallingford Ltd, Wallingford, UK.

Dinar, Ariel, and Jyoshna Mody. 2004. "Irrigation Water Management Policies: Pricing and Allocation Principles and Implementation Experiences." *Natural Resources Forum*. 28: 112–22.

Easter, William, and Yang Liu. 2005. "Cost Recovery and Water Pricing for Irrigation and Drainage Projects." Agriculture and Rural Development Discussion Paper 20, World Bank, Washington, DC.

Facon, T. 2002. "Downstream of Irrigation Water Pricing – The Infrastructure Design and Operational Management Considerations." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Finkelstein, Israel, and Yoav Kislev. 1997. "Prices versus Quantities: The Political Perspective." *Journal of Political Economy* 105(1): 83–100.

Fontenelle, J., and F. Molle. 2002. "The Intricacies of Water Pricing in the Red River Delta, Viet-nam." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Gambarelli, Gretel. 2006. "Review of Agricultural Water Projects' Quality at Entry (FY02-05 portfolio)." Washington DC: Agriculture and Rural Development Department, World Bank.

Hamdy, A. 2002. "Water Pricing in Agricultural Sector Charging Mechanisms and Implementation." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Hatim, Naji, and Ahmed Shawky. 2007. Chapter 5: Advancing Irrigation Cost Recovery in the Republic of Yemen: A Community Cost-Sharing Approach. In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank.

Johansson, Robert C., Yacov Tsur, Terry L. Roe, Rachid M. Doukkali, and Ariel Dinar. 2002. "Pricing and Allocation of Irrigation Water: A Review of Theory and Practice." *Water Policy* 4(2): 173–99.

Massarutto Antonio. 2004. "Water Pricing: A Basic Tool for a Sustainable Water Policy?" In *Challenges for New Water Policies in XXI Century*, eds. E. Cabrera and R. Cobacho, 126–139. Amsterdam: Balkema.

Massarutto, Antonio. 2003. "Water Pricing and Irrigation Water Demand: Economic Efficiency vs. Environmental Sustainability." *European Environment* 13: 100–19.

Massarutto, Antonio. 2002. "Irrigation Water Demand in Europe. The Impact of Agenda 2000 and the Water Framework Directive." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Moore, Michael, and Ariel Dinar. 1995. "Water and Land as Quantity-Rationed Inputs in California Agriculture: Empirical Tests and Water Policy Implications." *Land Economics* 71(4): 445–61.

Moore, Michael R. 1999. "Estimating Irrigators' Ability-to-Pay for Reclamation Water." *Land Economics* 75(4): 562–78.

Nayar, Mark, and David Aughton. 2007. Chapter 2: Canal Automation and Cost Recovery—Australian Experience Using Rubicon Total Channel Control™. In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank.

OED (Operations Evaluation Department). 2004. "Bridging Troubled Water." Operations Evaluation Department, World Bank, Washington, DC.

Schur, Michael. 2000. "Pricing of Irrigation Water in South Africa." World Bank, Washington, DC (Unpublished).

Scott, Susan. 2003. "Abolition of Domestic Water Charges in Ireland." Accessed on June 7, 2006 at http://siteresources.worldbank.org/INTWRD/903845-1112344347411/20424161/31203ARDenoteWRMEIScott.pdf

Scott, Susan, and John Eakins. 2002. "Household Income Effects and Implementation Options." Chapter 4 in *Green and Bear It? Implementing Market-Based Policies for*

Ireland's Environment, eds. Daniel McCoy and Sue Scott. Dublin: Economic and Social Research Institute.

Tsiourtis, N.X. 2002. "Water Charge, The Cyprus Experience." Accessed on June 7, 2006 at http://www.worldbank.org/agadirconference.

Tsur, Y., A. Dinar, R. Doukkali, and T. Roe. 2004. "Irrigation Water Pricing: Policy Implications Based on International Comparison." *Environment and Development Economics* 9(6): 735–55.

Vermillion, Douglas. 2006. "Irrigation Management Transfer: Lessons from Global Experience and Key Steps for Success." Agriculture and Rural Development Department, World Bank, Washington, DC.

Wichelns, Dennis. 1991. "Increasing Block-Rate Prices for Irrigation Water Motivate Drain Water Reduction." In *The Economics and Management of Water and Drainage in Agriculture*, eds. Ariel Dinar and David Zilberman, 275–294. Dordrecht: Kluwer Academic Publishers.

Yaozhou, Zhou, and Bingcai Wei. 2000. "Pricing of Irrigation Water in China." World Bank, Washington, DC (Unpublished).

Yaron, Dan. 1997. "Israel." In "Water Pricing Experiences, an International Perspective," eds. Ariel Dinar and Ashok Subramanian. World Bank Technical Paper 386, Washington, DC: World Bank.

Annex: Details of Cost Recovery in PADs, 2002–05

2002 PADs		
No. of Projects	**Pricing/Cost Recovery**	**Cost Sharing**
1	Non	10–30% Inv
2	Cost Sharing	15% Rehab cost
3	Rs. 257/ha	Non
4	Non	12% Inv
5	Non	38% Civil work; 20% Equip
6	10% O&M	50% Inv
2003 PADs		
1	10% of O&M of main infra	Non
2	15$/ha	10% Inv
3	Non	5–50% Infrastructure work
4	All O&M (GW 10–20%)	20k Down-payment
5	Non	Full payment of infra below sec level
6	Non	20% of Inv
7	Non	Non
8	Non	Non

No. of Projects	Pricing/Cost Recovery	Cost Sharing
2004 PADs		
1	None	Upfront payment of 20% of inv
2	None	60% of cost of asset
3	None	None
4	None	None
5	None	80% of investment
6	Full CR of O&M	Upfront 3,000LEK per ha of gravity (more for pump)
7	None	None
8	None	11% of total Inv
9	None	Upfront 50% of project Inv
10	None	None
11	None	10% of value of Civil works
2005 PADs		
1	None	None
2	None	None
3	None	None
4	None	20–70% of Inv
5	None	None
6	None	Full cost of Imprv over 3 Yrs
7	None	1 time subscription to water rights
8	Full CR of O&M	None
9	None	10–15% of Inv
10	None	Rs 500 for Inv (200 upfront)
11	None	20% of Irrig development

Source: Based on Gambarelli 2006.
Note: CR = cost recovery; GW = groundwater; ha = hectare; LE = Egyptian pounds; O&M = operation and maintenance; Rs = Indian rupee; US$ = U.S. dollars.

2. Canal Automation and Cost Recovery—Australian Experience Using Rubicon Total Channel Control™

Mark Nayar[1]
David Aughton[2]

Abstract: This chapter provides an overview of the Total Channel Control™ (TCC™) canal automation system. The system has recently been implemented in a number of irrigation districts in Australia. The chapter describes how these irrigation districts use a range of methods to recover the investment cost in the TCC system, including the sale of water savings to irrigators and government environmental agencies as well as conventional cost recovery through infrastructure charges. Australian irrigation districts have well-established frameworks for cost recovery and active water markets. The chapter explains how these institutional arrangements, in turn, are leading to increased investment in irrigation water use efficiency. It also describes how TCC automation is one of the key infrastructure solutions for improved water use efficiency in canal irrigation schemes in Australia. The staged implementation of TCC in irrigation systems in less developed countries is briefly assessed and an explanation of how this implementation could assist in the drive to achieve cost recovery is proposed.

1.0 Introduction

1.1 Irrigated Agriculture Sector

Irrigated agriculture in Australia was introduced in the late 1800s. The twentieth century saw increased development of storage dams and canal irrigation districts with water supplied under gravity to irrigation districts. Today, some 2 million hectares (ha) of land is irrigated using about 15.5 cubic kilometers (km^3) of surface water per year and generating a gross farm-gate value of Australian dollar[3] ($A) 7.2 billion per year in 2001 (see table 2.1).

The range of irrigated agriculture in Australian irrigation districts is diverse as is the economic returns to water use. Gross revenue of irrigated water use is variable ranging from $A 189 per thousand cubic meters for rice cropping through to $A 1,776 per thousand cubic meters (m^3) for intensive horticulture.

1.2 Water Use Efficiency

Irrigation accounts for about 70 percent of the total surface water extraction in Australia and the majority of the groundwater use. Irrigators in the large canal irrigation districts of the Murray and Murrumbidgee Rivers of the southern Murray-Darling Basin (MDB) divert some 10 to 11 km^3 surface water resources per year (Murray-Darling Basin Commission 2005). This represents up to

Table 2.1 Water Use and Gross Value of Irrigated Agriculture, Australia (2001)

Irrigated Enterprise	Gross value ($A m)	Net water surface water use (km^3)	Irrigated area (ha)	Value per unit of water ($A/thousand m^3)	Use per unit of land (thousand m^3/ha)
Pastures and grain crops	2,540	8.79	1,174,687	289	7.5
Vegetables	1,119	0.63	88,782	1,776	7.1
Sugar	517	1.23	173,224	420	7.1
Fruit	1,027	0.70	82,316	1,467	8.5
Grapes	613	0.65	70,248	943	9.3
Cotton	1,128	1.84	314,957	613	5.8
Rice	310	1.64	152,367	189	10.8
Total	**7,254**	**15.5**	**2,056,581**	**468**	7.5

Source: Australian Bureau of Statistics. 2004.
Note: $A = Australian dollars; km^3 = cubic kilometers; ha = hectare; m^3 = cubic meters.

88 percent of the natural flow of these rivers before the development of irrigation. Flow and seasonal conditions in these rivers has been markedly affected by irrigation, with detrimental impacts on water quality and the health of river ecosystems (Murray-Darling Basin Commission 2005). The management of salt accumulation and mobilization associated with inefficient irrigation practices is another critical constraint.

The practice of conveying water in leaky earthen irrigation canals is perceived by the broader community (not always fairly) as wasteful. Community concern over perceived inefficiencies in irrigation, and increased competition for scarce water resources, has led to an increased emphasis on the technical and economic efficiency of water use at the farm and delivery system level.

The requirement to improve farm efficiency has driven investment by irrigators in pressurized systems and has led to the broad adoption of more efficient surface irrigation layouts. The development of water markets that permit the trade of water rights to higher-valued crops has facilitated improved farm efficiency (Pratt Water 2004). Irrigation districts have implemented and are investigating a range of water-saving activities, including canal automation, canal seepage and leakage remediation, and pipelining.

1.3 Irrigation Districts and Cost Recovery

The major irrigation districts in Australia operate with a high degree of financial autonomy from government. A range of different governance models are in use for irrigation districts, including (1) government-owned corporations (GOCs) with separate capital bases, independent revenue streams, and professional management; (2) private companies; and (3) irrigation cooperatives. The irrigation district operator typically functions at arm's length

from government, sources the majority of its revenue base from scheme users, and is clearly accountable to its shareholders for the financial and operational performance of the district (Langford, Foster, and Malcom 1999).

Pricing arrangements for irrigation districts generally seek to recover the cost of the replacement and renewal of capital assets as well as annual maintenance and operations. For capital items, irrigation schemes draw on funds built up from infrastructure annuity charges paid by irrigators. In the future, some of the large irrigation GOCs propose to use commercial debt markets to fund capital infrastructure (State Water Corporation 2005).

2.0 Total Channel Control™ System

2.1 Background

In response to a greater awareness of the value of water, irrigation farming practices in Australian have improved considerably over the last 20 years. To meet the demands of progressive irrigators, districts must be able to deliver water at short notice and with a high degree of reliability in terms of flow rates onto farms. This has led the industry to vigorously pursue improvements in service standards.

The evolution of control systems has now progressed to the stage at which canal automation is being applied to operate complete irrigation district networks. This progression has followed the implementation of centralized planning and scheduling systems (15–20 years ago) and wireless SCADA (Supervisory Control and Data Acquisition) control of regulating structures (10–15 years ago).

Centralized planning and scheduling systems are used to schedule variable demand from irrigators. Orders for water are placed via interactive voice response or Internet technology. Many irrigation districts have dedicated wireless SCADA networks in place with coverage across their channel systems. An ongoing program to implement gate actuation, control, and automation of regulating structures is also under way in many districts.

2.2 TCC: The Technology

TCC canal automation was developed by Rubicon Systems Australia Pty. Ltd. The system includes remote-controlled overshot gates (FlumeGate™), which are fitted to canal structures such as checks and regulators (see figure 2.1); offtakes and turnouts; a SCADA communications network; and advanced channel control and modeling software, which runs from a host computing site. The TCC system has been installed in four irrigation districts—Coleambally Irrigation Area, Macalister Irrigation District, Emerald Irrigation District, and the Central Goulburn area. The installations in these districts involve more than 2,000 gates and an ongoing program of additional installations.

Based on extensive practical experience, compared with a network under manual operation, it is now established that a TCC-equipped canal network can provide better control and more responsive customer service with the added benefit of significant gains in distribution efficiency thanks to reduced flows from waterways. The TCC system has shown considerable potential in

Figure 2.1 FlumeGates™ installed in Canal Regulators – Central Goulburn Irrigation Area, Australia

Source: Authors.

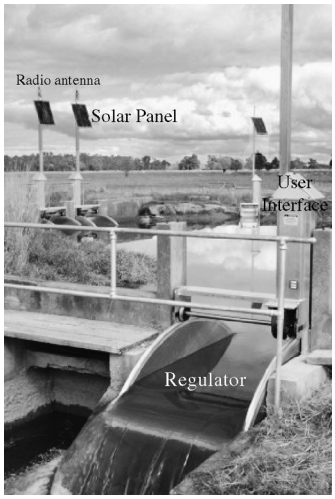
the detection and monitoring of leakage and seepage losses in canals. Using the TCC system, it has been demonstrated that multiple pondage and inflow-outflow tests can be conducted simultaneously across the canal network.

2.2.1 Reliable and Cost-Effective Gate Technology

The modernization of irrigation district canals conventionally involves the conversion of manually operated gate structures to actuated control. Until recently, these gates have been upgraded using overshot leaf-gate or undershot sluice-gate designs. The recent development of the FlumeGate™ has been key to the success of canal automation. The FlumeGate is a single unit constructed mainly of stainless steel and aluminium (see figure 2.2). It is fully self-contained and consists of a frame, a gate, housings for electronic equipment and the mechanical drive system, a solar panel to provide power, and a radio antenna to communicate with the host system. Integral to the gate frame are two stilling wells that house the upstream and downstream water-level sensing equipment. The gate is designed to be retrofitted to existing check or regulating structures with a minimum of modification to the structure. The gates are of robust construction designed for a long life in a harsh irrigation environment.

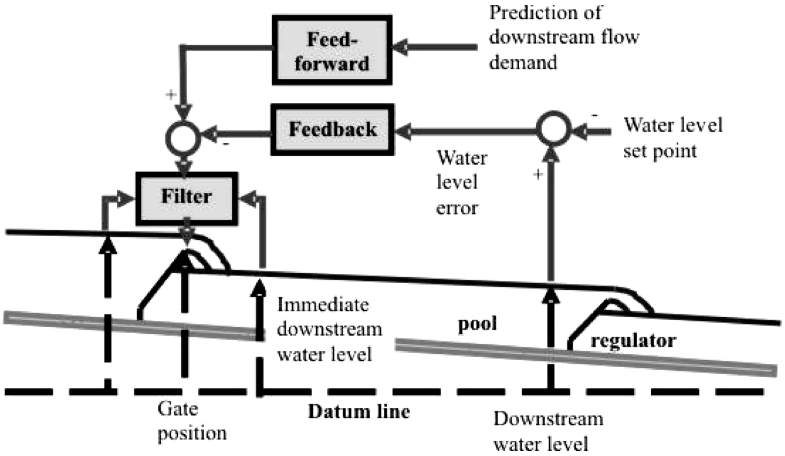
A major feature of the FlumeGate is its accurate flow measurement capability. Hydraulically, the behavior of the FlumeGate is similar to a knife-edge weir. Water flows over a sharp crest or "gate" and by measuring the water level upstream and downstream of the gate, and by knowing the position of the

Figure 2.2 FlumeGate™ Components



Source: Authors.

Figure 2.3 TCC-Distributed Real-Time Control Structure for Water Distribution and In-Canal Water Level Regulation



Source: Mareels, Ooi et al. 2005, p. 6.

gate, a flow rate can be calculated. Sharp-crested weirs are a well-established method to accurately measure flow in open channel systems.

2.2.2 Robust Control Technology

The experience of the irrigation industry over the last 30 years has demonstrated the difficulties of implementing automation in canal systems. The control of open channels has specific complexities, both in controller design and in controller tuning, and is by no means a simple undertaking. Rubicon has worked with the University of Melbourne over the last 10 years to develop specialized control technology to optimally operate canal networks (see figure 2.3). Major breakthroughs have been achieved, including System

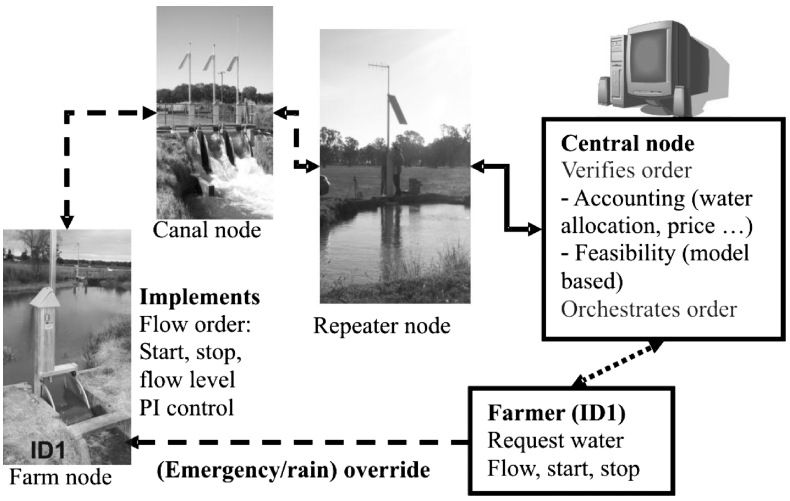
Identification Models (gray box models derived from data), global control software for TCC systems that combine feed-forward and feed-back control, local controllers (that is, distant downstream control), and optimal tuning processes for the control gates in their channel system applications (Mareels, **Weyer**, et al. 2005, p. 1). Much of this work has been patented.

2.2.3 Central Software System

A key feature of the TCC technology is the integrated host software system that combines the features of SCADA, water ordering, planning, and scheduling with the demand management system. A fundamental aspect of most network control systems, regardless of the application, is what happens when demand exceeds capacity. Unless supply capacity is unlimited, the control system will deteriorate.

Many irrigation district networks in Australia are subject to capacity restrictions at certain peak periods and require a means to predict and limit demand when maximum capacity is reached. An integral element of Rubicon's channel control technology is the Demand Management System (DMS), a software application that predicts and manages demand flows from irrigators when they approach the maximum rate of change and maximum flow capacity of the channel system (see figure 2.4). A network model derived via the control system underpins the DMS. Orders can be placed with minimum lead time (for example, less than one hour). With the TCC system, orders are typically accepted more than 90 percent of the time. This level of service equates to near on demand and achieves near maximum utilization of the channel network. The DMS is able to track all system losses down to the pool level (channel reach). Under the TCC system, losses caused by seepage, leaks, or theft can be quickly identified and corrected.

Figure 2.4 TCC System Architecture



Source: Mareels Ooi et al. 2005, p. 5.

2.3 TCC: The Benefits

Of all the viable alternatives in the Australian irrigation industry, it is now established that channel control technology has, by far, the biggest potential to improve water use efficiency in distribution networks. Studies are showing that channel control using the TCC system can deliver many of the benefits of a piped system, or off-stream storages, at a lower cost. It is also well known that the incorrect application of channel control technology, particularly based on simple forms of control at stand-alone sites, can lead to inefficiencies that are higher than those currently experienced under manual operation.

Addressing the total supply chain of the distribution network (from source to user to disposal) and implementing integrated technologies that are able to manage the total network not only improves operations from an irrigation authority perspective, but also significantly enhances on-farm operations. Benefits from this approach for the different stakeholder are as follows:

- **Benefits to the Water Supply Business**
  - Optimized channel performance
  - Reduced water loss
  - On-demand supply capability (irrigators receive water when required)
  - Minimal channel-level fluctuations
  - Reduced cost of operation
  - Occupational Health and Safety (risk exposure addressed)
  - Precise volumetric measurement (accurate billing and regulatory compliance)
- **Benefits to the Irrigator**
  - New level of service (irrigators have the ability to precisely control their water environment)
  - Water is available when required (close to on demand)
  - Water is supplied at rates that match crop needs
  - Eliminates fluctuating flow or long lead times to order
  - Ability to order and monitor water via phone, Internet, or cell phone
  - Improved environmental management (salinity control, reduced outfalls)

3.0 Cost Recovery in the Australian Irrigation Sector

3.1 Full Cost Recovery

As discussed in section 1.3, irrigation districts in Australia are mostly financially autonomous from the government. To fund operations, maintenance, and capital expenditure, they rely primarily on revenue recovered through water charges levied on irrigation users.

The level of irrigation cost recovery from users is variable. In privatized irrigation districts, shareholders determine the level of cost recovery. Pricing arrangements in government owned districts involve an economic regulatory

regime and an economic regulatory agency. The level of cost recovery in this case is subject to a regulatory pricing process. According to the standard regulatory pricing process followed, full cost recovery includes all of the following costs: (Productivity Commission 2006):

- Operational, maintenance, and administrative costs
- Asset depreciation
- Taxes
- Return on the capital
- Externalities (the natural resource management costs incurred by a water business)

Most of the large irrigation districts in Australia recover the full operational, annual maintenance, and administrative cost. In some cases, the scheme operators have taken a deliberate policy to defer expenditure and shift capital replacement costs to future years. In other cases, governments continue to subsidize water-related public functions, including dam safety upgrades and environmental initiatives.

To support cost recovery, irrigation districts apply accepted corporate governance standards. This includes fully audited annual financial reporting, professionally developed asset management plans, and expertise-based boards of directors with obligations to achieve appropriate levels of financial risk management. Decisions by management to under recover costs are made with the full knowledge and assent of shareholders.

Given the relatively high cost of labor in Australia, much attention has been focused on productivity savings. Centralized systems to plan and schedule orders have been implemented on a wide scale and manually operated structures have been replaced with remotely controlled SCADA gates.

3.2 Consumption-Based Pricing

Consumption-based two-part tariffs are widely deployed in irrigation pricing and cost recovery (Heaney et al. 2004). The most common form of pricing is the two-part tariff. This typically includes the following:

- A fixed component—a charge collected by the scheme operator from irrigators for each of the irrigation property meter outlets or a charge per unit volume of water right. This charge is billed to the irrigator once a year at the beginning of the irrigation season.
- A variable charge—a charge for usage as measured through the farm meter outlet. Water usage by individual irrigators in gravity irrigation districts is metered using a variety of devices, including Dethridge meter wheels, Rubicon FlumeGates, electromagnetic meters, and ultrasonic meters. Meters are read progressively through the season and users are billed two or three times a year.

Prices for water are determined independently for each irrigation district and for each subscheme or customer class within a district. Water prices vary according to operational practices, the age and condition of the infrastructure,

the level of past government subsidies, and the scheme operator's policy toward the recovery of long-term capital replacement costs.

3.3 Investment in Improved Water Use Efficiency

Government is a significant investor in improved efficiency in the irrigation sector. The cost of infrastructure modernization is in some cases recovered through the sale of the saved water to government environmental funds. These funds have been established specifically to purchase water for environmental flow purposes. Water use efficiency improvements are also being funded through the allocation or sale of the saved water to irrigators for productive purposes.

3.3.1 Irrigation Scheme Level

More than $A 1200 million has been allocated by governments to improve the efficiency of water use in irrigation scheme distribution systems. The objective of this funding is to invest in infrastructure projects that can recover water savings for the environment from distribution losses. A summary of the major water savings projects in irrigation districts of the Southern MDB is provided in table 2.2.

The projects listed above will be mostly funded with investment from government-supported environmental funds. In return, irrigation schemes will relinquish their rights to an agreed proportion of their distribution loss. The rights to the water saving are transferred to an environmental manager for use as an environmental flow.

3.3.2 Farm Level

The farm sector in Australia is improving irrigation water use efficiency. A key driver of this trend has been the development of markets for water rights. Water rights are private property defined in a broad set of laws and administrative regulations and have many of the characteristics of other common property rights such as land title (Tan 2002).

The operation of the water market is underpinned by a titling system with a register of water rights maintained by the government. This provides legal certainty over the existence of the right. Trading rules for water rights are set by scheme operators for trade within irrigation districts and by state governments for trade between districts and headworks systems. Water rights can be traded between water users either permanently or temporarily (for a one-year period). Water rights are traded via private electronic exchanges, water traders and by private transaction.

Over the last 10 years, permanent water rights in the Southern MDB have traded for between $A 900 and $A 2,000 per thousand m^3. Temporary water rights have traded between $A 30 and $A 350 per thousand m^3 (Peterson et al. 2004). Of the total pool of water rights held by irrigators, in an average year, about 4 percent is traded temporarily and 0.5 percent permanently (Meyer 2005). Trade is most active in the large water supply schemes supplied by the Hume, Dartmouth, and Eildon reservoirs.

Table 2.2 Water-Saving Projects: Irrigation Districts, Southern MDB (as at Feb 2006)

Project Name	Year Completed	Scheme Operator	Summary	Expected Water Saving (million m^3)	Estimated Cost ($A m)	Cost ($A/thousand m^3)
Lake Mokoan Decommissioning	2008	Goulburn-Murray Water	Decommissioning an inefficient regulating storage	39.2	39.6	1,360
Barren Box Swamp Reconfiguration	2009	Murray Irrigation	Partitioning of a regulation storage to reduce evaporation losses	20	30	1,500
Seepage Control (main canal)	2002	Murrumbidgee Irrigation	Canal lining	30	18	600
Metering of Domestic and Stock Usage	2005	Goulburn-Murray Water	Metering of previously unmetered usage	16.4	11	670
Monitoring and Control of Outfall Structures	2006	Murray Irrigation	Monitoring and control of outfall structures to reduce outfall losses	3.7	3	800
Yanco Creek Reconfiguration	2007	State Water	Rerouting of supply to reduce river losses	24	40	1,670
CG1234 Channel Automation	2006	Goulburn-Murray Water	Channel automation (TCC)	18	23	1,280
Coleambally Channel Automation	2005	Coleambally Irrigation Cooperative	Channel automation (TCC)	40	15	600

Source: Authors' compilation.
Note: $A = Australian dollars; m^3 = cubic meters; TCC = Total Canal Control™.

With the development of water rights markets, irrigators have realized that on-farm water losses caused by poor application efficiency are a valuable resource. Enterprising farmers are improving on-farm water efficiency and using the saved water to generate income from the trade of water rights to higher-valued uses. Improved application efficiencies are being achieved through the conversion of surface irrigation to drip irrigation or overhead sprinklers and improved surface irrigation techniques.

Efficient farmers can realize a better return than the market value and price their water higher. Market forces drive a selection process that is forcing the less efficient farmers from the industry and enabling the better irrigators (who generally are more financially able farmers) to expand their enterprises.

The introduction of TCC automation provides irrigators in the schemes equipped with the technology and the incentive to grow higher-value crops, taking advantage of the ability to control the supply of water to match the crop's water needs. TCC control provides the technology to improve on-farm irrigation efficiency in schemes in which service levels are set to meet the needs of the traditional or prevailing on-farm irrigation technique and cropping enterprise. With a TCC-equipped channel network, higher-value enterprises are no longer restricted by the requirements of the lower-value enterprises.

4.0 Examples of TCC Application in Irrigation

4.1 Coleambally Irrigation Cooperative: TCC Project

The Coleambally irrigation district is located in the Murrumbidgee River in the State of New South Wales (NSW). The district includes 650 km of canal network and supplies 350 customers. The average volume of water diverted by the scheme is 0.62 cubic kilometers per year. The main irrigated crops grown in the district are rice, wheat, soybeans, and maize. The scheme is operated by Coleambally Irrigation Cooperative Limited (CICL), an irrigator cooperative. CICL is financially autonomous and the district irrigators are the shareholders. The cooperative holds a water license in the Murrumbidgee River storage headworks system.

4.1.1 Situation before the TCC System

Before the TCC system was installed, the CICL experienced the following issues with operating its channel network system:

- Controlling outfalls from the canal network; some 20 percent of the intake at the river outfalled from channels into drains.
- Although there was excess capacity in the channels to store water, this could not be exploited because of a lack of channel control.
- Irrigation customers suffered from fluctuating channel levels.
- Water orders required with four days notice and orders could not be varied or cancelled.
- Meters were up to 50 percent inaccurate in favor of water users; this inaccuracy arose because the typical flow rates for rice irrigation were too low to accurately register on the meter wheels at farm outlets.

4.1.2 TCC Installation

In 2002, CICL commenced a three-year program to replace several hundred control structures and meter outlets with Rubicon FlumeGates and the TCC control system. To date, 200 regulating structures (60 percent of the total) and 101 outlets (17 percent of the total) have been converted to TCC automated gates. The district will be fully equipped with TCC system by 2007.

In the district, TCC has been installed at two levels. The first involves the installation of FlumeGates in the channel regulators and check structures only. This configuration provides less control over channel stability and flow rates to farms compared with the full TCC model with FlumeGates in farm outlets. Because the CICL channel system is relatively homogenous in its layout and structure, good channel control could be achieved with the TCC gates in regulators only. The second level involves the full TCC model, which includes replacing meter outlet wheels with FlumeGates as well as channel regulators.

The first regulated channel sections commenced operation in the 2002–03 season. The TCC system initially experienced problems but settled into operation over the following irrigation season. These initial problems related primarily to pressure sensors and control software. The gate sensors and software were refined based on this early experience in CICL.

The installation of TCC resulted in a significant reduction of escape or outfall losses from the section of the automated CICL network (see table 2.3).

With the installation of the TCC system, customers noted substantial improvements in flow rates and channel-level control. The water ordering

Table 2.3 Outfalls from Channel 9 Coleambally Irrigation Area Australia before and after TCC Automation

Operating Regime	Month	Outfall from Canals Equipped with TCC (thousand m^3/day)
Before TCC (manual operation)	Sep. 02	267
	Oct. 02	314
	Nov. 02	309
	Dec. 02	107
After TCC (automatic operations)	Jan. 03	38
	Feb. 03	32
	Mar. 03	0
	Apr. 03	0
	Sep. 03	4
	Oct. 03	12
	Nov. 03	5
	Dec. 03	12

Source: Nayar 2004.
Note: m^3 = cubic meters; TCC = Total Canal Control™.

system worked impressively, allowing two-hour advance water ordering. A survey of farmers conducted by the CICL following the project installation found that irrigators, especially those in the bottom end of the system, had increased their on-farm efficiency because of the higher flow rates and better flow control afforded by the TCC system.

4.1.3 Measures for Improved Cost Recovery

The cost of the TCC implementation in the CICL has been recovered from revenue generated by first selling the water saved from reduced distribution losses to the district's irrigators and second from accumulated reserves built up through annual financial contributions by irrigators. The CICL is distributing a portion of the water savings to eligible customers via an annual water rebate on the user's usage. In 2005–06, this water rebate was equivalent to 5 percent of the customer's long-term water use.

Because of persistent drought in recent years, the conversion of water from distribution loss in the district's canals to productive use has been particularly important to maintain farm incomes in the district. This, in turn, has improved the ability of irrigators to pay for the infrastructure services provided by the CICL. The improved accuracy of TCC metering over existing meter wheels results in greater equity among customers in terms of cost recovery. This has provided customers with the confidence that all users are being treated equally in terms of sharing water availability and supply costs.

4.2 Central Goulburn Project

The Central Goulburn (CG) irrigation district is located on the Goulburn River in the State of Victoria. The district includes 1,400 km of supply channel and 1,100 irrigation customers. The district's estimated annual usage is 0.84 km^3. The district is operated by Goulburn-Murray Water (G-MW). G-MW is a government-owned corporation and the Victorian state government is the primary shareholder.

A unique feature of the CG district is the high level of service provided to irrigators. Once a water order is accepted, irrigators can vary the order, which provides irrigators with a high level of flexibility over the volume and timing of irrigation. This level of service comes at the cost of higher staffing levels and more complex channel operations.

4.2.1 Situation before the TCC System

Before the TCC system was installed, the CG system experienced the following problems:

- Significant volumes of water were lost to outfalls from the canal network; some 10 percent of the intake at the river flows was lost at the end of the system.
- Water was lost from undetected leakage through channel banks.
- Irrigation customers, particularly at the downstream end of canals, suffered from fluctuating water levels and erratic supply rates.
- Water could be ordered only four days in advance.

- The health and safety of district's field staff and irrigators was compromised by the need to manually operate heavy gates in exposed locations.
- Meters were up to 30 percent inaccurate in favor of water users, because existing mechanical wheel meters were not well maintained or were operated outside the expected operating range.
- Irrigators could take unaccounted-for water by allowing water to flow through the meters at low flow rates that could not be accurately registered on the meter.

4.2.2 TCC Installation

The project automated part of the CG system that included 320 canal regulators in 264 km of canal. An initial pilot program tested the TCC technology in the CG Channel 2 in 2002. The full system, comprising CG Channels 1 to 4 (CG1-4), was commissioned in October 2005.

Total distribution losses in the CG1-4 project were estimated to be 38,000 m^3 per year. The TCC project reduced the volume of outfall losses to close to zero. Initial analysis of leakage and seepage losses, using pondage tests conducted with the FlumeGates and TCC sensor system, found that an estimated 80 percent of the leakage and seepage loss in the system occurred in 20 percent of the length of channel system (Oakes 2004). Based on these results, it was estimated that 18,000 m^3 of water savings could be generated by lining the 20 percent of the channels with high rates of loss.

4.2.3 Measures for Improved Cost Recovery

Under the business case for the project, the cost of TCC implementation will be 100 percent recovered from the revenue that is generated from the sale of the water savings to an environmental water fund. The environmental funds include a joint government enterprise called Water for Rivers, which was established to acquire water for environmental flow purposes in the Murray and the Snowy Rivers.

The provision of accurate and real-time measurements of flow with accurate metering provides much greater accountability for water use between irrigators and irrigation subsystems. Previously, traditional meter wheels produced accuracies varying from plus 10 percent to minus 30 percent of the actual flow. Now all irrigators are guaranteed that they will receive equal treatment in terms of the measurement of flow and subsequent water use tariffs. Opportunities for water theft through the unauthorized opening of meter wheels have also been eliminated, providing greater equity among all users (Nayar 2006).

In the CG channel system, it is proposed that irrigators have formal rights to channel capacity or delivery shares (The State of Victoria Department of Sustainability and Environment and Department of Primary Industries 2005). The use of the TCC real-time water planning system will allow users to trade channel capacity during peak usage periods. This could be further extended by allowing users to purchase additional channel capacity rights through payments to G-MW to upgrade capacity in the channel system.

As with the other irrigation schemes in which TCC has been installed, evidence is emerging that the enhanced standard of service supplied to irrigators has resulted in reduced numbers of water orders and increased ordered flow rates (Luscombe 2004). It has been suggested that the on-farm savings have been used to increase irrigation production or alternatively have been sold to other users via the water market.

4.3 Macalister Irrigation District Project

The MID is located over several coastal catchments in the Macalister River catchment in the southeast portion of the State of Victoria. The district has annual water usage of 198 gigaliters (GL). The supply network is composed of 618 km of canal, supplying 971 irrigation holdings. The MID scheme is operated by Southern Rural Water (SRW). SRW is a government-owned corporation.

4.3.1 Situation before the TCC System

The fundamental design and performance of the MID canal network reflected outdated design standards and on-farm practices. Major problems before the TCC system was installed included the following:

- Accurate measurement facilities were lacking.
- Sluggish operational response made it difficult to cater to variable and dynamic on-farm demand.
- Requirements for hazardous manual operation of regulator and check structures
- Customer meters created significant inequities in terms of measurement.
- The overall system distribution efficiency in the MID was less than 65 percent.

4.3.2 TCC Installation

The first stage of the TCC project was implemented in the Main Northern Channel (MNC) area, one of the three main supply sections in the MID. The TCC automation project in the MNC involved the installation of 205 Rubicon FlumeGates in regulators and selected meter outlets. The project includes automation of the irrigation valves at the headworks dam. The first stage of the project was completed in 2005; the second stage is forecast for completion in 2007.[4]

The major benefits to MID of automation with the TCC system include improved standard of service to customers with near on-demand water ordering (one-day advance ordering for water, during which time the irrigation farmer can call the district office to adjust the flow rate or shut off the flow); increased flow rates (using the upstream sensor on a gate to guide on-farm works to maximize the available head); and more stable flow rates (TCC stabilizes the channel and the on-farm gate removes the remaining smaller fluctuations). Additionally, the system is achieving improved water distribution efficiency through reduced outfall losses (Byrnes 2006).

The TCC system is expected to achieve improved operational and capital efficiency through better decision making stemming from the enhanced understanding of the hydraulics of the canal network system. It is expected

that the TCC system will reduce operating costs because of the reduced number of field staff and the travel required to operate the canal network, as well as reduced occupational, health, and safety costs.

4.3.3 Cost Recovery for the Project

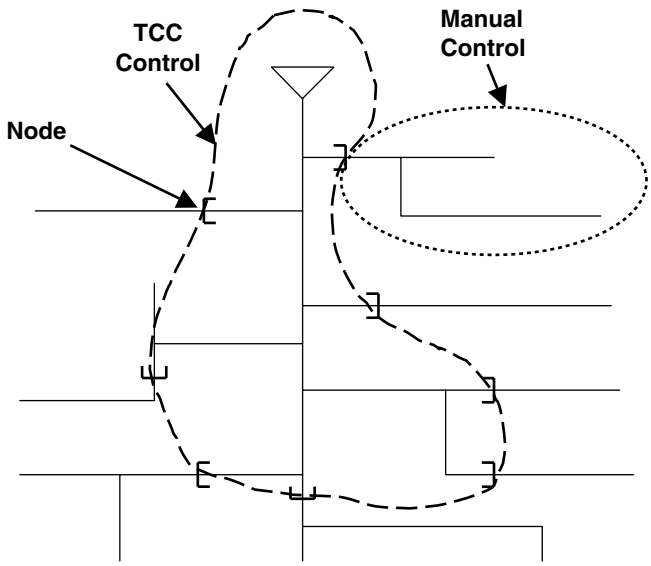
The Victorian government agreed to contribute $A 7 million to fund the MID project in return for 5 million m^3 of water savings from MID's distribution loss rights.. MID has sold some of the water recovered from distribution losses to its irrigation customers. A tranche of saved water through a pipelining project was auctioned to irrigators in 2005 and earned a reported average price of $A 1,980 per thousand m^3 (Victorian Water Industry Association 2005).

5.0 Application of Canal Automation in Less Developed Countries

Although labor savings are not a strong driver for canal automation in less developed countries, research by the University of Melbourne has shown that manually operated canal systems, regardless of the level of human operator input, cannot replicate the outcomes achieved by an automated canal system (Mareels, Ooi et al. 2005). Manually operated channel systems perform at water efficiency and service standard levels considerably lower than that of automated systems. Unfortunately, there is no midway option to move from manual to automated control.

One option, however, is to consider a staged implementation based on how far automation extends into a channel network (see figure 2.5). By automating the upstream end of a supply system, high levels of performance can be attained at a storage facility and in the main canal downstream to a control point or

Figure 2.5 Schematic of TCC Rollout Option



Source: Authors.

node closer to the farmer. If these nodes are strategically selected, then it is possible to have an automated channel network supply a district or a community. Having a supply point that provides an accurate measurement structure and controllable flows can deliver the benefits of automation to a cluster of farms. This results in a shift in accountability for the amount of water used to smaller community groups for which water use efficiencies are more visible and the potential exists to drive cost recovery principles to the supply point node. Rather than having a meter at individual farms, the first step would be to provide one meter to a number of farms. Costs would be recovered based on water use at these strategically placed meters. It is expected that responsibilities for efficient and equitable use of water would become more visible. Farmers would be responsible for ordering the water they require; if they take more water than they ordered, other farmers in the group would be affected.

The downstream section of the channel network that is not automated would be operated under normal manual operating practices. It would be possible to implement central planning systems and order water based on farm requirements. Roster systems could be retained downstream of the automated node, but there would be greater flexibility in their management because of the smaller number of farms supplied by the node. For example, a hybrid arrangement could include manual adjustments to channel the secondary canal, which would occur twice a day (for example, morning and evening regulation).

The selected node or regulating structure becomes the meter for the community and, through TCC, provides an on-demand supply at that point. The node would become the point of cost recovery. Accountability for cost recovery and efficiencies would first occur at a group level, rather than implementing the full TCC system down to the individual farmer level.

Another reason to confine the automation to the larger conveyance channels is that it is likely that the new plant (gates and so on) can be better secured than it could be at the farm level. Ideally, over time, the community would be educated on the need to care for these assets, and their ongoing maintenance would be handled by the farmers, which is another benefit of cost recovery. To some extent, this has been the experience in Australia.

Measures need to be taken to secure TCC gates in remote locations. In Australia, there has been little vandalism or theft of gate components and related equipment used in the TCC system. Although vandalism was initially anticipated, the approach taken was to gauge the risk once the system was in place and then take the necessary action to secure the specific sites that were subject to security risks.

Another challenge associated with the delivery of TCC in less developed countries is identifying personnel who have the required skills to operate and maintain the system. Because most of the canal operating staff will not have the necessary prerequisite skills, the requirement for a central control center with skilled operators will be challenging. Training, during implementation and after, is an important part of a successful TCC system. The installation

scale influences the critical mass of the support resources that can be allocated to a project, although the support skills for a TCC system can also be obtained from other utility organizations, for example, telecommunications.

6.0 Conclusion

Fundamentally, TCC canal automation delivers information on water movement in a network. This information leads to greater accountability and transparency in operational decision making, whether it be at the farm-gate level, the network level, or the basin level. This, in turn, creates an environment for improved cost recovery and greater water use efficiency. A key to any cost recovery regime is accurate and accountable measurement. With TCC canal automation, irrigation scheme operators become empowered with the knowledge of the product and service they are providing to irrigation customers. Cost recovery cannot proceed without this knowledge. Cost recovery may be a natural consequence of the acquisition of this knowledge, rather than cost recovery forcing the measurement regime.

Notes

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[3] $A = Australian dollar ($A 1 equals approximately US$0.75).

[4] Oakes, personal communication: March 17, 2006.

References

Australian Bureau of Statistics. 2004. "Water Account Australia 2000-01." Cat. No. 4610, Canberra.

Heaney, A., S. Thorpe, N. Klijn, S. Beare, S. and Want. 2004. "Water Charges and Interregional Trade in the Southern Murray Darling Basin." ABARE Conference Paper 04.14, Melbourne, August 9.

Langford, K., C. Forster, and D. Malcom. 1999. "Toward a Financially Sustainable Irrigation System, Lessons from the State of Victoria, Australia, 1984–1994." World Bank Technical Paper, No 413. Washington, DC: World Bank.

Luscombe, C. 2004. "Total Channel Control Pilot on CG2 Channel Tatura." Pilot Management Board Report of Findings, December.

Mareels, Iven, Su Ki Ooi, E. Weyer, David Aughton, and Tony Oakes. 2005. "Total Channel Control™—The Value of Automation in Irrigation Distribution Systems." Proceedings USCID 2005, SCADA and Related Technologies for Irrigation District Modernization, Vancouver, Washington, United States, October 26–29.

Mareels, Iven, Erik Weyer, Su Ki Ooi, Michael Cantoni, Yuping Li, and Girish Nair. 2005. "Systems Engineering for Irrigation Systems: Successes and Challenges." 14th IFAC World Congress, Prague, July 3–8.

Meyer, S. 2005. "The Irrigation Industry in the Murray and Murrumbidgee Basins, CRC for Irrigation Futures." Technical Report 03/05, Canberra, June.

Murray-Darling Basin Commission. 2005. "Water Audit Monitoring Report 2003/04" Murray-Darling Basin Commission, Canberra, June.

Nayar, M. 2006. "Assessment of Water Savings from the CG1-4 Project." Consultant Report: Albury, Australia, April.

Nayar, M. 2004. "Audit of Total Channel Control Implementation." Consultant Report: Coleambally Irrigation Cooperative Limited. Coleambally, Australia, August.

Oakes, T. 2004. "Total Channel Control an Important Role in Identifying Losses." ANCID (Australian National Committee on Irrigation and Drainage) Conference 2004, South Australia, October.

Peterson, D., G. Dwyer, D. Appels, and J. Fry. 2004. "Modelling Water Trade in the Southern Murray-Darling Basin." Staff Working Paper, Productivity Commission. Melbourne, November.

Productivity Commission. 2006. "Irrigation Externalities: Pricing and Charges." Staff Working Paper, Productivity Commission, Melbourne.

State of Victoria Department of Sustainability and Environment and Department of Primary Industries. 2005. "Securing Our Water Future Together—Delivery Shares." Fact Sheet, October, Melbourne.

State Water Corporation. 2005. "Bulk Water Pricing Submission to the Independent Pricing and Regulatory Tribunal Volume 1." Dubbo, Australia, September 1(September): 58.

Tan, P. 2002. "Legal Issues Relating to Water Use." Issues Paper No. 1, Project MP2004, Murray-Darling Basin Commission, Canberra.

Victorian Water Industry Association. 2005. "Nuntin Pipeline Water Savings Auction." *Water News* August: Vol.6, Issue 4: 7.

Pratt Water. 2004. "The Business of Water Savings, The Report of the Murrumbidgee Valley Water Efficiency Feasibility Project." Campbellfield, Australia: Pratt Water Ltd., December.

3. Satellite Measurements to Assess and Charge for Groundwater Abstraction

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Abstract: Information is lacking on the accurate size of extracted groundwater volumes for irrigation purposes. Wells often are not metered and, consequently, abstractions have to be assessed indirectly. Such assessments, however, are often inaccurate, inconsistent, expensive, and subject to fraud, which is an obstacle for volumetric charging to recover costs and may jeopardize sustainable aquifer exploitation. This chapter deals with a relatively new methodology that computes evapotranspiration (ET), net groundwater use, and groundwater abstractions in irrigated areas using satellite-based measurements of land surface temperature and surface reflectance with a minimum of field data. Examples demonstrate that abstraction can be assessed in a reliable and standardized way. Because of fixed costs per region, remote-sensing costs per hectare decrease with the size of the irrigated area. Volumetric charges can be implemented on the basis of crop consumptive use, net groundwater use, or abstractions, which are alternatives to the conventional irrigated and crop acreage–based charges. A high level of expertise is needed, but only a short testing session is necessary.

1.0 Introduction

Groundwater plays a vital role in sustaining agricultural production in many irrigated areas of the world. The rapidly growing competition for surface water resources among domestic use, industry, nature, and agriculture has triggered many irrigation schemes to substitute groundwater for surface water. Currently, most of the 750 to 800 cubic kilometers per year (km^3/yr) of global groundwater withdrawals are used for irrigated crops (Shah et al. 2000). Groundwater input in irrigated agriculture accounts for 69 percent of the water resources in Bangladesh, 53 percent in India, 50 percent in Iran, and 34 percent in Pakistan (www.iah.org/briefings). The number of private tubewells in a country such as Pakistan has increased a hundredfold from 5,000 in 1960 to more than 500,000 in 2000 (Ahmad et al. 2000). This development has resulted in overexploited aquifers. Groundwater table declinations of 1 meter (m) per year—or more—are common in the alluvial plains of, for example, Northeast China, Indus Basin, and the Rio Bravo Basin. Groundwater depletion is a matter of concern for the long-term viability of the agricultural sector and rural development in overexploited river basins: all water pumped now cannot be used in the future. Hence, it is in the interest of all stakeholders to take no more water than required to meet crop evapotranspiration (ET). Extracted groundwater volumes change with the evaporative conditions of the atmosphere, and ET can be used as a point of

departure to assess groundwater use. A vegetable crop with a low leaf area index (LAI) and a growing season of 100 days will require less water for ET than a cotton field with a high LAI and a duration of 180 days.

Policies for sustainable groundwater management and financial sustainability of irrigation services require insight into the volume of groundwater abstracted. Cost recovery in groundwater-irrigated areas requires knowledge of the costs to extract water. These costs consist of fixed costs for capital investments and variable operation and maintenance (O&M) costs (such as energy and labor costs), which increase with the volume of water extracted and change with the depth of the groundwater origination point. A nonlinear relationship exists between abstraction and the pumping costs, and this relationship changes with depth (Khan et al. 2006).

Hellegers and Perry (2004) recognized that measuring and accounting for water—as well as the crucial distinction between water applied to the field and water consumed by the crop—is technically and administratively complex. Abstracted water volumes—in cases in which wells are not metered—cannot be accurately assessed by means of conventional methodologies. Even if data are available, they are often incomplete, unreliable, or not easily accessible (Murray-Rust and Merry 1994). Comprehensive statistics on the use of groundwater for irrigation thus are not available (Foster et al. 2000). These statements imply that the reliability of cost recovery studies improves with the availability of basic data sets.

Hence, there is a need for an independent, direct, and standardized method that can assess vast irrigated areas and provide the data quickly. The main thesis of this chapter is to show that new improvements on modern technology could help cost recovery and financial sustainability of groundwater-only irrigated systems. Examples will be provided to demonstrate how independent groundwater abstraction data can be acquired from remote-sensing measurements (section 2.0). The data have not been used for cost recovery studies (these studies were done mainly for academic exploration and aquifer restoration plans), but they do provide an explanation of the technology (section 3.0). The required institutional arrangements and reliability of the remote-sensing method will be discussed in section 4, and insight will be provided on the costs (section 5) and benefits of this method (section 6).

2.0 Methodology

Earth observation satellites measure spectral radiation that is reflected and emitted by the land surface and propagated through the atmosphere. These satellites measure earth radiation with different spatial resolutions (from 0.5 to 5 km spatial grids) and temporal resolutions (15 minutes to time intervals of 23 days). The spectral signatures of the land surface radiation have a physical meaning. By combining surface radiation measurements in different parts of the spectrum, it will be feasible to (1) determine the biophysical properties, (2) state conditions of the Soil-Vegetation-Atmosphere-Transfer, and (3) assess the physical land surface processes related to irrigated crops (Bastiaanssen and Bos 1999; Menenti 2000). Remote-sensing algorithms standardize the conversion from spectral radiance into dynamic soil and crop processes such as

photosynthesis, runoff, and ET. A well-balanced overview of remote-sensing algorithms for the prediction of crop ET was prepared by Courault, Seguin, and Olioso (2005). Most ET algorithms are based on the land surface energy balance, which describes the incoming energy (solar radiation, atmospheric emission) and outgoing energy fluxes (reflected solar radiation, surface emission, sensible heat flux, soil heat flux, ET flux). The energy related to the phase transfer of liquid water into vapor is derived from the latent heat flux (Watt/m^2) and latent heat flux is equivalent to crop ET. Allen and Bastiaanssen (2005) summarize the recent developments in the field of ET and remote-sensing science as an introduction to a special publication on this theme. The Surface Energy Balance Algorithm for Land (SEBAL) is one such algorithm that is applied worldwide for ET mapping. SEBAL originated in the early 1990s (Bastiaanssen et al. 1992) and has been subsequently improved to host a wide range of environmental and irrigation conditions (Bastiaanssen et al. 2005).

Mapping of ET in irrigated crops has been accomplished using the following earth resources satellites:

- MODerate resolution Imaging Spectrometer (MODIS) (http://edcimsww.cr.usgs.gov/pub/imswelcome)
- Advanced Very High Resolution Radiometer (AVHRR) (www.class.noaa.gov)
- Landsat (http://landsat7.usgs.gov)
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (http://asterweb.jpl.nasa.gov)

Satellite imagery has a thermal-infrared channel that can infer land surface temperature, which is necessary to determine surface energy balances.

All ET originates from soil moisture that is extracted by the roots (transpiration T) and from surface skin moisture (evaporation E). In the absence of surface irrigation water, the source of this soil moisture is precipitation or groundwater. By comparing the ET from remote sensing with the gross rainfall (P_{gross}) from remote sensing (or rain gauges), it becomes feasible to determine the rainfall surplus ($P_{gross} - ET_{act}$) for every pixel on a week-to-week and month-to-month basis. In the case of a positive monthly surplus ($P_{gross} > ET_{act}$), excess rain will run off or feed the groundwater system.

In the case of a monthly negative surplus ($P_{gross} < ET_{act}$), which is typical for an irrigated crop in an arid climate, the crop must use groundwater, either directly from the unsaturated zone (this occurs only in small quantities) or from irrigation with tubewells. In the absence of surface water resources, Net Groundwater Use (NGU) can be formulated in a simple equation as follows:

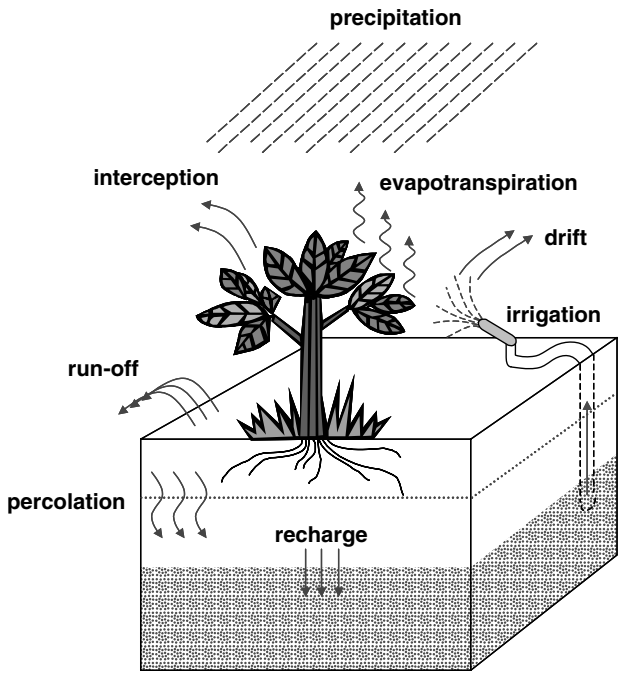
$$NGU = ET_{act} - P_{gross} + \text{surface losses} \quad (1)$$

Where NGU describes the difference between groundwater abstraction Q and percolation q_{down} at a given pixel:

$$NGU = Q - q_{down} \quad (2)$$

The surface losses described in equation (1) include interception losses, surface runoff losses, and drift losses. By solving these losses through empirical

Figure 3.1 Schematic Overview of All Losses



Source: Authors.
Note: The schematic overview includes all losses (drift, interception, runoff, percolation) that occur between irrigation application and crop ET.

equations (see Bastiaanssen, Chavez, and Ahmad 2006) or by applying simple efficiency corrections, it becomes feasible to derive NGU and groundwater abstraction Q from spatially distributed actual ET and precipitation.

Seasonal accumulated crop ET requires a larger set of images to describe the weekly ET variations. Gieske and Meijninger (2005), for example, used 70 individual AVHRR images to estimate the seasonal ET of a mixture of cotton and grapes in the Gediz Valley, Turkey. AVHRR images have a low resolution (1 km) and are available at daily intervals. The advantages of low-resolution 1 km images (MODIS, AVHRR) are as follows:

- Vast coverage, suitable for regional-scale aquifers, subbasins, and river basins
- Short time intervals (if clouds permit)
- Suitable for describing the dynamic irrigation processes in large irrigation schemes
- No costs for raw image data
- Cheap per unit of land

The advantage of high-resolution satellite images (Landsat/ASTER) with a pixel resolution of 30 m are as follows:

- Ability to spot individual fields

- Potential to link ET and groundwater abstraction to specific crop types
- Survey of related farm management practices

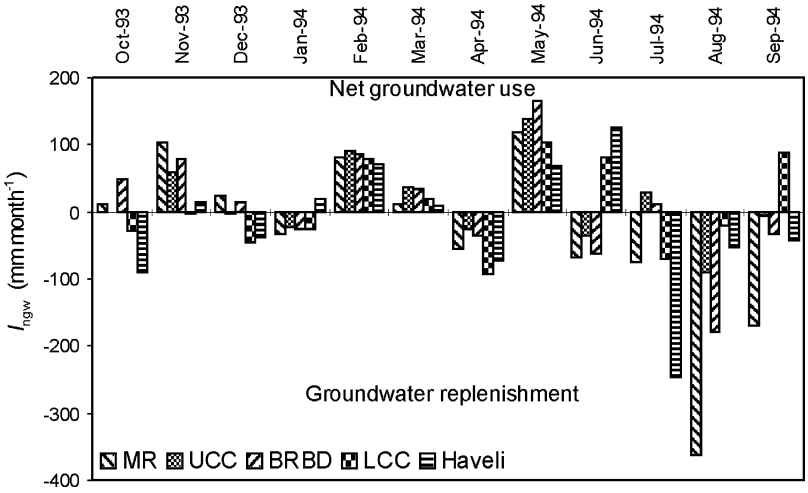
3.0 Examples of Groundwater Use Assessments from Thermal Remote-Sensing Data

3.1 Rechna Doab (Pakistan)

As part of a doctoral research program, Ahmad, Bastiaanssen, and Feddes (2005) studied NGU of the irrigated plains of the Indus Basin (Punjab) using AVHRR measurements. The 3 million hectare (ha) Rechna Doab area is located between the Chenab and Ravi Rivers. This area is known for its wheat, rice, and cotton, and is called the breadbasket of Pakistan. Conjunctive use of surface and groundwater resources are common practices, because farmers consider groundwater to be a safety factor when the surface network does not provide the right amount of water at the right moment (Perry 2005). The depth of the water table is shallow (±2 m) in the rice areas and deep (±20 m) in other places.

Monthly ET values for all 1 km pixels containing irrigated land were computed using the SEBAL model. The ET calculations were validated against Bowen ratio ET measurements, yielding a deviation of 10 percent at the field scale and 5 percent at the regional scale from water balance measurements (Bastiaanssen, Ahmad, and Chemin 2002). In situ measurements of NGU in cotton-wheat yielded 611 mm (Faisalabad) and rice-wheat yielded 604 mm (Pindi Bhattian).

Figure 3.2 Example of Monthly Variation of Net Groundwater Use



Source: Ahmad, Bastiaanssen, and Feddes 2005.
Note: The examples for different canal command areas in Rechna Doab were computed using SEBAL and AVHRR images. NGU is positive in February/March when groundwater abstraction of winter cereals reaches the maximum demand and negative in July/August when replenishment in the monsoon season takes place. MR = Marala-Ravi; UCC = Upper Chenab Canal; BRBD = Bambanwala-Ravi-Bedian-Depalpur; LCC = Lower Chenab Canal.

NGU, in addition to being easier to derive from the water balance, provides more complementary information than abstraction Q. Percolating water from the root zone ultimately recharges the unconfined aquifer, and NGU is thus the sink of groundwater for agricultural use. For a cotton-wheat rotation in Faisalabad, annual recharge (that is, the downward water flux at the phreatic interface) from the control field was 233 mm/yr and for rice-wheat systems in Pindi Bhattian was 389 mm/yr. Applied water Q was thus 844 and 993 mm/yr, respectively. The NGU for the entire 3 million ha Rechna Doab appeared to be 82 mm/yr, which at a lateral inflow of 53 mm/yr will yield a storage change of –28 mm/yr. At a specific yield of 0.15, this yields a general drawdown of the water table of 19 cm/yr. Inside this large area, smaller areas with an NGU of 600 mm/yr and more could be detected, as could pockets with a serious lack of sustainability. These values agree with the in situ measurements of NGU at 611 and 604 mm/yr. For every 1 km pixel, annual groundwater abstraction can be estimated. Although it was not the goal of the Rechna Doab study, water charges technically could have been determined using Q, NGU, or ET.

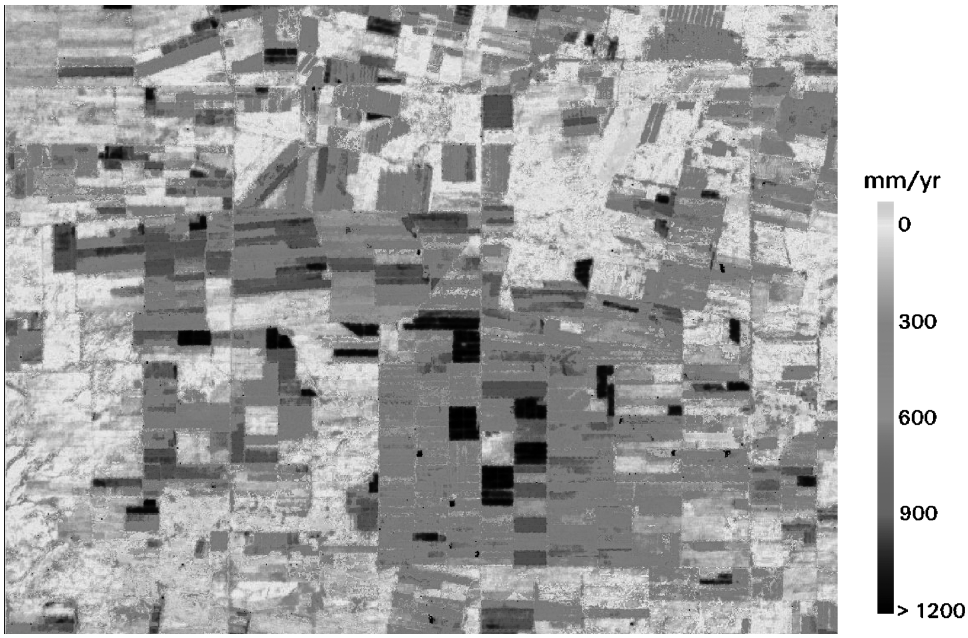
Conjunctive use makes the analysis of groundwater abstractions more complex, and this use undoubtedly affects accuracy in assessing groundwater abstraction Q. In the Rechna Doab study, surface water supplies at farm gates were estimated from discharge measurements at major cross regulators at the distribution head (Ahmad, Stein, and Bastiaanssen 2004). The flow estimates were checked with flow measurements. Approximations of distributed canal water flows will make it feasible to parse ET, in addition to rainfall and groundwater abstraction, into canal water irrigation. Thus, groundwater abstractions in conjunctive use studies are feasible provided that discharge measurements at major offtakes in the main and secondary canals are known.

3.2 Sonora State (Mexico)

Sonora State is located in the arid zones of Northwest Mexico. The most important irrigation systems are Valle del Yaqui (in which the green revolution for wheat took place), the neighboring Valle del Mayo, and Costa de Hermosillo. During its most prosperous period, Costa Hermosillo had 260,000 ha of irrigated land. Because of the increase in irrigated area, the total water demand for all the thirsty crops exceeded the supply from rivers. Farmers consequently used groundwater to augment the insufficient water resources. Costa de Hermosillo relies entirely on groundwater resources because the surface water resources are exploited for industrial and domestic use. The groundwater heads have fallen 30 to 60 m, and seawater intrusion has made the remaining part of the aquifer saline. The Comisión Nacional del Agua (CNA) limits aquifer overdraft. The Generencia de Aguas Subterraneas (GAS) is the department of CNA that is responsible for drafting a national aquifer exploitation and well permitting plan. GAS needed a swift and low-cost independent scan of nonpoint groundwater abstraction data in Mexico.

Therefore, GAS initiated a case study in Costa Hermosillo with a hybrid analysis of low- and high-resolution satellite images (15 AVHRR and 3 Landsat images). Figure 3.3 presents the first result using spatially distributed

Figure 3.3 Geographic Distribution of Annual Net Groundwater Use



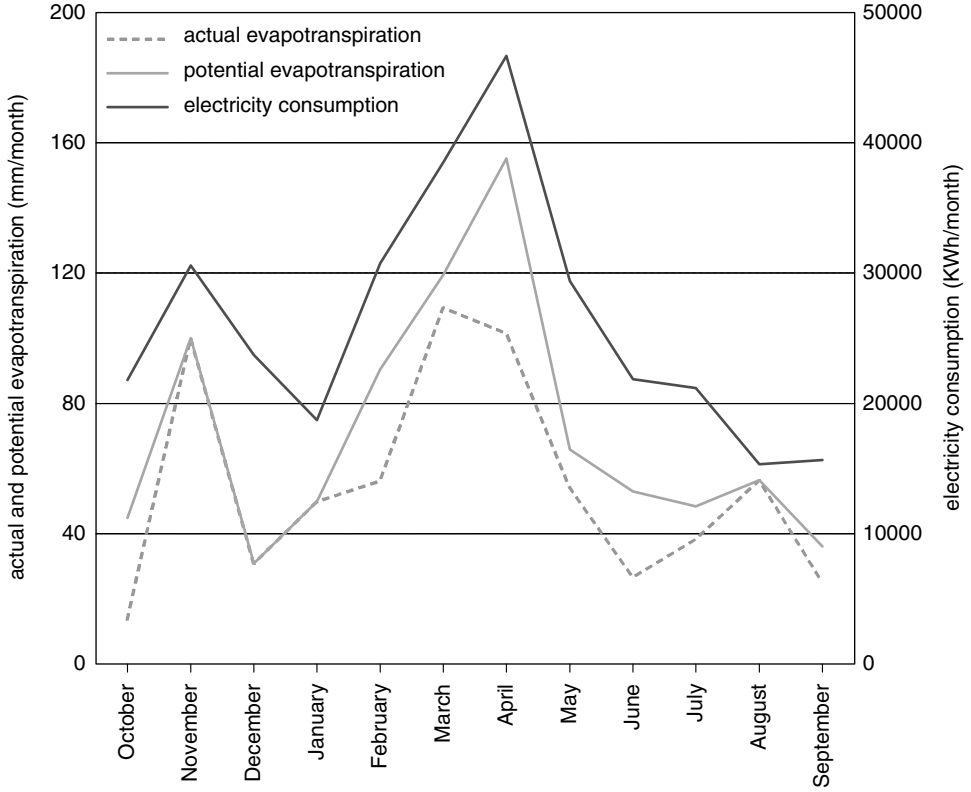
Source: WaterWatch 2005.
Note: Geographic distribution of annual NGU (abstraction minus recharge) observed in Costa Hermosillo (Mexico) with a spatial resolution of 30 m (from October 1999 to September 2000).

ET data for the derivation of seasonally accumulated NGU estimates on a field-to-field basis. The high-resolution output products open the door to assess crop-wise NGU evaluations. Certain fields exhibit a significant spatial variation of NGU, which demonstrates that groundwater use is not uniformly distributed within these orchards. The maximum depth of applied groundwater is 1,375 mm/yr on citrus (oranges) and the minimum value is approximately 125 mm/yr on chickpeas. The orchards have a drip system with an on-farm irrigation efficiency of approximately 80 percent. The current area under irrigation in Costa Hermosillo is 44,681 ha and the average NGU is 507 mm. If we take this irrigation efficiency of 80 percent, and 20 percent surface losses, then the average groundwater pump capability is 634 mm/yr. Based on this average, the total abstraction in Costa Hermosillo is approximately 283 million m^3/yr.

Average groundwater abstraction for a delta and for individual farm plots can be detected using remote sensing. NGU and Q can be assessed up to a spatial detail of 30 m, which creates the technical opportunity to introduce volumetric charging in irrigated agriculture.

The ET and NGU results of Costa de Hermosillo were compared with the registered total power consumption of the region. Despite the fact that the periods were not identical (there is a year shift in the images and the electricity bills), a statistical relationship on the basis of monthly time steps could be

Figure 3.4 Monthly Variation of Electricity Consumptions and ET



Source: WaterWatch 2005.
Note: Monthly variation of electricity consumptions and ET for the irrigated crops in Costa de Hermosillo, Sonora (Mexico). mm = millimeters; KWh = kilowatt hours.

found ($R^2 = 0.81$). Figure 3.4 demonstrates that peak power consumption occurs in November, during land preparation for winter wheat, and in April, when the evaporative demand of the atmosphere is high and rainfall is absent. The twin peaks of electricity consumption nicely coincide with monthly ET variations and confirm that the SEBAL computations for ET and NGU—without any irrigation information from the ground—are realistic.

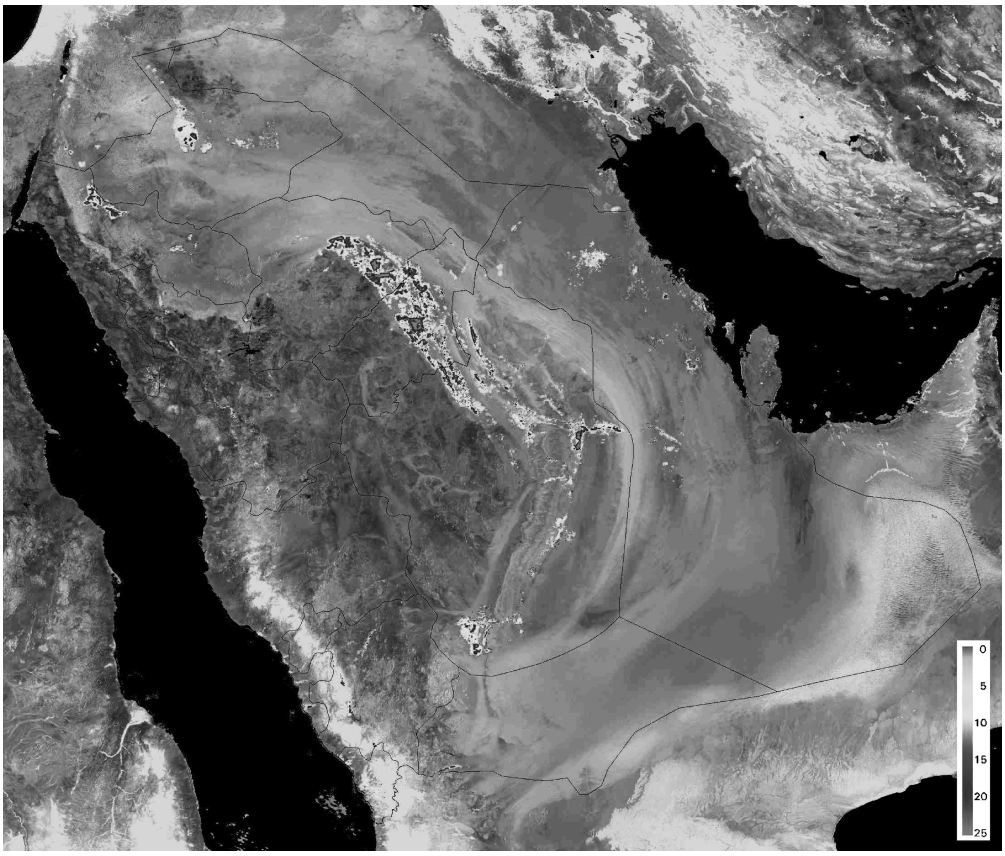
3.3 Saudi Arabia

By the late 1970s, self-sufficiency of food production was a target in Saudi Arabia. Since then, center pivot irrigation systems have been introduced on a large scale with a peak irrigated acreage reaching 1.2 million ha (summer and winter crops) during the mid-1990s. Strongly subsidized fuel costs and guaranteed wheat prices provided the foundation for making agribusiness farming in the remote sandy deserts lucrative. The annual average rainfall is 70 mm/yr, and natural recharge of the fossil groundwater systems is minimal. Therefore, most of the irrigation systems mine the groundwater systems. Almost all irrigation systems use groundwater resources. Most of the water is pumped from depths between 200 and 400 m. In 1993, uncertainty about the

sustainability and risk of national water security prompted the Government of Saudi Arabia, to cut back cereal subsidies, and as a consequence, irrigated acreage is now shrinking at a pace of 1.4 percent per year.

To design a plan for controlled future groundwater abstractions, a water-sector strategy and action plan was needed. Flows in the major aquifer systems are numerically modeled, and the accumulated historic abstractions needed are for the following: (1) calibration of simulation models and (2) assessment of current abstractions as a percentage of the total water amount stored in the aquifer. The SEBAL remote-sensing model was applied every three years from 1975 to 2004. Hence, eight years of Saudi Arabia–wide groundwater abstraction maps have been computed. The results are demonstrated in figure 3.5. In areas with a high density of perennial crops, such as alfalfa and date palms, the accumulated groundwater abstraction in the 30-year period between 1975 to 2004 was a water column of 25 m, hence 833 mm per year. At certain spots, the total abstraction added up to a water column of 44 m. The study was conducted with 1 km AVHRR pixels that are only partially irrigated. Because the ET from the desert is negligible, the ET of the crop is significantly greater than for the equivalent depth of 1 km pixels.

Figure 3.5 Spatial Variation of the Accumulated Groundwater Abstraction, 1975–2004



Source: WaterWatch 2006.

The estimated abstraction for 2003 was 21.75 km^3/yr for the entire area. Using census data and crop water requirement models, Abderrahman (2005) estimated an abstraction of 21.5 km^3/yr for 2004, which is an encouraging result.[3] The abstraction data are organized per aquifer type to obtain a better overview on storage, abstraction, and recharge of each aquifer.

The Saudi Arabian case study highlighted the fact that historic groundwater abstraction in the irrigation sector could be assessed retrospectively. This is important to verify historic well permits and plan the total abstractions per administrative area and aquifer into the future. Such strategic data can be used to introduce economic incentives to reduce groundwater abstractions and monitor the abstractions to understand the impact of new groundwater policies.

These three case studies (Pakistan, Mexico, and Saudi Arabia) show that groundwater abstraction (Q) and NGU can be acquired using thermal-infrared satellite measurements. Although it is technically feasible, the authors are not aware of any examples that this strategic information has been explored for cost recovery studies.

4.0 Institutional Arrangements and Reliability of the Methodology

4.1 User Identification

The end users of the remote-sensing technology include a target set of stakeholders that can benefit from this information, such as irrigation districts, irrigation service delivery agencies, river basin authorities, and catchment management agencies. These line agencies are usually under the auspices of ministries of water resources, irrigation, and agriculture, and are responsible for the supply side of the water cycle. On the recipient side of the water cycle, Water Users Associations (WUAs) and water boards represent the beneficiaries of the irrigation system. To give the reader insight into the state of the progress, a few concrete real-world examples are described here.

The Sindh Irrigation and Drainage Authority (SIDA) in Hydrabad (Pakistan) has shown serious interest in monitoring irrigation deliverables, particularly for revenue collection on the basis of volumetric charging, using remote-sensing data. Although Sindh mainly uses surface water, Punjab has extensive irrigation systems with conjunctive use of surface and groundwater resources. It is SIDA policy to charge more revenues to those who use more water, but the ability to measure the water flows is lacking.

The Ministry of Water and Electricity (MOWE) of Saudi Arabia is currently drawing a strategic plan for the future allowed aquifer abstraction quota for the entire Kingdom. A plausible next step is to use this remote-sensing technology for compliance service after the groundwater quota for each aquifer and administrative region is determined.

CNA in Mexico wants to engage remotely sensed energy balances to monitor their 600 national aquifer systems. Describing groundwater flow processes in a standard manner for various aquifer systems, which have scarce data sets and are scattered across vast areas, is essential to implement legislative

groundwater information requirements. In Mexico, ET validation is investigated by the Technical Institute of Sonora (ITSON) and the University of Sonora (UNISON). This partnership shows how involvement of local universities and research institutes can create trust and confidence. Local experts need the equipment to measure ET fluxes with modern apparatus (for example, eddy covariance and scintillometers) along with flumes and soil moisture probes to assess the recharge fluxes. ITSON and UNISON have these instruments (see Garatuza-Payan, Shuttleworth et al. 1998).

The Hai Basin Commission of the Hai River on the North China Plain has the formidable challenge of decreasing irrigation with groundwater resources, restoring streams, and diluting surface water resources. Their plan is to control ET to a level at which the basinwide ET is lower than the basinwide precipitation. The ET is controlled by the provision of ET quota per county and the interpretation of that quota into allowable groundwater withdrawals.

Larger irrigation and water resources departments often have their own remote-sensing laboratory (for example, the Ministry of Irrigation and Water Resources in the Arab Republic of Egypt and the Department of Water Affairs in South Africa). These remote-sensing laboratories have the ability to process satellite images for the identification of irrigated acreages, sometimes complemented with crop types. The mapping of ET from thermal-infrared satellite measurements is a relatively new field. The Idaho Department of Water Resources is one of the few water organizations that operationally apply energy balance models to plan and monitor groundwater abstractions (Allen et al. 2005; Morse et al. 2003).

The user identification shows that interest in remote-sensing products is fast growing and that a logical next step is to integrate the data sets with cost recovery frameworks in irrigation and drainage systems.

4.2 Product Definition and Awareness Creation

Visualization of water resources condition maps and dissemination of these maps to stakeholders is expected to sharply enhance the interaction and feedback between water institutes and water users groups. Disseminating the maps via Web-based accessibility of groundwater abstractions, water stress conditions, and crop production can create enthusiastic user groups of remote-sensing data, which can improve the management of aquifers. Waterboard Zuiderzeeland in the Netherlands has opened a remote-sensing Web site for its beneficiaries—who partially own the waterboard—to view locations with drainage problems in reclaimed polders (www.zuiderzeeland.nl/agrariers/waterstructuurplan, in Dutch). The demonstration of subsealevel water-prone areas with insufficient drainage capacity has created transparency—and thereby trust—between the administration and the stakeholders.

A similar Web application has been developed by the Idaho Department of Water Resources (http://www.idwr.idaho.gov/gisdata/ET/et_data.htm). This application helped the department improve its dialogue with stakeholders. Such discussions about problems are facilitated when a common knowledge base exists about the conditions in an irrigation and drainage system.

A new technical possibility is to view groundwater abstractions in a Google Earth environment. Although this freeware is made to view geographic surface features, it can be superimposed with groundwater abstraction maps. The advantage of this Google application is that it has a low user threshold, which invites more user groups to study and use the remote-sensing results (see, for example, www.waterwatch.nl).

Awareness creation in Arizona was achieved by Moran (1994). She showed that farmers could use two fewer irrigation turns than standard guidelines call for. For a standard application depth of 60 mm, this will save 120 mm or 1200m^3/ha, which at a water price of US$0.03/m^3 saves US$36/ha. This level of cost savings goes far beyond the level of costs needed to produce this result.

4.3 Remote-Sensing Data Organization

Remote-sensing laboratories of irrigation and water resources departments should obtain the skills needed to analyze and process energy balance data. These remote-sensing laboratories should also have field staff who inspect the irrigation conditions in the field and interact with farmers and WUAs about their perception of the remotely sensed products. In-house analysis by irrigation agencies and departments can reduce the costs after a number of years, although the level of expertise required is considerable and initial investment costs are high.

Table 3.1 summarizes the advantages and disadvantages of organizing local or national remote-sensing laboratories versus outsourcing the data provision. On the basis of table 3.1, it can be concluded that there is no clear preference. The degree of ownership and data policy are large drivers in favor of establishing in-house remote-sensing capacity. Another advantage to be considered is that a government agency has access to more data sources then any third party. Conversely, the skills required to operate energy balance models and feed them with remote-sensing data should not be underestimated. The scientific community, including outreach programs, can facilitate capacity building.

Local meteorological institutes could facilitate the introduction of remote-sensing technology. The Department of Meteorology in Sri Lanka demonstrated that they could compute evaporative fluxes from their own AVHRR receiving station with a minimum of technical backstopping. With no more than two weeks' international training and some local backstopping, they were able to process 88 AVHRR images to cover the annual hydrological cycle for Sri Lanka and publish their results in an international journal (Chandrapala and Wimalasuriya 2003). This example proves that it is feasible to transfer remote-sensing technology, including radiation physics and soil-atmosphere physics, to developing countries.

At the University of Idaho, the existing remote-sensing staff of the Idaho Department of Water Resources was trained on the physics and application of surface energy balance models (Allen et al. 2006; Morse et al. 2003). Thus, if this training is properly organized, it seems plausible to create remote-sensing laboratories within existing line agencies.

Table 3.1 Defining a Remote-Sensing Laboratory within a Government Water Institute

Position of Unit	Advantages	Disadvantages
National level unit	• High level of expertise • Effective training programs	• Dependency on bureaucratic organization • Not committed to local problem solving
Regional unit in own organization	• Maximum indigenous knowledge • Local ownership • Short communication lines • Adjustable to policy and problem needs	• Multiple initial investments • Multiple initial training programs • Recruitment of remote-sensing experts could be problematic • Drainage of technology if specialists leave • Biased to local perceptions on key water issues
Outsource to consultants	• High-quality standards • Timely delivery • Maximum flexibility • Political neutrality	• Limited ownership of technology • Limited in-house experience build up • Dependent on third parties

Source: Authors.

4.4 Reliability

The SEBAL algorithm has been widely tested against field measurements with lysimeters (see Allen et al. 2005), Bowen ratio technologies (Bastiaanssen, Ahmad, and Chemin 2002), Eddy covariance (French et al. 2005), scintillometers (Hemakumara, Chandrapala, and Moene 2003), and water balances (Mohamed, Bastiaanssen, and Savenije 2004). Bastiaanssen and others (2005) concluded that the overall accuracy of ET from SEBAL for single-day events on the order of 100 ha is +/−15 percent. Space and time integration improves accuracy. The seasonal differences are smaller (1 percent to 5 percent) because of a reduction in the random error component. Catchment-scale studies reveal an overall annual deviation of 4 percent. It is unlikely that these accuracies will improve much in the short term because most regional hydrological databases lack sufficient accuracy.

These validations are performed outside the SEBAL team by international research organizations and universities, including the United States Department of Agriculture, the University of Idaho (United States), the University of Wageningen (Netherlands), Southampton University (United Kingdom), Institute National Research Agriculture (France), and the Chinese Academy of Sciences.

Although they are meaningful, because no signals pinpoint poor performance, the preliminary accuracy tests on groundwater abstraction and NGU in Pakistan, Mexico, and Saudi Arabia have a more qualitative nature. The accuracy of spatially distributed groundwater abstraction needs more field evidence, preferably in locations with a high density of metered data. Because of the availability of accurate field data sets, it would be beneficial if the SEBAL-based ET and Q estimates were verified against metered data in Australia and the United States. More test cases are needed before we can assume that the technology is ready to determine Q in an operational way; ET_{act} and NGU are easier—and thus more accurate—to solve than Q.

Irrigation countries that receive donor support usually have the following typology:

- Fully groundwater irrigated
- Fully surface water irrigated
- Conjunctive use of groundwater and surface water

For cost recovery studies, the ET-NGU-Q procedures have sufficient accuracy for full groundwater or surface water irrigation systems (±90 percent to 95 percent). For conjunctive use situations, the accuracy is approximately 80 percent to 95 percent.

5.0 Costs

5.1 Charging Mechanisms

Charges for irrigation service or the water resource can be calculated on the basis of the following:

- Irrigated area
- Crop type
- Crop water demand
- Crop water consumption
- Irrigation water applied

For practical reasons, it is common to charge a certain water fee on the basis of an irrigated area. A more detailed approach would be to differentiate among crop types. The emphasis in this chapter is to demonstrate that crop water demand (ET_{pot}), crop water use (ET_{act}), and amount of irrigation water applied (Q) could be good alternatives. Although water charges are traditionally based on supply (thus Q), they could be based on ET as well. The advantages of using ET as a driver for water charges are as follows:

- Accounting on the basis of evaporative depletion is the most sound method (why pay for return water that flows to drains and is reused by neighbor farmers?)
- Spatially distributed ET is more accurate (±95 percent) than distributed Q (±85 percent).

5.2 Price of Groundwater

In Sri Lanka, water is not priced to temper the market prices of rice and other products, or to make food accessible to disadvantaged individuals. In many Islamic countries like Saudi Arabia and Egypt, water is (by Islamic Law) a common public good, and it is not priced and freely exchanged. For Pakistan, groundwater is an open access resource; anyone can exploit it by drilling a tubewell in his or her ground. Users have to pay revenue, however, for service delivery. When water is traded, an open market is established and a price is set between the water donor and the water recipient. Tahir (1997) found that, in Punjab, the main factors that influence the price of groundwater are the type of tubewell, quality of tubewell water, and tubewell density within a watercourse. Cropping patterns as a major demand factor also influence the price of groundwater.

The price of groundwater—or for irrigation water resources, in general—is approximated here for the sake of comparison with O&M costs and the costs of remote-sensing technologies. Note the difference between costs and price. Although the costs of water can be virtually nothing, there is a certain price for making the resource available to the users.

Wahaj (2001) mentioned that pumped groundwater in Punjab in a particular distributary is sold between US$0.03 to US$1.67/m^3. Kloezen (2002) investigated the production costs in the Lerma-Chapala basin in Central Mexico. Here, water trading is established among WUAs, and the prices vary with season and year. In the summer of 1995, the price varied between US$0.40 to US$0.93/1,000 m^3, but in the summer of 1997, these prices rose to between US$3.44 and US$3.50/1,000 m^3 (a factor of 4 to 10 higher). Because the extremely high water applications exceed crop water needs by 100 percent, total water charges in this part of Mexico can reach US$70/ha.

Hellegers and Perry (2004) conducted an economic analysis in different surface water irrigation systems and found a price paid by irrigators of US$4.00/1,000 m^3 in Egypt, US$5.00/1,000 m^3 in India, US$200/1,000 m^3 in Morocco, US$2.00/1,000 m^3 in Indonesia, and US$20.00/1,000 m^3 in Ukraine. The cost for annual water consumption for these five global systems averages US$34.00/ha. Assuming that these irrigation systems have an average efficiency of 50 percent, the amount of water supplied needs to be doubled to meet the crop ET. This implies that the price of water can be US$68.00/ha, which is similar to Kloezen's findings (2002).

5.3 O&M Costs

Hellegers and Perry (2004) summarized the O&M costs of five irrigation systems in different countries with diverging infrastructures (see table 3.2). Although these costs relate to surface water systems, and they cannot be compared with costs of pumps and energy, they do provide an indication of O&M costs. The O&M costs vary between US$12.00 and US$165.00/ha/yr.

A portion of the O&M costs relate to data collection. Data collection costs sometimes exceed total revenue; therefore, it is appropriate to control the costs of labor and equipment to measure irrigation flows. The compliance

Table 3.2 Cost Structure to Operate Irrigation Schemes in Various Parts of the World

Irrigation Scheme	Country	Total O&M Costs	Water Consumption	Total O&M Costs
		($/m^3)	(m^3/ha)	(US$/ha)
Kemry	Egypt, Arab Repub. of	0.01	16,500	165
Haryana	India	0.0013	10,000	13
Tadla	Morocco	0.017	7,400	125
Brantas	Indonesia	0.001	12,000	12
Crimea	Ukraine	0.012	3,000	36
Average		0.0083	9,780	70

Source: Hellegers and Perry 2004.
Note: Costs relate to irrigation schemes that essentially are operated by surface water resources.
ha = hectare; m^3 = cubic meters; O&M = operation and maintenance US$ = U.S. dollars.

monitoring of a well permitting plan can be achieved by comparing the volumetric permission with the ET rates from remote sensing. Allen and others (2005) used an energy balance model to compare administered water rights with actual ET in the Snake River Plain in Idaho. They conclude that through this technology (1) the ability is offered to monitor whether water has actually stopped being used for irrigation after a water shutoff order has been issued, (2) it can be discovered whether more water has been used than is authorized, and (3) a system is in place that can be used as proof of beneficial use of a right.

5.4 Remote-Sensing Costs

The determination of groundwater abstraction from remote-sensing measurements requires a remote-sensing laboratory within existing water management institutes. The equipment and costs are similar to what a remote-sensing laboratory would cost that is created for land use mapping and crop identification. The remote-sensing experts should hold a master of science in geographic information systems (GIS) or remote sensing. One of the team members should have a master of science in irrigation or agricultural water management with an affinity to remote sensing. The head of the laboratory should have an international doctorate and possess the technical skills to improve and fine-tune the ET-NGU-Q algorithms. He or she should supervise the remote-sensing results and coach the field team to collect the proper data sets for the validation of the remote-sensing predictions. The annual costs for properly operating a remote-sensing energy balance program for an irrigation country like Sri Lanka will be approximately US$180,000/yr (approximately US$0.23/ha/yr).

5.5 Costs of Earlier Remote Sensing Studies

The remote-sensing costs of the case studies discussed in section 3.0 are summarized in table 3.3. The costs are real costs paid by the World Bank to a

Table 3.3 Remote-Sensing Studies for the World Bank, Mapping of Groundwater Use

	Pakistan	Mexico	Saudi Arabia
Crop types	Wheat, rice	Fruit orchards	Wheat, alfalfa, dates
Study area (ha)	2,970,000	500,000	196,000,000
Irrigated area (ha)	2,380,000	44,681	1,200,000
Number of high-resolution images	—	4	—
Number of low-resolution images	20	14	96
Costs remote-sensing study (US$/ha)	0.021	0.24	0.021

Source: Authors.
Note: — = not applicable; ha = hectare; US$ = U.S. dollars.

consultant to execute these groundwater studies. Coincidently, the remote-sensing costs in Pakistan and Saudi Arabia match (US$0.0021/ha). The higher cost per unit of irrigated area for Mexico (US$0.24/ha) is due to the fact that this study contained a limited number of high-resolution images; it was an example of fusion of high- and low-resolution images.

The total costs for ET-NGU-Q image processing are independent of the area. For small areas (<100,000 ha), the analysis costs are US$60,000 per year; this price includes purchases of high-resolution images and the capacity required to process high-resolution images, including remote-sensing experts to process and interpret the results. These are fixed costs and do not vary with the size of the irrigated area, because the total image needs to be purchased and the staffing required to interpret the image are not affected by the amount of pixels considered in the computations. For regional-scale and basin-scale studies (>100,000 ha), costs are only US$40,000 because low-resolution images (1 km) are freely available. Costs are also fixed for low-resolution imagery. For cost recovery studies and to obtain a larger picture of groundwater abstractions, a regional-scale analysis with 1 km pixels may be sufficient. For compliance monitoring at the field scale, 30 m high-resolution imagery needs to be purchased. A larger area is relatively cheaper per unit area.

Bastiaanssen (1998) summarized costs of remote-sensing studies on land use mapping for five countries and indicated that these costs range from US$0.03/ha (India) to US$0.20/ha (Morocco). The costs to conduct remote-sensing studies were discussed and summarized during a World Bank Expert Consultation held in Ede/Wageningen in May 2001 (Bos et al. 2001). The group of experts concluded that the price to monitor irrigation and drainage performance is approximately US$0.80/ha for an irrigation scheme of 20,000 ha, but that the price drops to US$0.08/ha for an area of 500,000 ha.

The conclusion is that the cost for an ET and groundwater abstraction study is approximately US$2.00 to US$4.00/ha for a high-resolution 30 m resolution

product and a study area of 15,000 to 30,000 ha, while a low-resolution study will cost US$0.20 to US$0.40/ha and cover 100,000 to 200,000 ha (a factor of 10 lower).

If an average remote-sensing study with low resolution costs US$0.30/ha and a study with high resolution costs US$3.00/ha, and O&M costs are US$70/ha, then remote-sensing costs 0.4 percent and 4 percent of the O&M costs for low- and high-resolution images, respectively. The same fraction applies of remote-sensing costs for the price of water as a resource.

6.0 Benefits of Remote-Sensing Technology

Water policy makers and water managers are expected to use advanced information technologies, if the associated gains and results exceed the additional costs. The value of remote-sensing data relies on the balance between costs and benefits.

Remote sensing for groundwater irrigation management can be used for the following:

- Determining groundwater abstraction
- Assessing crop consumptive use
- Charging water use per unit supply or unit evaporative depletion
- Reducing costs for groundwater data collection
- Assessing power/fuel costs related to pumping
- Preparing groundwater permits and acquiring water rights
- Compliance monitoring of well permits

When combined with crop yields from remote sensing and market prices, it becomes feasible to quantify some key aspects of costs and benefits, although no complete monetary flows can be obtained.

The benefits of using remote sensing for groundwater management are as follows:

- Improving transparency and building trust between water supply agencies and water users
- Balancing water demand and water availability
- Reducing abstraction and conserve groundwater
- Restoring aquifers
- Improving water productivity
- Improving application efficiency

The groundwater examples provided for Pakistan, Mexico, and Saudi Arabia all relate to evaluation. Evaluation is meaningful to describe how much water an irrigation scheme is extracting Q, the amount of water consumed by crop ET, and the return flow via percolation (q_{down}) and drainage.

The establishment of sustainable extractions and restored aquifers is difficult to express in currency units, but it is a prerequisite for any environmental

sustainability activity. The application of spatially distributed ET-NGU-Q data for cost recovery analysis is in its infancy. The technique, however, has matured for evaluating case studies.

Remote-sensing technology cannot be manipulated (that is, it is a measurement) and fraud can be excluded. Satellite measurements are suitable to compare variability among villages, aquifers, and sub-basins especially in cases in which there is conflict and distrust among water using groups. The satellite serves as a watchdog, because electronic sensors are unbiased and politically neutral.

7.0 Conclusion

The thermal-infrared application in remote sensing has, after 20 years of research and applications, reached a level that can be operationally applied to water resource studies for irrigation and drainage systems, as well as for the analysis of entire river basins. Although there are case studies for aquifer management planning, the authors are not aware of applications for cost-benefit analysis.

Operational remote-sensing energy balance products are being implemented. We are at a point on the development curve at which the ET technology can become operational. The examples of ET-NGU-Q studies presented in this chapter demonstrate that ET has been validated (overall accuracy 95 percent of seasonal crop ET). More work needs to be done to validate spatially distributed abstraction data Q. Abstraction assessments from remote-sensing data should be established in areas with a high density of metered tubewells. Such validation efforts should be arranged in cooperation with a local university that can prepare a scientific statement on the accuracies attained. The latter is fundamental, because lessons learned from ET mapping indicate that local water managers accept the technology only if it has been locally verified. If, in the next one or two years, evidence grows that NGU and Q can be obtained with a high level of confidence, then remote sensing can be operationally applied to groundwater management.

The size of the region and the required spatial detail affect the total costs of determining ET- NGU-Q maps. Overall, the costs per unit area decrease by increasing areas of interests. Remote-sensing costs are typically 0.4 percent to 4 percent of the O&M costs for low- and high-resolution images, respectively. The relative costs compared with volumetric water charges are similar.

The benefit of having a spatially distributed map of groundwater abstraction is that the dominant costs for operating an irrigation system can be estimated with greater accuracy than from (1) electricity, (2) fuel consumption, (3) hours of operation, and (4) drawdown of the groundwater levels. Some demonstration projects should be formulated to test these applications.

Because of the increasing crisis in water and food security, the preparedness for investment in remote-sensing technology is growing. The lack of awareness and insufficient trust in these advances are the main reasons for low applicability. Training and capacity building programs can help to overcome these obstacles. The end users should become involved in case studies for greater awareness and appreciation of the technology. Institutes

should be equipped with remote-sensing laboratories or outsource the computations to familiarize themselves with these advances in technology before making their own investments. Many government water management institutes already have their own remote-sensing/GIS facility, and these existing laboratories can be upgraded to meet international standards for energy balance modeling. Selecting adequate image processors for undergoing intensive training sessions has been fundamental to building local capacity.

Cost recovery studies in irrigation and drainage systems can benefit from the ET-NGU-Q remote-sensing data in different ways:

- Pumping costs can be made variable according to the volume extracted and be assessed for large irrigated areas with scattered activities across the region
- Volumetric water charges becomes feasible (either on the basis of water as a resource or capital investment and O&M)
- Opportunity to charge on the basis of consumptive use exist, which is better than on the basis of supply (because a majority of the supply is returned)

The remotely sensed data provide a strategic vehicle to assess a part of the total irrigation *costs* that otherwise is difficult to quantify. The physical production of irrigated crops can be assessed by remote-sensing technologies as well and can be used to quantify the *benefits*. The latter issue has not been addressed in this paper.

Notes

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[3] Abderrahman, W.A, personal communication, December 2005, Riyadh.

References

Ahmad, S., M.M. Ahmad, M. Yasin, G. Akbar, and Z. Khan. 2000. "Assessment of Shallow Groundwater Quality: Case Study of Mona SCARP, Proc Mona Salinity Control And Reclamation Project." Regional Groundwater Management Seminar, Pakistan Water Partnership (PWP), Islamabad, Pakistan, October.

Ahmad, M.D., W.G.M. Bastiaanssen, and R.A. Feddes. 2005. "A New Technique to Estimate Net Groundwater Use across Large Irrigated Areas by Combining Remote Sensing and Water Balance Approaches." *Hydrogeology Journal* 13: 653–64.

Ahmad, M.D., A. Stein, and W.G.M. Bastiaanssen. 2004. "Estimation of Disaggregated Canal Water Deliveries in Pakistan Using Geomatics." *International Journal of Applied Earth Observation and Geoinformation* 6: 63–75.

Allen, R.G., and W.G.M. Bastiaanssen. 2005. "Editorial: Special Issue on Remote Sensing of Crop Evapotranspiration for Large Regions." *Irrigation and Drainage Systems* 19(3/4): 207–10.

Allen, R.G., M. Tasumi, A. Morse, and R. Trezza. 2005. "A Landsat-Based Energy Balance and Evapotranspiration Model in Western US Water Rights Regulation and Planning." *Irrigation and Drainage Systems* 19(3/4): 251–68.

Allen, R.G., M. Tasumi, A. Morse, R. Trezza, J.L. Wright, W.G.M. Bastiaanssen, W. Kramber, I. Lorite, and C.W. Robinson. 2006. "Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (metric) – Applications," *ASCE Journal of Irrigation and Drainage Engineering*

Bastiaanssen, W.G.M. 1998. "Remote Sensing in Water Resources Management: The State of the Art." International Water Management Institute, Colombo, Sri Lanka.

Bastiaanssen, W.G.M., M.D. Ahmad, and Y. Chemin. 2002. "Satellite Surveillance of Evaporative Depletion across the Indus Basin." *Water Resources Research* 38(12): 1273–282.

Bastiaanssen, W.G.M., and M.G. Bos. 1999. "Irrigation Performance Indicators Based on Remotely Sensed Data: A Review of Literature." *Irrigation and Drainage Systems* 13(4): 291–311.

Bastiaanssen, W.G.M., R. Chavez, and M.D. Ahmad. 2006. "Thermal Remote Sensing for Groundwater Management." *International Journal of Geohydrology*

Bastiaanssen, W.G.M., E.J.M. Noordman, H. Pelgrum, G. Davids, and R.G. Allen. 2005. "SEBAL for Spatially Distributed ET under Actual Management and Growing Conditions." *ASCE Journal of Irrigation and Drainage Engineering* 131(1): 85–93.

Bastiaanssen, W.G.M., C.W.J. Roest, H. Pelgrum, and M.A. Abdel Khalek. 1992. "Monitoring of the Irrigation Performance on the Basis of Actual Evapotranspiration: Comparison of Satellite Data and Simulation Model Results." In *Advances in Planning, Design and Management of Irrigation Systems as Related to Sustainable Land Use,* eds. J. Feyen, E. Mwendera, and M. Badji, 473–83. Leuven: Center for Irrigation Engineering and ECOWARM.

Bos, M.G., S. Abdel Dayem, W.G.M. Bastiaanssen, and A. Vidal. 2001. "Remote Sensing for Water Management: the Drainage Component." Report World Bank Expert Consultation, Ede-Wageningen, May 15–16. Washington DC: World Bank.

Chandrapala, L., and M. Wimalasuriya. 2003. "Satellite Measurements Supplemented with Meteorological Data to Operationally Estimate Evaporation in Sri Lanka." *Agricultural Water Management*. 58(2): 89–107.

Courault, D., B. Seguin, and A. Olioso. 2005. "Review on Estimation of Evapotranspiration from Remote Sensing Data: From Empirical to Numerical Modeling Approaches." *Irrigation and Drainage Systems* 19(3): 223–49.

Foster, S., J. Chilton, M. Moench, F. Cardy, and M. Schiffler. 2000. "Groundwater in Rural Development. Facing the Challenges of Supply and Resource Sustainability." World Bank Technical Report No. 463. Washington, DC: World Bank.

French, A.N., F. Jacob, M.C. Anderson, W.P. Kustas, W. Timmermans, A. Gieske, Z. Su, H. Su, M.F. McCabe, F. Li, J. Prueger, and N. Brunsell. 2005. "Surface Energy Fluxes with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) at the Iowa 2002 SMACEX Site (USA)." *Remote Sensing of Environment*. 99(1/2): 55–65.

Garatuza-Payan, J., W.J. Shuttleworth, D. Encinas, D.D. McNeil, J.B. Stewart, H.A.R. de Bruin, and C.J. Watts. 1998. "Measurement and Modeling Evaporation for Irrigated Crops in Northwest Mexico." *Hydrological Processes* 12 (9): 1397–418.

Gieske, A., and W. Meijninger. 2005. "High Density NOAA Time Series of ET in the Gediz Basin, Turkey." *Irrigation and Drainage Systems* 19(3/4): 285–99.

Hellegers, P.J.G.J., and C.J. Perry. 2004. "Water as an Economic Good in Irrigated Agriculture, Theory and Practice." Agricultural Economics Research Institute (LEI), Report 3.04.12. The Hague, The Netherlands.

Hemakumara, H.M., L. Chandrapala, and A.F. Moene. 2003. "Evapotranspiration Fluxes over Mixed Vegetation Areas Measured from Large Aperture Scintillometer." *Agricultural. Water Management* 58(2): 109–22.

Idaho Department of Water Resources. 2004. Evapotranspiration data. Accessed on December 7, 2006 at http://www.idwr.idaho.gov/gisdata/ET/et_data.htm.

International Association of Hydrologists (IAH). 2004. IAH The world wide groundwater organization. Accessed on December 7, 2006.

Khan, S., R. Tariq, C. Yuanlai, and J. Blackwell. 2006. "Can Irrigation Be Sustainable?" *Agricultural Water Management* 80(1/3): 87–99.

Kloezen, W.H. 2002. "Accounting for Water, Institutional Viability and Impacts of Market-Oriented Irrigation Interventions in Central Mexico." Ph.D. Thesis, Department of Water Resources, Wageningen University, ISBN 90-5808-657-7.

Menenti, M. 2000. "Irrigation and Drainage." In *Remote Sensing in Hydrology and Water Management*, eds. G.A. Schultz and E.T. Engman, 377–400. Berlin: Springer Verlag.

Mohamed, Y.A., W.G.M. Bastiaanssen, and H.H.G. Savenije. 2004. "Spatial Variability of Actual Evaporation and Soil Moisture across the Sudd Determined by SEBAL and the Impact on Monthly Water Balances." *Journal of Hydrology* 289(1): 145–64.

Moran, M.S. 1994. "Irrigation Management in Arizona Using Satellites and Airplanes." *Irrigation Science* 15(1): 35–44.

Morse, A., R.G. Allen, M. Tasumi, W.J. Kramber, and R. Trezza. 2003. "Application of the SEBAL Methodology for Estimating Evapotranspiration and Consumptive Use of Water Through Remote Sensing, Phase III: The Transition to an Operational System." Raytheon Systems Company Earth Observation Data and Information System Project. Accessed on June 7, 2006 at http://www.idwr.idaho.gov/gisdata/ET/phase_3_final_report.pdf .

Murray-Rust, H., and D.J. Merrey. 1994. "Irrigated Agriculture beyond 2000: Institutional Adaptation and Transformation." *IIMI Review* 8(3): 21–28.

Perry, C.J. 2005. "Irrigation Reliability and the Productivity of Water: A Proposed Methodology Using Evapotranspiration Mapping." *Irrigation and Drainage Systems* 19(3/4): 211–21.

Shah, T., D. Molden, R. Sakthivadivel, and D. Seckler. 2000. "The Global Groundwater Situation: Overview of Opportunities and Challenges." International Water Management Institute (IWMI), Colombo, Sri Lanka.

Tahir, Z. 1997. "Agro-economic Characteristics of Chistian Irrigation Sub-division, Fordwah-Eastern Sadiqia Irrigation System, the Punjab Pakistan." Internal IIMI Report. Pakistan National Program of the International Irrigation Management Institute, Lahore, Pakistan.

Wahaj, R. 2001. "Farmer Actions and Improvements in Irrigation Performance below the Mogha." Ph.D. Thesis, Department of Irrigation, Wageningen University, Wageningen, The Netherlands.

WaterWatch. 2006. "Historic Groundwater Abstractions at National Scale in the Kingdom of Saudi Arabia." Consultancy Report to the World Bank.

WaterWatch. 2005. "Estudio Historico de Uso y Extraccion del Agua Subterranea en Dos Areas-Piloto del Estado de Sonora." Consultancy Report to the World Bank and World Meteorological Organization.

4. Cost Recovery in the Irrigation and Drainage Sector: User's Participation as a Mechanism for Its Promotion

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Abstract: The Arab Republic of Egypt has no history of charging or pricing for water. Major infrastructures and facilities of the irrigation and drainage (I&D) system—such as dams, barrages, pumping stations, levees, main canals, and drains—are funded, operated, maintained, and rehabilitated under the government budget allocated to the Ministry of Water Resources and Irrigation (MWRI). Irrigation water is provided free to farmers upstream the level of the private watercourse located within their farms (mesqa). In new lands, they pay partially for the construction of the branch canal system as well as operation and maintenance of the field canals. However, Egyptian water law requires cost recovery from beneficiaries for the construction of mesqa improvements. The law requires cost recovery from users of the construction improvements to the field pipe drainage system. It is unlikely that cost recovery will be achieved without formal and effective user participation in irrigation projects management. User participation may include a wide range of activities at different levels. Efforts have been made to involve communities in water supply and small irrigation systems, thus improving the performance of irrigation schemes. Community participation should be oriented toward developing and enhancing a sense of ownership and responsibility within the communities. Experience shows that public participation provides the basis for promoting cost recovery of I&D projects. The legal framework for the formation of Water Users Associations (WUAs) and cost recovery of mesqa construction costs was fully established by the Law 12/1984 amendments and its 1995 bylaws. It authorizes the establishment of WUAs and permits the recovery of mesqa construction costs. This chapter analyzes several types of service charge implementation schemes that have been used in the Arab Republic of Egypt and evaluates their strengths and weaknesses.

1.0 Background on Cost Recovery in the Arab Republic of Egypt

The Ministry of Water Resources and Irrigation (MWRI), which currently employs more than 80,000 people, is responsible for implementation, construction, operation, and maintenance of major irrigation and drainage (I&D) projects. Agriculture is by far the most economically viable sector consuming water.

Current responsibilities of MWRI in performing its agriculture sector duties through irrigation water distribution and drain water collection have put a

heavy burden on the Ministry's annual budget. The Ministry, in general, is most effective at the higher levels of the irrigation system (for example, management of the High Aswan Dam, Nile Barrages, main carrier canals, and so on). At the lower levels of the system (for example, farm ditches, feeder, distributor and ranch canals, field drains, and so on), the adequate fine-tuning of I&D operations requires much more human and financial resources than the Ministry can offer.

As the agricultural land is expanding from one year to the next and increased costs are associated with operation and maintenance (O&M) activities, a greater budgetary pressure is created. In addition, public irrigation is heavily subsidized and has become an enormous fiscal drain. In 1995, the public subsidy to irrigation services was almost Egyptian pounds (LE) 670 million, representing about 3.2 percent of total gross domestic product (GDP) and about 20 percent of the agricultural GDP (Attia 2002). Therefore, greater emphasis has been placed on cost recovery mechanisms for situations in which the resources for O&M, at a minimum, must come from the direct beneficiaries (that is, the water users).

Up to the late 1980s, government revenues from agriculture were derived from implicit taxes on agricultural production, prices of farm products were low, marketing was controlled, cropping patterns were set to meet government priorities, and the Government of Egypt (GOE) captured substantial profits from the sale of commodities (especially cotton) on world markets. The result of these policies and practices, combined with increasing domestic demands, led to a rapid deterioration in the agricultural trade balance. To restore farmers' incentives, a radical program of reforms to agricultural policy was initiated in 1986. Closer correspondence between international and domestic prices for the majority of crops was allowed, and controls on cropping patterns were gradually eliminated. The response to these policy changes has been dramatic: yields and production of major crops have increased sharply, and farm incomes have improved (after allowing for the increased cost of inputs) by some 40 percent in real terms (Attia 2002). This period of rapid adjustments, during which time government revenues from the sector fell sharply, provided the opportunity to adjust other prices to more appropriate levels. To some extent this was done and subsidies for farm inputs were reduced.

Parallel to the radical changes in the agricultural sector, complementary measures were also taken with regard to I&D service. More emphasis was directed to encourage farmers to participate in the O&M activities at the farm level. WUAs were initiated as pilot projects in three regions representing upper, middle, and lower Egypt. Later, formal WUAs were established on the lowest level of the irrigation system (farm ditches or mesqas).

WUAs organize themselves in the manner in which irrigation activities would be performed. They pay the costs for the maintenance of their mesqas. A series of workshops was held during the past 10 years to establish guidelines for introducing recovery procedures for all mesqa, distributary channels, and farm improvement costs, and to familiarize farmers with the procedures and necessary documents to legalize the WUAs. These procedures have been

established by the relevant enacted laws primarily for Irrigation Improvement Projects (IIPs) and subsurface drainage. In addition, several studies have analyzed the design and implementation of successful cost recovery policies for irrigation services in Egypt and the major impacts of such policies on water management, in general, and on the social and economic conditions of the users, in particular.

2.0 Current Forms of Cost Recovery in Egypt

Egyptian farmers' financial involvement in water management varies considerably from area to area and from task to task. Today, farmers in Egypt pay very few taxes relative to their incomes. Under the present system, as agricultural incomes rise in response to liberalized market conditions, tax revenues do not automatically follow. Farmers with three feddans or fewer of land and no other source of income are exempt from land tax and additional taxes that are attached to agricultural land tax. In all cases, these exemptions do not apply if the taxpayer has other sources of family income. To obtain an exemption, however, farmers must apply to their local authorities each year and go through an extensive bureaucratic process. As a result, most farmers seem to pay their land tax whatever the size of their holding.

Table 4.1 presents the average costs that the farmer pays per feddan of agriculture land whether it is in the form of O&M or land taxes and other duties (Abdel-Aziz 2003). Charges for water services (to agriculture or to other users) had not been introduced.

The GOE initiated several programs to implement cost recovery mechanisms for irrigation services. The government implemented several programs to recover costs for water services. The IIP is one of the main projects dealing with water user participation. Following is a brief description of these main programs and a detailed explanation of the IIP.

Table 4.1 Average Farmer's Contribution to Water Management in Old Lands

Water Management Activity	Nonimproved (cost in LE/feddan/year)
Cleaning field ditches (marwas)	11
Desilting field canals (mesqas)	13
Pumping cost/individual farmer	250
Cleaning field drain	15
Desilting private field drain	17
Capital cost subsurface drainage	35
Land tax	30
Total	371

Source: Abdel-Aziz 2003.
Note: US$1 = LE 5.75 in 2005–06 prices.

2.1 Cost Recovery within the Irrigation Improvement Project

MWRI has changed its policies shifting gradually from a supply management concept to demand management. A package of demand-oriented measures has been prepared and applied to the Egyptian agricultural sector under IIP. IIP includes improving control structures, using modern methods in land leveling and tillage (used only for demonstration plots), supporting on-farm development, rehabilitating main and branch canals and mesqas (field canals), promoting equity of water distribution, and attaining a form of cooperation between the irrigation directorate and the farmers by forming WUAs. WUAs that were established under the IIP are an excellent example of the effect of user involvement and cooperation on the system management. Although all the users are farmers who belong to the same economic sector, it is the concept of stakeholder involvement in decision making during the various stages of planning and implementation that is emphasized. When users are involved from an early stage, it is evident that they will accept the proposed improvements and will be able to operate and maintain them easily afterward. Moreover, users resolve conflicts among themselves.

Several physical improvements were introduced to the old irrigated lands in Egypt to save water by increasing water use efficiency and reducing water losses. These improvements necessitate structural and nonstructural changes in the lower parts of the irrigation system. These changes include identification of a single intake pump from the distributary canal, lining field canals and farm ditches (mesqas and marwas), and weeding and maintaining the field irrigation system. WUAs participate in recovering all costs related to construction and establishment of the system (capital costs) as well as the O&M costs.

MWRI established a special fund that is financed mainly by the recovered capital costs of improved systems—excluding interest over a period of not more than 20 years—to finance future mesqa improvements. These capital costs are collected by WUAs. In addition to recoveries from farmers, the fund would be financed by budgetary transfers and foreign grants and loans.

Mesqa improvement costs consist of three main components (Royal Haskoning 2004):

- Investment costs for the mesqa pumps. These costs would be repaid over a period not exceeding five years.
- Investment costs for civil works. These costs include mesqa remodeling, polyvinyl chloride pipes, lining, and so on; these costs would be repaid by beneficiaries not later than the end of the first year following the completion of mesqa improvements. The investment costs would be paid to the government over a period of not more than 20 years, without interest, based on the farmer's capacity to pay.
- O&M costs. Farmers would pay these costs directly to the WUAs. The WUAs would determine the basis of recovery of O&M costs of the mesqa from their members and would be encouraged to base recovery on a proxy for the volume of water (for example, according to the time of pumping)

rather than on a per feddan basis. This practice would provide incentives for improved water use efficiency.

The cost recovery for the mesqas and pumping stations in IIP areas constitutes about 86 percent of the total cost of improvement. The remaining 14 percent goes to the improvement in the branch canals (downstream control gates, stone pitching, bridges, and so on) that farmers are not repaying under the existing legislation.

The payment for mesqa investment, which is expressed as a proportion of incremental income attributed to irrigation improvements, varies between 15 percent and 25 percent. This shows the ability of beneficiaries to pay, and it also shows that farmers have a strong incentive to participate in the IIP. O&M costs are the responsibility of farmers located downstream from the delivery point. Failure to fulfill this obligation results in the work being undertaken by MWRI and charged to the farmers on a general average value plus a 10 percent administration charges. Hence, farmers pay LE 18 per feddan per year (US$1 = LE 5.75) for mesqa maintenance in the old lands.

One of the lessons learned from the implementation of the IIP was the farmers' acceptance of the new changes in water management. IIP was introduced to the farmers as a package that involved engineering aspects and institutional arrangements, such as the establishment of WUAs. Farmers appreciated the engineering improvements, but they did not welcome the institutional arrangements associated with them. They did not see the point in establishing WUAs, and they strongly rejected practices that placed undue financial burdens on them. Therefore, social mobilization and extension work is important to raise awareness.

Another aspect to be considered in the process of implementing the WUA mechanism is the level of awareness among farmers. At the beginning of the project, the WUAs were informal and didn't have enough social and extension work with the farmers, most of whom are extremely small and poor farmers with low levels of education and few capital assets. Their participation in decision making is almost nonexistent, and the highly skewed land holding creates power relations that work against the interests of the small farmers. The majority of these small farmers are convinced that their participation in WUAs is neither possible nor important (IDRC 2005).

Despite some drawbacks in the adoption of the IIP, the project evaluation showed that it had various other benefits in the command areas where it was practiced. These benefits include the following:

- Increasing water distribution efficiency in most command areas by 30 percent to 40 percent
- Reducing the costs of pump operations by LE 25 to LE 40 per feddan for one crop—most of the cultivated area in Egypt is cropped twice a year, which means that total savings range between LE 50 and LE 80 per feddan each year; the annual cost of pumping for the individual farmers has been estimated by LE 250

- Reducing the time required to irrigate by 50 percent to 60 percent for each irrigation—reducing the number of working pumps from 10 to 30 pumps on the old mesqa (1 or more pumps for each farmer) to 1 to 3 pumps on the improved mesqa for all farmers irrigating from the mesqa, which helped reduce the annual maintenance costs for the mesqa
- Attaining equity of water distribution among all the farmers on the mesqa and eliminating the tail-end problems by using a single-point lift at the head of the mesqa and letting farmers schedule irrigation among themselves—this decision was directly reflected in the improved productivity of all farmers
- Eliminating direct pumping from secondary canals by nearby farmers—they now have a reliable continuous supply that reduced excessive irrigation, which previously led to waterlogging and drainage problems; thus, productivity increased
- Transferring the new irrigation technologies to the farmers to demonstrate its real effect on their income—this encouraged farmers in other unimproved areas to look forward to this improvement and to be willing to share in the costs
- Developing and encouraging a new spirit of cooperation among farmers with the introduction of WUAs

The success of the IIP in forming WUAs during the pilot encouraged the parliament to issue legislation for such associations. The legislation defined these associations as private organizations owned and operated by members of the WUAs of the watercourse, for their own benefit, and as organizations working in the field of water use, distribution, and related organizational activities to raise agricultural productivity.

The application of the WUA model in Egypt was successful as a mechanism for partial cost recovery of water services, although it has not yet reached the same level of success as a model for full user participation in water management. Full participation will require greater effort in the extension and awareness of the farmers regarding their basic rights and obligations. This effort should continue to build a new generation of users who can effectively participate in water management. Thus, the government should focus on the formulation and implementation of these policies.

2.2 Cost Recovery for Subsurface Drainage Implementation

Irrigated agriculture represents 98 percent of Egypt's agriculture. Typical adverse impacts of perennial irrigation are soil salinity and water logging. In 1970, Egypt launched a large drainage program. The program was planned to cover all of the old agricultural lands in the Nile delta and valley. After completion of the installation of the drainage systems the Egyptian Public Authority for Drainage Projects (EPADP) will continue to operate and maintain them in addition to rehabilitating and replacing the old drainage systems (Barakat 2000).

Egypt's drainage program is considered to be one of the largest, if not the largest, drainage programs in the world. It has been extremely successful in

preserving Egypt's soil and allowing for high crop production. The MWRI is responsible for implementing main, local, and field drains. Open field drains are not preferred by the farmers, however, because they use parts of the fields. Therefore, EPADP launched an intensive project for tile field drains. After the implementation of the field drainage system in an agricultural area of more than 5 million feddans, an increase in crop yield by more than 20 percent was observed. Such an increase resulted in higher profits for the farmers. Thus, more farmers were encouraged to participate in the drainage program and contribute to installation costs. A similar mechanism to recover the investment costs for mesqa improvements is followed in the case of subsurface drainage investments.

2.3 Cost Recovery for Irrigation Systems in New Lands

In the new lands, the government constructs the main parts of the irrigation system, including main regulators, main pumping stations, drainage reuse stations, main canals, and drains at no charge. Farmers are charged for the investment costs for all infrastructures located downstream of the booster pumps that draw from distributary canals, which serve between 100 and 200 feddans. Such investments may be undertaken independently at the farmers' expense or by the government with cost recovery according to the established rules.

Thus, the policy of the government with respect to capital cost recovery is to recover no charges upstream from the delivery point (the mesqa head in the old land, the booster pump in the new land) and to recover only a proportion of the investment costs downstream from the delivery point. Thus, the subsidy on capital investments is between 80 percent and 90 percent of the total cost of any irrigation system (main and tertiary). The existing policy for capital cost recovery should be reviewed in light of the high subsidy resulting from present procedures.

Settlers on new lands, new graduates, landless peasants, or large investors are given a grace period of 10 years before they are subject to any taxes. Total land tax collections for year 2000/01 came to LE 133 million at an average of LE 20 per feddan per year. Most farmers pay an additional 15 percent of land tax to their local administrative authorities. Farmers pay other taxes for other local services, fees, stamp duties, and so on. The average payment is about LE 15 per feddan per year.

2.4 Cost Recovery on Megaprojects

The Egyptian government has started to develop three megaprojects (North Sinai, Toshka, and North-West Delta). These projects will attract investors, although some areas have been set aside for new graduates. Privatization was introduced from the start and is already included in the planning process of these projects. The GOE sets up holding companies to invest in the main system to provide water to the farm gate at a lower level on the basis of cost recovery. The GOE targets a maximum level of cost recovery. This concept was issued by presidential decree. From the farm gate onward, private parties take over the development and O&M, including investments in the water system

infrastructure. In areas with relatively few landowners, water boards are set up at the branch and district levels.

3.0 Main Aspects of User Participation in Cost Recovery

Charging users for the provision of water and water services is a sensitive issue in many countries. It involves political, historical, social, religious, and economic factors. The GOE made the decision that charges to recover water supply costs are acceptable (ISPAN 1993). The question then becomes what is the best way to do this? Three preliminary questions were raised in this regard:

- Should the present system—without water charges—be replaced by a new one with water charges (metering system)?
- Should the water charging system be uniform or diversified, depending on the availability of infrastructure and other considerations?
- Should the impact of water charges on water demand be limited to redistribution within the tertiary irrigation unit, the irrigation district, and the directorate, respectively, or should it have impacts at the central level and be linked to water allocation decisions for nonagricultural purposes?

The first question focuses on technical aspects related to the installation of meters at the farm gates for individual farmers, because the farmers' demand response is currently insensitive to water charges. The metering system would force an effective response by farmers to imposed water shortages. The second and third questions have greater administrative and political implications.

Regarding the second question, a diversified water-charging structure could be proposed, versus a uniform one. In the irrigated area, differences already exist in financial arrangements with farmers, especially about how to repay the land development and improvement costs. A diversified charging system could adjust to structural local conditions—such as soil salinity and the alternatives of drainage or groundwater—and temporary national conditions, such as the variations in annual release from Lake Nasser. A flexible system of water services cost recovery is suggested, but at the same time a highly regulated and transparent system could avoid undue discretionary powers at local levels. A model is not available and experience is lacking for such a complex water system or for an elaborate crop-based charging system.

3.1 Implications Related to Water Allocation

In the present situation, water is allocated to directorates on the basis of their water demands, as notified by the directorates at the central level. The Nile provides the country with more than 95 percent of its total annual requirements, and the country's share is fixed by internal agreement at 55.5 billion cubic meters (bcm). Thus, the major constraint is that the total water demand does not exceed the total available supply for the water planning year and the water allocation period concerned (MWRI 2000).

The first option for the old lands is to continue with this method of allocation at the directorate level and fine-tune the tertiary levels using formal and

informal methods. The second option is to charge for water on a per crop basis, and the third option is to charge for water on a volumetric basis. The third option does not appear to be attractive, because it requires meter installation at various outlets along the irrigation network. According to the International Irrigation Management Institute (IIMI 1995), this is not a cost-effective option, whereas options two and three were almost equally efficient with respect to water savings. However, the IIMI study concluded that a reduction in agricultural incomes of 25 percent to achieve an average water saving of only 15 percent is clearly unacceptable at the political and social levels. Under the first option, a similar level of water reduction can be achieved by a production loss between 4 percent and 7 percent, depending on the division of the reductions over head and tail ends (Lofgren 1995).

It may be appropriate to introduce water charges based on a volumetric basis for parts of the old lands, such as those where IIPs have been completed, and for significant parts of the new lands. The World Bank–financed IIPs estimate that farm incomes will increase by LE 730 per year for a two-feddan farm, while the cost of capital repayment amounts to about LE 140, after allowing for reduced pumping costs.

In the megaprojects such as Toshka, the water service recovery charges are proposed as a combination of non-crop-based area charges and volumetric charges with an area charge of US$100 per feddan per year. The volumetric tariff structure that has been proposed ranges from 5 piastres per cubic meter (m^3) for supplies below 4,000 m^3 per feddan per year to 8 piastres for supplies above 6,000 and below 7,000 m^3, which is the maximum considered.

For the second option of crop-based water charges, the tariff structure for non-crop-dependent components needs to be investigated. The preliminary issue is a choice between options one and two. Remaining questions relate to effectiveness and administrative compatibility, the overall approach, and compatibility with the agricultural system, which has been almost completely liberalized.

A second aspect is a choice between a uniform and a diversified water charging system. A uniform system will not be able to charge on a volumetric basis, because infrastructure on the "old lands" does not support this.

User participation in financing and operating the irrigation system is questioned with regard to the extent to which water charges are allowed to influence water allocations at different levels. If all farmers are willing and able to pay for the higher water charges related to rice production, the total water quantity demanded is expected to exceed the total available supply. This expectation is based on the following reasons:

- The agricultural demand for water is relatively insensitive to the water charge; in technical terms, the "price elasticity" is low
- Because water charges relate to the recovery of water supply costs, the level of water charges is limited. Most likely, especially in the short run, those charges will be below equilibrium prices, which would "equate demand and supply" for water.

3.2 Aspects Related to Service Charges

The efficiency objectives of cost recovery have been partially addressed in the past. The analysis indicated that the level of service charges required to meet the financial objective are so low (6 percent of farm costs; 4.5 percent of income) that their impact on farmers' cropping decisions is minimal.

The analysis clearly showed that even volumetric charges are unlikely to produce significant efficiency results within the feasible range of charges. In further support of this contention, it is helpful to evaluate the benefits of volumetric supply in relation to possible costs. The following conclusions, based on previous studies, can be made in relation to water volumetric charges:

- Charges for water services would not induce significant changes in cropping patterns, or improvements in system performance, because the cost of system operation is low in relation to the benefits of irrigation.
- Until revised accounting procedures are in place, there is no way to meaningfully link charges to service at the local level. Thus, reducing the financial burden on the government is the only likely impact of introducing water service charges.
- Analysis of the potential improvements in productivity—should irrigation water become scarce from more equitable water distribution, forcing farmers to select water-efficient crops—shows that the benefits are small in relation to the likely financial costs of infrastructure.
- Administrative complications and the associated need for more clearly defined water rights further reduce potential benefits, suggesting that maintaining the balance between supply and demand should be a high priority.
- A crude crop-based charge (water charges set at levels proportional to typical farm demand, by crop) is almost as efficient as full volumetric pricing.
- The volumetric charge required to induce a 15 percent decrease in demand for water for agriculture would account for 25 percent of farm incomes.
- Alternatively, by rationing water among farmers, efficient use can be induced. Production was predicted to fall by 4 percent as a result of the 15 percent reduction in supply. In this case, rationing was uniform over both head and tail ends.
- If rationing affected only the tail end, production would fall by 7.1 percent, indicating the benefits that will correspond to better management if shortages arise.

3.3 Implications for Crop-based Charges

The main reason to apply crop-based charges is the fact that different crops have different water requirements and charging on a crop basis can be an administratively manageable and cost-effective method. Water requirements per crop in Egypt range from 1,000 to 12,000 m^3 per feddan. This system presupposes that the water distribution infrastructure and irrigation practices do allow for water allocation that is appropriate in quantities and in time for

the specific crop and that individual farmers can pay for their allocations The charges will be applied on an area basis and can have a fixed component—independent of the crop—and a variable component related to the type of crop. The variable component can be proportional to the crops' water requirements.

A crop-based charging system does not and cannot exist in a vacuum, but rather it exists in a situation in which water boards and WUAs have been established along with traditional and more informal arrangements. The overlap, complementarity, and incompatibility between crop-based charges and the other instruments typically depend on the extent to which the tertiary water infrastructure and local irrigation practices will allow for a proper targeting of the intended quantity of water to the intended farmlands.

It can be argued that crop-based charges should be linked to equity considerations, that is, to relate the charges to be paid to the income position of the owner (or the tenant) on an individual basis related to wealth or income position, or on a categorical basis, such as size of land holding, family head, or family composition. Nevertheless, it probably would be better to make charges dependent only on the characteristics of the land and its location (directorate, district, or even smaller, but not head or tail end) and on the quality of the water and not on the characteristics of the recipients. Individual characteristics should be considered separately, that is, in relation to other instruments.

4.0 Proposed Mechanisms for Cost Recovery

For many years, farmers have benefited from the irrigation system without paying anything other than land tax. Hence, at this time, it will not be acceptable to most farmers particularly in non-improved areas to introduce an extra fee for I&D services. This is especially true because the service rendered is not always good, rotations among canals are not respected, tail-end farmers receive less water, and irrigation from drains is common. Lower service results in smaller returns and lower cropping intensities than in improved areas, so there is little incentive to pay additional charges. The costs paid by farmers in these unimproved zones for I&D services are reflected in the land tax they pay.

Cost recovery for I&D services would be limited to those infrastructures that are used solely for the purpose of direct irrigation and drainage. This means that all canals of a higher order than the branch canal, and drains of lower order than the branch drain, should be excluded. Therefore, some infrastructures usually serve more than one water user. Although cost recovery should eventually be extended to nonagricultural users, shortcomings in the MWRI's information and accounting systems presently make it impossible to allocate costs of services to different types of water users.

The Haskoning Study in 2004 summarized the boundary conditions for an acceptable cost recovery mechanism as follow (Royal Haskoning 2004):

- Need for I&D improvement
- Limitation to the irrigation branch canals and mesqas
- Limitation to the subsurface laterals, collector drains, and open branch drains

Table 4.2 Options for Cost Recovery Levels

Recovered Components	Option One	Option Two	Option Three	Option Four	Cost in LE per Feddan
O&M Costs					
Mesqa plus Pump	■	■[a]	■[a]	■[a]	33.8/39.3[b]
Subsurface Drainage	■	■	■	■	5.0
Branch Canal	■	**n.a**	■	**n.a.**	11.5
Branch Drain	■	**n.a**	■	**n.a**	7.4
Capital Costs					
Mesqa Improvement	■	■	■	■	145/120[c]
Pump Sets	■	■	■	■	150
Subsurface Drainage	■	■	■	■	90
Branch Canal Improvement	■	■	**n.a**	**n.a**	15
Incremental LE per feddan versus present cost recovery	38.9	20.0	23.9	5.0	

Source: Royal Haskoning 2004.
Note: LE = Egyptian pound; O&M = operation and maintenance.
a. Indicates that the recovered sums remain with the WUAs to cover the cost of the component.
b. The first figure gives the cost in winter, the second refers to the cost in summer.
c. The first figure gives the cost for the actual contract, while the second refers to the future contracts.

Within these boundary conditions, the Haskoning Study considered four options regarding the levels of cost recovery, depending on the cost components to be recovered. These options are given in table 4.2.

Option one represents the most far-reaching cost recovery situation; it envisages the collection of O&M costs at the mesqa, branch canal, subsurface drainage, and branch drain level. It also covers capital cost recovery for improvements of the mesqa and branch canal and for the installation of subsurface drainage.

Option two covers capital cost recovery charges for all improvements of the irrigation system on the farm level and all installations of the subsurface drainage system. It also covers the part of the O&M costs that is related to the mesqa and subsurface drainage system.

Option three covers mesqa improvements and pump setup costs and the installation costs of subsurface drainage, as well as the O&M costs for mesqas, subsurface drains, branch canals, and branch drains.

Option four reflects the present situation in the improved irrigation project areas and areas within the subsurface drainage project, and improves the collection of the maintenance cost of the subsurface drains system.

Most options considered the O&M costs for the mesqas and pumps that are already authorized and held that the WUAs would cover the costs of the maintenance activities. The options differ in terms of the components of public

system costs that they aim to recover. Option one is the most inclusive, covering all O&M and capital costs of branch canals and drainage systems.

None of the options consider recovery of costs at levels higher than the branch canal system. Although the proposed Law 12/1984 amendments do not restrict cost recovery to branch canals and although the O&M costs of the higher levels of the public system are relatively minor, recovery of these costs was ruled out on the grounds of practicality and equality. At these levels of the system, nonagricultural water uses and discharges exist, and at present, MWRI's water and financial accounting systems do not collect and generate the kinds of information needed to allocate costs among multiple types of users.

The Haskoning Study recommended the adoption of the new cost recovery approach only in improved areas. The principal reason for this limited recommendation is the political difficulty of asking users to pay without a demonstrable prospect of improvement in the quality of service.

4.1 Evaluation of Options

Stakeholder agreement is essential for the success of a cost recovery system. Stakeholders in the Egyptian situation of cost recovery for irrigation and drainage include the GOE, water boards, and mesqa WUAs. The agreement of stakeholders depends on the benefits they perceive from the recovery system. For the MWRI, it is clear that the main benefit and principal objective is the transfer of part of the O&M costs to the farmer, thus reducing the burden on the general taxpayer.

Cost recovery should ensure that at least the full O&M costs are recovered, because they reflect the service costs of providing farmers with irrigation water and ensuring adequate drainage. Capital cost recovery need not be total, because the investments provide benefits to other sectors of the economy as well.

The farmers' ability and willingness to pay are key factors for cost recovery. So far, it seems that improvements to the I&D systems have benefited the farmers, although they may suffer some crop losses during the construction process. These crop losses are usually compensated. However, in the long run, farmers would be happy with the improvements. Extending the cost recovery mechanism to include the branch canal and branch drains requires an extra cost to the farmers, but the analysis of the farm budget has indicated that the extra costs are minor and quite affordable. Recovery rates are the main indicator of whether the cost recovery system is acceptable and functioning.

The following list summarizes the criteria against which the cost recovery arrangements should be judged (that is, they represent the criteria for success in cost recovery adoption):

- Agreeable to the stakeholders
- Adequate returns fully cover O&M and contribute to capital cost
- Within the farmers' capabilities to pay
- Simple to administer
- Legally sound

4.2 Strengths and Weaknesses of the Existing System

Cost recovery levels for the existing I&D improvements are inefficient. The rates achieved for drainage improvements are less than 60 percent. The collection mechanism through the land tax authority is inefficient, because farmers lack the incentives to do the additional work required. Nevertheless, the present situation has a number of strong points that can be summarized as follows:

- A legal framework supporting capital O&M cost recovery in drainage and irrigation improvement areas
- The presence of cost recovery of capital costs in I&D improvement areas
- The success of cost recovery for the O&M costs in irrigation improvement areas (through WUAs)
- The ownership of the mesqa and resulting care for its functioning by the farmers
- The existence of WUAs at mesqa and branch canal levels
- The collection of capital costs for I&D improvements by land tax collectors
- The acceptance of land tax payments in irrigated land

Additionally, there are weaknesses in the present recovery system:

- Recovery rates for drainage capital costs are low
- Measurement of supplied water quantities is not possible
- The branch canal is not an economic unit of O&M contracts
- I&D command areas are not always the same
- Farmers do not place much confidence in irrigation services when water management is supply driven and allocation to branch canals rotates
- Farmers do not perceive that money collection by the land tax authority contributes to better I&D management
- In any collection round, various service charges as well as land taxes are collected at the same time and farmers are allowed to make partial payments

Table 4.3 presents the multicriteria analysis and notes the pros and cons of the various options under evaluation.

Options two and four, in which branch-level O&M costs are not recovered, deserve little attention because O&M costs for branch canals and drains are significant, and these two options do not include recovery of these costs. Although option three is recommended over option one for reasons related to the quality of user participation, at present, users are not significantly involved in the selection or design of branch canal improvements. Thus, based on the above-mentioned analysis, option three is preferred. It envisages the collection of branch canal O&M costs; the involvement of branch canal water boards (BCWBs) in maintenance, planning, and monitoring; and the complete devolution of branch canal operation.

Implementation of the proposed cost recovery program will require legalization, changes in financial management structure, and capacity building.

Table 4.3 Evaluation of Cost Recovery Options

Criteria	Option One	Option Two	Option Three	Option Four
Stakeholder Agreement: – MWRI – Water Boards – WUAs	 Acceptable Direct benefit Direct benefit	 Acceptable No direct benefit Direct benefit	 Favorable Direct benefit Direct benefit	 Acceptable No direct benefit Direct benefit
Recovery of O&M Costs	Mesqa and branch canal/ drain	Mesqa level only	Mesqa and branch canal/ drain	Mesqa level only
Recovery of Capital Costs	Mesqa, subsurface drainage, and branch canal	Mesqa, subsurface drainage, and branch canal	Mesqa and subsurface drainage	Mesqa and subsurface drainage
Farmers' Ability to Pay (increase net farm income)	6.5%	6.9%	6.7%	7.1%
Impact on Gov. Budget: – Irrigation O&M – Drainage O&M	 −2% −3%	 No Impact −3%	 −2% −3%	 No Impact −3%
Administrative Complexity	Complex (3 levels)	Complex (3 levels)	Complex (3 levels)	Simple (2 levels)
Legality	Needs amendment to Law 12	Needs amendment to Law 12	Needs amendment to Law 12	Needs amendment to Law 12

Source: Royal Haskoning 2004.
Note: MWRI = Ministry of Water Resources and Irrigation; O&M = operation and maintenance; WUA = Water Users Association.

Consideration of the various MWRI water users' advisory services is also recommended. The following steps are needed for the full introduction of the selected cost recovery program:

- Accepting the proposed cost recovery approach by MWRI
- Continuing the present systems for cost recovery of mesqa improvement and subsurface drainage construction
- Amending Law 12/1984 to enable the BCWBs to recover costs from their members
- Strengthening the irrigation advisory capabilities of MWRI by combining the advisory services provided by the Central Department of Advisory Services with those of IIP and drainage
- Expanding BCWBs in the irrigation improvement areas
- Strengthening the planning and cost-sharing capabilities of the boards and encouraging them to work together with the ministry's general directorates

- Introducing the new cost recovery mechanism for public infrastructure
- Introducing the amended cost recovery mechanism for private infrastructure
- Monitoring cost recovery and the introduction of changes if needed

5.0 Conclusion and Recommendations

Growing recurrent costs for O&M of irrigation services and facilities are creating enormous budgetary demands in Egypt. In addition, because public irrigation is heavily subsidized since the liberalization of the agriculture sector, pressures are growing on MWRI to perform its O&M duties of the I&D network. Therefore, farmers have to participate and share in recovering all or even part of the costs spent by MWRI in the system O&M. Cost recovery for various activities within I&D operations need to be introduced, emphasized, and encouraged. Cost recovery becomes more effective when it is combined with Irrigation Management Transfer (IMT) and Participatory Irrigation Management (PIM) approaches. Specifically, the implementation of cost recovery is crucial for IIP's successful implementation and has been made a requirement of the World Bank project. Farmers should gradually participate more fully in the O&M of their branch canals to improve the overall irrigation system management in Egypt. Cost recovery would be accomplished through the development of district water boards. The legal framework for the WUA formation and cost recovery of mesqa construction costs was fully established by the Law 12/1984 amendments and its 1995 bylaws. It authorizes the WUAs and permits the recovery of mesqa construction costs and payment of full O&M costs.

The capital costs for mesqa improvements under IIP are to be recovered through annual installments over not more than 20 years. The costs of pumping units as well as the costs for land leveling are to be repaid over three years in equal annual installments. At present, nonagricultural users pay no fees to the government. Within agriculture in general, in the nonimproved mesqas, there are no procedures for cost recovery or for sharing of capital or O&M costs for water services at the main and delivery system levels. At the mesqa level, farmers are responsible for O&M of their "private" mesqas. Clearly, the many social benefits to participation cannot be easily measured in economic terms.

Participation, however, does impose costs on farmers in the form of time and other resources spent in these activities. Participation has a known opportunity cost to farmers. Water boards must be transparent in their management. They must develop managerial, fiscal, and recordkeeping procedures that are open and detailed enough to ensure success in the cost-sharing program. These boards should be fair and reasonable in their decisions and administration of resources.

The appropriate option for cost recovery in the form of service charges should be investigated. Water service fees like volumetric water charging (water pricing) would not be economically, socially, or politically feasible. A key lesson learned from international experience is the crucial importance of linking cost recovery to accountability for the services provided. The basis for

irrigation service charges should be crop based and should reflect crop water consumption (phasing to start with a flat rate). The Ministry of Finance will collect irrigation service charges, advised by MWRI. These charges should be deposited in a special revolving fund to be used for water delivery services. The implementation of irrigation service charges should follow three stages: (1) political commitment to the introduction of service charges, (2) passage of these commitments through people's assemblies, and (3) design of collection procedures and introduction of service charges.

Because of the significant policy change required and the number of related decisions and actions needed, it is expected that the introduction of service charges will take time. Most important, the introduction of full cost accounting is needed to accurately and transparently indicate the cost of providing the service. Additionally, senior management should decide whether the nature of the irrigation service should change, designating the service delivery point as the directorate or federation of WUAs.

Notes

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References

Abdel-Aziz, Yehya. 2003. "Decentralisation and Participatory Irrigation Management." Water Demand Management Forum, Cairo, Egypt, February 2-4.

Attia, Bayoumi. 2002. "Report on Policy Analysis of Water, Food Security, and Agriculture in Egypt." Unpublished technical report submitted to the World Bank, Washington, DC.

Barakat, Essam. 2000. "Cost Recovery for Irrigated Agriculture: Egyptian Experience." Irrigation Improvement Sector, MWRI, Cairo, Egypt.

IDRC (International Development Research Centre). 2005. "Research Results from the Minia Water Users' Associations Project." Minia University, Cairo, Egypt.

IIMI (International Irrigation Management Institute). 1995. Irrigation service cost recovery in Egypt: Report on a workshop in cooperation with Ministry of Public Works and Irrigation, and USAID, Cairo.

ISPAN (Irrigation Support Project for Asia and the Near East). 1993. "Irrigation Water Cost Recovery in Egypt: Determination of Irrigation Water Costs." USAID, Washington, DC.

Lofgren, Hanz. 1995. "Water Policy in Egypt: An Analysis with IFPRI's Agricultural Sector Model." International Food Policy Research Institute (IFPRI), Washington, DC.

MWRI (Ministry of Water Resources and Irrigation). 2000. "Towards Crop-based Water Charges." NWRP Project, Tec. Rep. No. 11, Cairo, Egypt.

Royal Haskoning. 2004. "Egypt: Study on Cost Recovery in the Irrigation and Drainage Sector." KFW, MWRI, Cairo, Egypt.

5. Advancing Irrigation Cost Recovery in the Republic of Yemen: A Community Cost-Sharing Approach

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Abstract: The Republic of Yemen is among the poorest countries in the world, with an alarming rate of demographic growth. It is a country for which agriculture is one of the economy's mainstays as well as a major employer. The Republic of Yemen is one of the most water-constrained countries in the world and has one of the highest water allocations to agriculture. The government's budget-strapped reform in the water sector called for improved cost-sharing initiatives that replace chronic patronage and supply-driven approaches, particularly in spate irrigation. These initiatives piggyback on other correlated policies for water conservation and participatory management. This chapter presents success stories and lessons learned from the cost-sharing and water user participation activities of the spate irrigation–dominant Irrigation Improvement Project in Yemen. The chapter also presents comparable experiences from other groundwater conservation projects in the Republic of Yemen. The chapter concludes that promising cost-sharing and water user participation results can be obtained when proper awareness-raising and incentives are fostered, including enhancing interfarm and interbeneficiary equity; improving on-farm productivity; and enabling the irrigators to participate in the design, contracting, implementation and supervision, and operation and maintenance of irrigation works.

1.0 Introduction

The Republic of Yemen is among the poorest countries in the world. Its agriculture is an important driving force of economic growth, contributing between 14 percent and 23 percent to the gross domestic product in addition to its significant indirect contributions to providing employment and income to more than 55 percent of the active population. Poverty is spread mainly in rural areas, where 83 percent of the poor derive their livelihoods and incomes from agriculture-related activities. The Republic of Yemen is one of the most populated countries on the Arabian Peninsula, with 3.2 percent demographic growth, which places high pressure on its natural resources.

From the water resources perspective, the Republic of Yemen is one of the most water-constrained countries in the world, with per capita availability of 150 cubic meters (m^3) a year, which accounts for 10 percent of the regional average and 2 percent of the global average. It has one of the highest sectoral water allocations to agriculture—more than 90 percent of total use.

With a largely arid to hyper-arid climate and no perennial rivers, the country relies heavily on the exploitation of groundwater. Groundwater reserves are being critically depleted. Renewable resources, estimated at about 2,100 million m^3 a year, are being supplemented by groundwater mining from deep aquifers at a rate of about 1,300 million m^3 a year (with desalination and reclaimed wastewater accounting for a negligible percentage). In some areas, groundwater tables are dropping at a rate of 3 meters a year, and many farms are being abandoned. Spate flood is the second-order means of irrigation; however, as opposed to groundwater, using spate water has proven to be costly to the government, because it requires developing and maintaining a spate-regulating off-farm infrastructure.

Irrigation has grown rapidly from groundwater and surface water. Traditionally, Yemenis applied many ingenious techniques to husband their scant water. Early development of modern spate schemes in the 1950s successfully adapted traditional flood recession technology to a more controlled system. In the 1970s, the introduction of the tubewell and motor pump revolutionized irrigation, and now full or supplemental groundwater irrigation accounts for more than two-thirds of the value of crop production. Irrigation efficiencies are low (the nationwide average is about 40 percent). Water consumption in the irrigation subsector continues to increase at an average rate of 30 million m^3 per year, or 5 percent per year. Already by 1990, irrigated agriculture alone was consuming 130 percent of the Republic of Yemen's renewable water resources, meaning that the overdraft beyond the "safe yield" was about 30 percent. By 2005, this latter figure had reached more than 50 percent. If agricultural expansion continues, groundwater overdraft could reach 100 percent by 2025—although many aquifers would be pumped dry before then.

Water markets exist in the Republic of Yemen, but only in the margins of the water-related activities. The private sector and market mechanisms are found only in irrigation water sales to water tankers and water sales between farmers. However, these markets are informal: clear rights in groundwater are lacking, third-party externalities are not accounted for, and an enabling or regulatory environment is nonexistent.

Water scarcity is exacerbated by significant spatial and temporal variations as well as by significant water (rights) allocation problems. With rapid population growth, water availability per capita expected by 2025 will decrease by 35 percent, well below levels that generally indicate severe water stress.

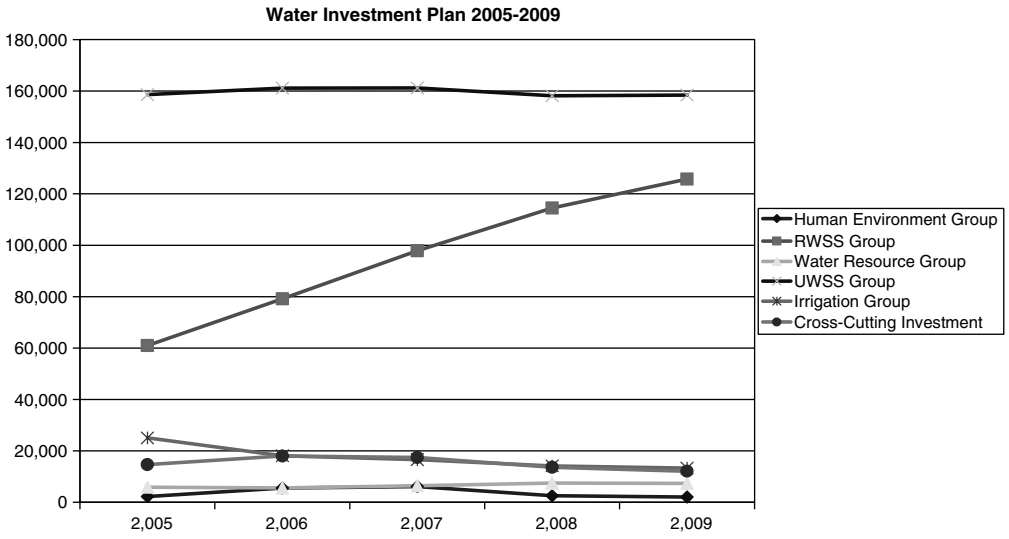
One challenge facing the Republic of Yemen is to reduce groundwater use in agriculture while maintaining the rural economy and farmer incomes. Another compounding challenge is to improve the sustainability of spate irrigation infrastructure and reduce the respective government financial burden. This could be accomplished by improving farmers' self-reliance on financing and maintaining spate irrigation systems. In the past, the government intentionally subsidized irrigation and drinking water to promote development, reduce the cost of living, raise farm incomes, and vest powerful influence groups with patronage. By the late 1990s, however, the government recognized that this trend posed economic and environmental threats, and new pricing regimes

were needed to target cost recovery and, to a lesser extent, demand management instruments.[3]

Despite a decentralization program for cost sharing in water investment programs, the government remains the dominant financier. From 2000–04, water sector capital expenditures were financed mainly by budget transfers (41 percent) and loans (29 percent), while user fees accounted for only 28 percent of the financing for the investment program. According to the five-year government investment plan proposed for 2005–09 (see figures 5.1 and 5.2), budget transfers are expected to represent only 30 percent of total financing for the water sector. Funds committed from donors (loans and grants) amount to 31 percent. Therefore, 39 percent of additional financing (the balance) is required by 2009. Self-financing may be needed to cover most of that balance. Furthermore, as shown in figure 5.1, there is an ambitious investment plan for the water supply and sanitation subsectors (aiming to achieve the Millennium Development Goals). Thus, the government would prioritize its sovereign financing of these subsectors over the irrigation and water resources management subsectors.

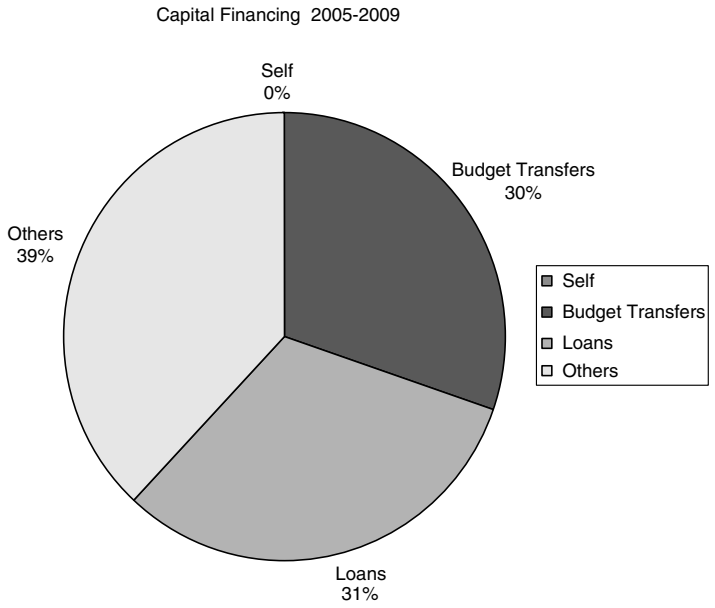
For the irrigation subsector, it can be concluded from figure 5.2 that cost recovery and demand management policies need to be coupled and fostered, thus replacing old patronage and supply-driven approaches. The government has set financial autonomy as a policy for rural decentralized water supplies and has started to work with water users groups to improve cost recovery, particularly in spate irrigation. This chapter presents success stories and lessons learned from the cost-sharing and water user participation activities of the Irrigation Improvement Project (IIP) in the Republic of Yemen. The chapter

Figure 5.1 Subsectoral Five-Year Investment Plan



Source: World Bank 2004.
Note: RWSS = Rural Water Supply and Sanitation
UWSS = Urban Water Supply and Sanitation

Figure 5.2 Projected Sources of Capital Expenditures for the Water Sector in 2009



Source: World Bank 2004.

also presents comparable experiences from other demand management–oriented projects in the Republic of Yemen.

2.0 Experiences from the IIP

Spate irrigation traditionally had no government involvement, but it did have its own highly wrought and historically validated systems of cost recovery. Only when governments began to step in during the 1950s to improve spate systems did the classic question of the division of costs between state and farmer become relevant. This division has been exacerbated because successive governments insisted on incurring the operation and maintenance (O&M) cost of all modernized schemes, which led to the predictable results of a vicious cycle of underfunding, declining services, and tumbling productivity. Toward improving utilization of spate irrigation in the Republic of Yemen, the World Bank Institute facilitated a review process of the prospects for Water Users Associations (WUAs) and ultimate transfer of spate schemes to users. This review resulted in awarding the 2001 IIP: an Adaptable Program Loan to support physical rehabilitation and to move the reform agenda forward (US$20 million). One of the components of the World Bank–supported IIP aimed to establish water user organizations (WUAs) that would share investment and rehabilitation costs of the main irrigation system and gradually take over O&M of the secondary and tertiary systems.

2.1 Formulation of Water Users Associations toward Cost Sharing

The IIP was formulated around the Participatory Irrigation Management (PIM) concept. The project prompted the government to create enabling legal

and institutional environments to establish two main water user organizations: WUAs and ICs (Irrigation Councils). Each WUA is in charge of implementing PIM in its respective irrigation command area, in which the WUA would do the following: (1) provide reliable and sustainable irrigation services; (2) perform maintenance and rehabilitation; (3) collect fees from beneficiaries; and (4) develop the capability for self-reliant O&M. At later stages, ICs in Wadi Zabid and Wadi Tuban were established with significant representation from the WUAs. The ICs act as the high executive and administrative authorities in each Wadi and are responsible for (1) applying the IC's bylaws and implementing its executive procedures; (2) coordinating activities between government authorities that continue to be in charge of O&M of headworks and primary canals and the WUAs in charge of O&M of the secondary and tertiary systems; (3) protecting water user rights and resolving conflicts and pending issues; and (4) monitoring the performance of WUAs from the social, financial, and technical viewpoints. The ICs represent the local government, WUAs, and the Ministry of Agriculture and Irrigation (through its Regional Development Authority/Agriculture Office).

The project initiated the PIM approach by undertaking a comprehensive awareness program to inculcate the concept of PIM in farmers' minds and to clarify the roles and responsibilities of irrigation beneficiaries within their representative user groups. The program targeted all related stakeholders, including farmers (owners, sharecroppers, and tenants), related government officials, local councils, and others. As a result of the program, informal water users groups (WUGs) were formed at the outset, which later materialized into formal WUAs. At an advanced stage of IIP, ICs were formed. The project then extended various training activities to build the managerial and technical capabilities of the WUAs and ICs.

The PIM called for farmers' participation in overall project activities, from decision making to completion of the rehabilitation and improvement works, as well as in-kind farmer contributions of 10 percent of the investment costs. Thereafter, farmers would assume responsibility and financing for the O&M of secondary and tertiary canals.

2.2 The IIP's Approach to Community Cost Sharing of Off-Farm Investments

For the investment and rehabilitation works, the IIP adopted an in-kind cost-sharing approach, which introduced the idea of having community-implemented contracts.

To enable low-income farmers to share capital costs of the project, civil works were divided into the following two categories:

- **Priority/trunk works** to be fully financed by the project (that is, by government funds and by the loan), including headworks, feeder roads, and flood/environmental protection works, which are all deemed "public goods" outside the canal system, thus requiring no earmarked user fees.
- **Community works**, requiring 10 percent of farmers' contribution to rehabilitation and improvement capital costs. This percentage was agreed

on by the project government team and farmer representatives (initially the WUGs and eventually the WUAs). Farmers were allowed to contribute that percentage in-kind (labor and material). In that arrangement, each WUA would implement one or two small community contract(s) up to US$10,000 per contract and up to an aggregate US$1.4 million per project. To further persuade irrigation beneficiaries to contribute 10 percent in-kind, the project ensured that the unit rates of the contracts awarded to WUAs (which would have otherwise embodied significant profit margins for the WUA contractors) would be 30 percent cheaper than those implemented by the national or regional contractors. This percentage thereby represents the total contribution from end beneficiaries and, intrinsically, from the WUA contractors.

2.3 Farmers' Response to Joining WUAs and Sharing Capital Costs

One major incentive for farmers to join WUAs was to give them the authority to codesign and coimplement spate subprojects.

Because of persistent centralized subsidies of irrigation in the Republic of Yemen, farmers at first had few incentives to buy in to the idea of forming WUAs under the project. The reluctance was caused by the fact that spate irrigation depends on erratic floodwater, which is becoming scarcer and less predictable over time. However, through the IIP's public awareness program, many farmers have come forward and joined the WUAs, paying subscription and annual fees, playing an active role in selecting the needed types of irrigation structures, and contributing to subsequent implementation and supervision of civil works contracts.

Farmers became more interested when they were vested with the right to participate in decision making and to directly implement small contracts for which they would share the cost for the rehabilitation and improvement works. The project included a prerequisite condition (in the Credit Agreement) stipulating that civil works cannot start before the establishment of the respective WUAs.

Farmers exhibited a willingness to share costs of on-farm improvements after the project produced improved yields and profits. A major component of the IIP demonstrated improved irrigation technologies and agronomic practices at the on-farm level. The demonstrations were conducted with 360 farmers and 590 farmers at Wadis Zabid and Tuban, respectively. More than 1,500 farmers were involved in the associated awareness campaigns. Some crop yields increased up to 100 percent as a result of the various on-farm interventions (see table 5.1). Through the Rapid Appraisal Survey conducted in March 2005, farmers rated the overall outcome as highly satisfactory and expressed their willingness to share 25 percent and 50 percent of the on-farm costs of improved technologies for the spate and tubewell demonstrations, respectively.

2.4 Backstopping the WUAs and Tackling PIM Implementation Difficulties

The project provided the needed training and necessary administration, financial, and technical backstopping for the WUAs. There have been various

Table 5.1 Yield and Farm Revenue Increases due to Improved Farming Practices: Planned Project Estimates versus Actual Measurements

Crop	Planned Yield Increase (%)	Measured Yield Increase (%) (end 2005)	Internal Rate of Return
Cotton	13% Zabid 15% Tuban	45–100%	Up to 6%
Sorghum Grain	5%	Up to 98%	9.5%
Sorghum Fodder	4% Zabid 8% Tuban	Up to 44%	4.5%
Sesame	10%	Up to 55%	8%
Maize	18% Zabid	62–97% Zabid	n.a.
Cucurbits	3% Tuban	Up to 200%	Up to 90%
Tomatoes	20%	87%	4%
Onions	20%	12–25%	2%
Eggplant	20% Tuban	44%	13%
Red Chilis	20% Tuban	n.a.	n.a.
Bananas	10–15%	n.a.	n.a.
Mangoes	10%	n.a.	n.a.
Okra	15%	25%	3%
Water melon	n.a.	28% Zabid	n.a.

Source: IIP Implementation Supervision *Reports (2005).*
Note: n.a. = not applicable.

difficulties in effectuating the roles of WUAs, primarily given their weak legal and financial status at start-up. These difficulties called for creating options to empower the WUAs to carry out the community contracts. For instance, it proved difficult for the WUAs to issue bank or commercial guarantees for the community contracts; alternatively, they were permitted to issue guarantee letters endorsed by the governors.

A training program has been conducted for each WUA board of directors and for their auditing and inspection committees to enable them to understand the legal status, objectives, and administration and financial management of O&M activities (with an emphasis on sustainable O&M). Irrigation Management Transfer (IMT) Agreements have been prepared in Arabic and have been endorsed by the governors. The project team has trained the WUAs' construction managers on the contracting procedures in the Project Operations Manual. The WUA representatives have participated in three workshops at the regional and national levels on topics related to institutional assessment of the irrigation sector. The draft bylaws to establish the ICs have been approved by the project interministerial steering committee, thus hastening the establishment of an IC for each of the two Wadis. About 30 working papers and operational manuals have been prepared by the training consultants for the project's PIM component.

The cost of training and WUA backstopping in the IIP has been considerable, amounting to about 20 percent of total project costs. Should the Yemeni government seek to scale up the PIM concept after the completion of Bank-supported projects, it would need to secure financing for software investments from the sovereign resources allocated to rural extension and research. From international experience, this is deemed to be an example of "virtuous" subsidies that a lean-and-mean government (as opposed to the private sector or beneficiaries) could shoulder.

2.5 Current Status, O&M Roles, and Expected Progress

Promising results have been observed thus far as irrigation stakeholders in the two Wadis participated in the IIP design, cost-sharing, and implementation stages.

All WUAs in Wadi Zabid and Wadi Tuban have been established and became fully operational with active boards of directors, proper bookkeeping, and necessary bank accounts. They have worked closely with the project management unit and the project consultants during the design and implementation of the rehabilitation and improvement activities. As part of the WUAs, Farmer Design Committees have been elected (with the facilitation of existing farmers' organizations) to determine the priority of the rehabilitation needs and to participate in their design.

The WUAs have efficiently been implementing the community contracts (explained above) and signing IMT Agreements for the secondary and tertiary canals. More important, they started contributing to the O&M costs of the secondary and tertiary systems (although it has been agreed that the O&M costs of the headworks and main canal system be shouldered by the government). The IIP has prepared an O&M manual, which includes a detailed inventory of required O&M items and a description of how WUAs could prepare O&M plans and budgets and collect O&M fees. The WUAs have been attending an extensive training program on how to use this manual and how to implement its plans. Thus far, the WUAs have been collecting user fees for heavy equipment rentals to carry out immediate O&M of the secondary and tertiary canals. The fees collected are deposited in WUAs' bank accounts and disbursed from these accounts. Thus far, collection of O&M fees has been carried out on an ad hoc basis, because O&M of the IIP-introduced civil works has not been in effect, awaiting completion of these works. Overall, the WUAs report that farmers are fully paying the WUA subscription and annual fees and have started to pay the O&M contributions. Reportedly, the collection process is transparent.

The ICs have started to hold regular meetings and to discuss issues related to water rights and water distribution. The role of the WUAs and the ICs will become more obvious after the completion of the rehabilitation and improvement works. One early sign of the WUAs' effectiveness in Wadi Zabid is that they persuaded powerful farmers to restore canal cross-sections and remove the control works that they unilaterally and subjectively placed in the canals to extend their irrigated area.

2.6 Summary of the IIP

The IIP has thus far been deemed a successful "process" project in testing and scaling up the PIM concept. The beneficiaries formulated grassroots-level WUAs and Wadi-level ICs that have successfully been accomplishing the following:

- Participating in decision making and in selecting design options
- Contributing to capital investment costs and to the implementation of civil work contracts
- Gradually taking over responsibilities for the recurrent financing and O&M of the tertiary and secondary systems

The viability of this process project is to be assessed for its interim and far-reaching impacts, including reduced governmental budgetary burdens; reduced avoidable transaction and overhead costs; financial autonomy on O&M of the community-level system; natural resource–based sustainability; and piloting, transferring, and scaling up best practices in PIM and on-farm modernization. Because most of the off-farm rehabilitation and improvement activities are still in progress, it is too early to draw conclusions on the quality of irrigation services provided by ICs and WUAs as opposed to those previously provided by corresponding government entities.

3.0 Experiences from the Groundwater Management Projects

The Republic of Yemen began taking tentative steps in the early 1990s to reverse the groundwater mining problem and improve cost sharing. A major constraint was the weak governance environment, which featured strong traditions of tribal and local autonomy and fragmented water institutions that had virtually no influence over the water extraction decisions made by tens of thousands of independent farmers. A decentralized and partnership approach was therefore proposed. The following sections touch on the PIM and cost-sharing experiences obtained from a number of irrigation demand management–oriented projects in the Republic of Yemen.

3.1 Groundwater Management Called for PIM

As a building block for an integrated approach to the water problem, the Bank-supported Land and Water Conservation Project (LWCP, 1994–99) was launched to demonstrate a package of technical improvements to reduce water use at the farm level. Targeting improvement to the Republic of Yemen's very low overall irrigation efficiencies (about 40 percent), the LWCP project offered technical advice to groundwater irrigators on water-saving technology and financed capital improvements on a cost-sharing basis (typically 30 percent from farmers and the balance from the government). Technology was piped into on-farm water distribution systems predominantly through the use of drip or bubbler micro-irrigation. Implementation was decentralized to local specialist teams, and farmer contributions were required up front (a credit facility was available). The project was well received by farmers and achieved its water-saving objectives.

A second phase, the Groundwater and Soil Conservation Project (GSCP), began in 2003 and is extending the technical and financial package from 11 to 15 governorates. It builds on the LWCP exercise by adding a key element: a technical advisory service. This service can complement physical investments in water use efficiency equipment with improved water management (through better irrigation scheduling and agronomic improvements), adjusted cropping patterns, and crop husbandry, which all raise farm returns per cubic meter of water. The project deepens the innovative partnership approach that LWCP introduced. The government has created a framework of rights, regulations, and basin planning that can (in the weak governance context) be implemented only through decentralized approaches, with the cooperation of groundwater users. Ways to develop this cooperation through partnership approaches are being tested at two levels: (1) the basin level, through basin committees that are based on basin hydrological boundaries rather than on governorate boundaries; and (2) the local level, through WUAs similar to those introduced under IIP. Complementary to the GSCP, a Japanese grant–financed pilot program, the Community Water Management Project (CWMP), has been implemented to test community self-management approaches to water conservation. The CWMP groups the irrigators for groundwater management and conservation by using participatory monitoring techniques (so-called peer monitoring).

3.2 Water Reforms Couple Demand Management with Cost Sharing

Alongside these field-level approaches, the government has been working to improve groundwater governance. A 2003 water law defines water rights and establishes a regulatory system of permits. The National Water Resources Authority (NWRA), created in 1996, is preparing basin plans, working with basin committees that unite the government and water users, and encouraging participatory and community-based solutions aimed at self-regulation and self-financing of recurrent costs by water users. The Sana'a Basin Water Management Project (SBWMP) is testing these approaches in the stressed basin around the nation's capital. At the same time, the government is fostering incentives for water conservation by macroeconomic measures, raising the price of diesel, and phasing out border protection on irrigated commodities. The government doubled the price of diesel in 2005, which was a key demand management measure.

3.3 Cost Sharing Created Revolving Funds to Finance Water-Saving Practices

The LWCP piloted improvements for groundwater and innovative approaches to watershed management. The adoption of cost sharing was key to demonstrating farmer commitment. Previously, projects had provided equipment for free, with disappointing results. Cost sharing now created a capital fund of about US$2 million to be used on a revolving basis to finance the expansion of the LWCP. The decentralized and participatory approach to identification, design, and implementation brought farmer knowledge and commitment into partnership with the skills and resources of the government. This approach laid the basis for the current GSCP-CWMP phase in which

partnerships increasingly will be made with user groups rather than with individual elites. Farmers invested about US$250 per hectare to achieve water savings of about 2,300 m^3 per hectare each year. The investment costs are thus about US$0.11 per m^3 of annual water saving. Savings in pumping costs amounted to US$0.06 per m^3, on average, so that the investment cost is recouped by farmers in just two years, without accounting for the opportunity value of the water saved in the aquifer.

3.4 The Political Economy of Introducing PIM to Groundwater Users

Although combating groundwater mining generally seemed to be pro-poor in the Republic of Yemen, initially, the better-off farmers may have been capturing most of the benefits. Under LWCP, a pro-poor filter was applied to the project's subsidized investments in water use efficiency by applying a ceiling on the area that the project would cofinance. This proved to be a weak mechanism, and a bias developed toward the better-off farmers who had land or water privileges and could afford the cost sharing. Better-off farmers control the majority of the groundwater and, therefore, Bank-supported actions to reduce groundwater mining inevitably have had to deal with those farmers. WUAs provide a means to help the disadvantaged realize the benefits. Forgoing the formation of WUAs could have posed the risk of excluding the poorer farmers—the landless and women. Incidentally, this risk was a hot issue in the preceding Bank-supported Ta'iz Rural Water Supply Project, in which there was a debate on the ethics of a Bank project dealing directly with the *sheikhs* who controlled most groundwater rather than with the WUAs that were poor and needy but did not actually own much water. The design of the Japanese-financed CWMP (see box 5.1) attempted to tackle this problem by promoting WUAs that integrate all water users, from big well owners to those who own no resources at all, on the basis of common responsibility.

3.5 Community-Based Monitoring and Evaluation System

To maintain sustainability, the IIP ensured that ICs closely monitor the performance of the WUAs. The project has established three broad performance indicators to monitor the WUAs: institutional, financial, and technical.

- *Institutional performance indicators.* These indicators include (1) representation—percentage of farmers subscribing for membership of each WUA; (2) transparency and accountability—whether the chair and members of the WUA executive body were properly elected, whether the executive body meets and produces minutes of meetings, whether WUA members are being informed promptly of the executive body decisions, and whether WUAs adopted proper Internal Rules and Regulations and bookkeeping concerning managerial, financial, and technical aspects; and (3) authority—the degree to which WUAs have the power to execute their decisions.
- *Financial performance indicators*. These indicators monitor whether WUAs are willing and able to collect or receive adequate funds to cover O&M and whether WUAs maintain proper bank accounts and accounting records.

Box 5.1. The Republic of Yemen Community Water Management Project

The Japanese government is providing a grant for a Community Water Management Project. The project, which is being executed by the World Bank, tests and develops replicable models for sustainable self-management of local water resources by poor farming communities in areas of the Republic of Yemen where water, particularly groundwater, is becoming increasingly scarce. The project has three components:

- A participatory water management component that would (1) identify areas in which social conditions are appropriate for local community self-management of water resources, and (2) build the capacity of local user groups over a discrete hydrological unit to manage the resource
- A water management and monitoring component that would work with user groups to define the water balance and a hydraulic goal, to draw up and carry out water management plans, and to monitor progress against the plan
- A monitoring and evaluation component that would document the project in full, evaluate and disseminate results, propose ways of scaling up successes, and create and support a network of practitioners

At the end of the four-year grant period, the project is expected to have developed models and institutional capacity in at least three representative areas. In these areas, local user groups will have the capability to work in partnership with local and central government agencies and to set, enforce, and monitor local water management plans. These plans should reduce net water loss and pumping from the aquifer while sustaining incomes equitably. The project will document the proven models, create a network of practitioners capable of scaling up the models, and influence the policies and practices of local and central government agencies to work with communities on local water management on a partnership basis.

Source: World Bank 2005.

- *Technical performance indicators.* These indicators demonstrate whether WUA members master the O&M and supervision plans and whether they are well informed of their foreseen costs.

WUAs and ICs may need to be empowered to fully undertake the monitoring and evaluation, and ICs may need to be formed as bottom-up rather than top-down entities.

The water law enacted in 2003 announced that WUAs and ICs need to be established and need to contribute to Wadi Integrated Water Management Plans that are adopted by the government. With technical backstopping from the regional line agencies and local authorities and councils, WUAs and ICs need to gradually take over the role of overseeing service provisions and facilitating the application of water-related incentives and regulations. They can be entrusted with more monitoring and benchmarking roles in coordination with the regional line agencies and with greater enforcement roles in coordination with local authorities.

The best alternative for a monitoring, benchmarking, and planning body would be the technical secretariat of a basin committee. The basin committee would be based on hydrological boundaries (an expanded, more comprehensive

modality of an IC, which is merely based on Wadi/district boundaries), with its board composed of multisector water user organizations, local authorities and line agencies, and local nongovernmental organizations. This would reduce the immense resource costs posed by the administrative boundaries and would limit the transaction costs posed by assigning monitoring and benchmarking roles to single-user water groups. The technical secretariat for the SBWMP thus far has been the Sana'a branch of the NWRA, which needs to be capacitated. Basin committees are mentioned in the recent water law, but the laws and bylaws are silent on the following: (1) whether the committee board would approve the basin plans (developed by its technical secretariat) by consensus or by majority; (2) an indispensable provision entailing that the board members be selected from user groups and local entities rather than from line agencies (which is currently not the case for the Sana'a basin committee board; it currently embodies many top ministerial officials); and (3) a provision stipulating that board members are to be elected rather than appointed, with the chairmanship of the board being rotated among members.

4.0 Conclusion

The following conclusions can be drawn from the cost-sharing and related PIM experiences in the Republic of Yemen's irrigation subsector:

- WUAs and ICs could play an important role in rendering (1) services responsive to farmer demands, (2) easier expansion of irrigation coverage, and (3) more timely water delivery, thus matching crop water requirements.
- Farmer participation and cost sharing create a sense of ownership of irrigation schemes, because farmers (1) become more proactive in dealing with emerging problems and in resolving the long-lasting social and technical problems that the government failed to resolve; and (2) start to speak openly about issues that were controversial in the past, such as revisiting water rights that no longer maintain equity between upstream and downstream users.
- Without sound water rights, rehabilitation and improvement of the irrigation infrastructure cannot contribute substantially to improving the equity of water distribution between upstream and downstream users. The relationship between landlords and sharecropper or tenant farmers needs to be clarified in terms of who does what and how much each party should contribute, thus avoiding exploitation of poor farmers.
- The key motivations for farmers to participate in cost sharing and to organize themselves in WUAs are threefold: (1) to provide ex ante public awareness activities—that is, before any physical interventions, which ensures up-front transparency and notifies farmers of the forgone benefits of not opting in to the PIM process; (2) to entrust farmers to participate in the design, implementation, and supervision of O&M activities of the feeder-level (as opposed to trunk-level) irrigation contracts; and (3) to provide ex post public awareness activities—that is, postcompletion of the physical interventions, so that farmers can witness the resultant increase in production and net revenue.
- Beneficiaries' contributions to capital and O&M costs relieve pressure on the government budget and contingent liability.

Notes

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[3] It is extremely difficult (because of cultural/religious reasons) to directly impose a resource conservation charge on groundwater extraction. It has been relatively possible, however, to raise diesel prices and to apply nonpricing demand management instruments. The latter includes peer monitoring of groundwater overdraft and reallocation (by command and control) of spate-water quotas across upstream and downstream farms.

References

The IIP Implementation Supervision Report, November, 2005.

World Bank. 2006. "Local Action: Partnership Approach to Sustainable Groundwater Management in Yemen." An unpublished background paper prepared for contribution to the 4th World Water Forum, "Groundwater Management in the MNA Region," Washington, DC: World Bank.

World Bank. 2005. "Yemen Country Water Resources Assistance Strategy." Technical Report No. 31779-YEM. Washington, DC: World Bank.

World Bank. 2004. "Draft Yemen Water Sector Public Expenditure Analysis." An unpublished report prepared for contribution to Yemen Country Water Resources Assistance Strategy. Washington, DC: World Bank.

6. What Is Common and What Is Specific in Initiatives Aiming to Improve Cost Recovery? A Synthesis of Case Studies

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Jonathan Agwe[2]

Abstract: Technical and institutional approaches aiming to improve cost recovery have several common issues and themes, such as the potential to increase water use efficiency, equity, reliability, and accountability. A key factor is the extent to which these approaches make service to users more reliable and agencies more accountable. Experience shows that farmers are willing to pay water charges when water supplies become reliable. The issue of cost recovery, however, cannot be narrowly considered from a single angle or point of view. The initiatives to get cost recovery to the level that financial and resource sustainability become achievable depend on a broader set of factors, which should be included within a broader reform framework. Full cost recovery could be wishful thinking, but the natural, cultural, economic, and political conditions determine the level of cost recovery that is acceptable and affordable by users in a specific situation. Good policy analyses of the prevailing situation could determine the best alternative, if full cost recovery cannot be achieved. This framework could employ the appropriate technology and institutional arrangement to use the opportunity to its full extent. The World Bank and other development agencies have an important role to play in working with governments to promote initiatives that improve the enabling environment and introduce higher levels of cost recovery. Research centers and the private sector can contribute to developing and adapting technology for the varying situations in developing countries.

1.0 Background

Over several decades, the World Bank adopted the strategy of cost recovery in the water sector as a measure to improve the sector's financial sustainability and conserve a scarce resource in developing countries. In the irrigation and drainage (I&D) subsector, this effort was driven by poor performance of services leading to reduction of the economic and financial viability of the schemes, low income of farmers, wasteful use of the resource, and environmental degradation. The Operation and Evaluation Department (OED) of the World Bank rated the Bank only marginally effective on water user charge issues. This prompted the Bank to launch several strategic initiatives and pursue sector work to improve cost recovery in I&D.

For a relatively long time, the World Bank considered cost recovery as an incentive to improve water resources management and ensuring financial

sustainability of the water sector in its client countries (World Bank 1993). Results, however, were mixed and pointed toward weak implementation, particularly in the I&D subsector (OED 2002). Dinar (2007) noted that the intent to ration water use in agriculture through various cost recovery approaches has invariably been exploited by interest groups whose political agendas pressure and compromise the ability to make significant progress in the irrigation sector. Paradoxically, as political rent-seeking and other multiple challenges take their toll on the need for financial sustainability, cost recovery emerges as a viable and effective mechanism.

OED (2002) noticed that few World Bank operations contain irrigation service-fee components in spite of the strong message to charge for water services sent by the Water Resources Policy Paper (World Bank 1993). The most recent reviews of the Bank's I&D portfolio indicate a slight increase in the number of projects with cost sharing, while the absolute number of projects with pricing and cost recovery components declined (Gambarelli 2006). Nevertheless, the number of projects with any form of cost sharing or cost recovery declined as a percentage of the total number of projects approved between 2002 and 2005. Compared with their desired cost recovery performance levels, the overall net experience of the I&D sector still falls short (box 6.1).

Box 6.1. Problems associated with low cost recovery

Low cost recovery leads to poor services. Management of underfunded schemes results in poor services, and poor services in turn reduce the economic and financial viability of the scheme, reduce farmer income, and reinforce reluctance to pay. In situations in which cost recovery is low, schemes fall back on the government budget, which is often an unreliable source subject to annual appropriations unrelated to need or performance. Decentralization and locally accountable management become difficult because large irrigation management is accountable to its government paymaster. Underfunding of scheme operation and maintenance causes service to deteriorate over time and the government may have to invest in rehabilitation.

Source: World Bank 2006.

With this gloomy picture, comes an attempt to identify success stories, particularly those woven around technological or institutional innovations to improve cost recovery. The four case studies presented in the preceding chapters (Attia 2007; Bastiaanssen and Hellegers 2007; Hatim and Shawky 2007; Nayar and Aughton 2007) shed light on recent practices that made some impact on or opened windows of opportunity for changes to achieve better cost recovery in I&D. Although contemporary technological and institutional advancements have had a positive influence on I&D cost recovery in some countries, knowledge about such experiences is not well known. Although small in number, these four case studies cover a wide range of situations within which lessons can be learned about the drivers of cost recovery (increasing water scarcity and decreasing level of public finance) and the impacts of cost recovery (improving water use efficiency and securing financial sustainability).

The work presented in this chapter is an attempt to identify how far technology and institutions can contribute to improvements in the rate of water cost recovery and their impacts on the overall performance of the I&D schemes. The four case studies that were considered and analyzed to make these conclusions included two case studies on technology and two on institutional arrangements. To make the analyses broader and comprehensive, Bank staff (particularly from the relevant regions) were consulted to discuss the case studies and reflect on the outcomes and determine how the findings could be used to scale up cost recovery in Bank operations.

The four case studies, although coming from different backgrounds and of different natures, do address many common issues and themes that determine their impacts on water resources management and the financial sustainability of the I&D schemes. The debate among experts[3] surrounding these four case studies highlighted additional issues that are linked to and influenced by successful cost recovery practices. They also highlighted the multiple challenges encountered in expanding and scaling up water charging (pricing and cost recovery) in the I&D sector.

This chapter is an attempt to synthesize the findings of the four papers presented in chapters 2 though 5 and the outcomes of the workshop to discuss these case studies. The following sections will lead the reader through the issues that cut across the various cost recovery approaches. The next section summarizes the cross-cutting issues and the strategies that were established to address such issues. This is followed by a section that presents more issues for reflection, including the range of application of the proposed approaches. It integrates reflections from I&D water cost recovery thematic experts and other stakeholders in the context of operational and organizational requirements for the technological and institutional approaches. This section also dwells on the enabling environment necessary to promote these approaches, covers the costs and benefits, and defines the opportunities and limitations for scaling up. This chapter ends with conclusions and suggestions for the way forward regarding I&D cost sharing and recovery.

2.0 Common Issues for Consideration

Although the four case studies presented in chapters 2 through 5 look at I&D cost recovery from different perspectives, they address issues that are common in most or all of the cases. Some cross-cutting issues include the following:

- Accurate or approximate measurements
- Water use efficiency
- Service reliability
- Financial sustainability
- Equity
- Acceptability of payment arrangements
- Sustainability of the cost recovery institutions
- Applicability

In addition to being addressed in the four cases, the importance of these eight issues and themes was alluded to in the introductory chapter. The following sections present a more detailed analytical review of how the four case studies addressed these issues and themes. The issues and themes are equally relevant for this synthesis chapter and are not presented in any order of priority.

2.1 Accurate or Approximate Determination of Water Use

Different mechanisms are used to charge for water delivered by an irrigation system to each farm (Attia 2007; Tsur et al. 2004; World Bank 1993). Volumetric measurements are the most accurate and straightforward method, but they require investment in controls and measuring infrastructure. This implies more cost of the irrigation system, which renders the service more expensive. One technology-based approach—Total Canal Control™ (TCC™)—improves the accuracy of measurement significantly through the use of a combination of control technologies and a central software system (Nayar and Aughton 2007).

Although benefit gains in situations similar to the Australian context offset the extra costs, it is unlikely justifiable in subsistent irrigation situations or feasible in situations in which measuring and monitoring facilities are lacking. Nonmeasurement methods, such as area-based or crop-based methods, provide indirect techniques for setting irrigation charges at nominal additional costs. The choice between the charging methods depends not only on the state of development and modernization in the country or project area but also on the degree of cost recovery established in certain strategy contexts (Attia 2007). Recent application of the remote-sensing (RS) technology in water management has emerged as a promising cost-effective method to monitor water use and improve the accuracy of estimating water delivered to the farms without having to install measurement equipment (Bastiaanssen and Hellegers 2007).

2.2 Water Use Efficiency

Many countries face multiple concerns about the growing water scarcity and its associated conflicts among users and, in some cases, with other countries. As demand grows and supply is constrained, improved water use efficiency and improved water productivity will be increasingly important. Although the biggest share of water resources is consumed by the irrigation sector, use efficiency is generally too low. This inefficiency explains why many countries and development agencies place a greater emphasis on improving water management, with a great deal of attention on agricultural water use (World Bank 2006). The World Bank Policy Paper (1993) recognized that economic incentives encourage consumers to adopt efficient water use practices. It further defined the interrelationship between those incentives and technologies and management approaches to make the use, allocation, and distribution of water more efficient (see box 6.2). Similarly, the Bank's Water Sector Strategy (2004) considers appropriate institutional arrangements to be a key to better cost recovery.

The case studies reported in chapters 2 through 5 strongly confirm this envisioned role of technology and appropriate institutional arrangements. The

Box 6.2. The role of technology and management

An important element of any strategy designed to deal with water is incentives to adopt technologies and management approaches to make the use, allocation, and distribution of water more efficient. Water fees and fiscal incentives can encourage firms to develop more water-saving technologies, including water reuse systems. Such technologies and management approaches make it easier to conserve water, increase the efficiency of water use and conveyance, and reuse wastewater. Similarly, water fees can provide incentives for farmers to shift into crops that use less water.

Source: World Bank 1993.

TCC™ system (Nayar and Aughton 2007) quickly identifies water losses caused by seepage, leaks, escapes and outlets, or theft and makes the correction measures. The system increased water use efficiency by providing irrigators with the incentive to grow higher-value crops. RS-based technology (Bastiaanssen and Hellegers 2007) assesses water use in vast irrigated areas where wells are not metered and quickly provides reliable groundwater abstraction data, which could be used when combined with adequate institutional arrangement to control abstraction and improve water management. Similarly, the establishment of Water Users Associations (WUAs) combined with system improvements increased water distribution efficiency in most command areas by 30 percent to 40 percent (Attia 2007). Additionally, institutional arrangements along with infrastructure improvements were found to be inseparable factors for improving efficiency and adopting recovery of investments and operation and maintenance (O&M) costs in the Republic of Yemen (Hatim and Shawky 2007). Farmers' participation and rehabilitation of the irrigation system allowed better irrigation scheduling and agronomic improvements, adjusted cropping patterns, and improved crop husbandry, which all raise farm returns per cubic meter of water.

2.3 Service Reliability

User willingness to pay for the cost of service depends on the reliability of the service. Even poor farmers are willing to pay when water supplies are reliable (World Bank 1993). Improved technology and institutional arrangements are key factors for better system performance and reliable service provision. The TCC™ technology (Nayar and Aughton 2007) ensures an enhanced standard of service through the modernization of irrigation district canals, which typically involve canal automation, accuracy of metering, minimum losses, and real-time measurements of flow. This results in greater reliability for water delivery to irrigators. With the RS approach (Bastiaanssen and Hellegers 2007), service reliability could be ensured with information on groundwater abstraction and use, which could be assessed retrospectively. Irrigation system improvement and establishment of WUAs eliminated direct pumping from secondary canals by nearby farmers, because these farmers had a reliable continuous supply. This, in turn, improved reliability of water supplies to canal tail-enders. It also reduced excessive irrigation, which caused

waterlogging and salinization (Attia 2007). Similarly, in the Republic of Yemen, irrigation system rehabilitation and user participation in decision making increased service responsiveness to farmers' demands (Hatim and Shawky 2007).

2.4 Financial Sustainability

An important objective of economic incentives that include water charges and cost recovery is to ensure financial sustainability of I&D projects. Performance of I&D infrastructure that depends on public finance usually declines because of deferred maintenance caused by a lack of funding. In the four case studies, several indications were made regarding the impact of the technology and the institutional options they considered to achieve financial sustainability. The technology-based approaches employ such methods as the sale of water savings to irrigators and government environmental agencies as well as conventional cost recovery through infrastructure charges to recover the investment cost (Nayar and Aughton 2007). To maintain financial stability, TCC™ irrigation districts in Australia have well-established frameworks for cost recovery and active water markets. The RS technology explores economies of scale whereby, because of fixed costs per region, costs per hectare decrease with the size of the irrigated area and thus decrease cost of monitory and evaluation (Bastiaanssen and Hellegers 2007).

In the Republic of Yemen, where the government underwent budgetary reforms, there was a need to improve farmers' self-reliance on financing and to maintain spate irrigation systems. New institutional arrangements introduced financial autonomy for the irrigation subsector within a legal and institutional framework that empowers farmer organization (Hatim and Shawky 2007). User participation was behind the establishment of a credit facility for use by farmers (community cost sharing) for up-front contributions toward achieving water-saving and financial stability objectives. The facility's expected interim and far-reaching impacts include the reduction of the government's budgetary burden, as well as the reduction of transaction and overhead costs. Maintaining financial sustainability with institutional approaches in the Arab Republic Egypt requires the collection of branch canal O&M costs, where farmers' ability and willingness to pay are key factors for cost recovery. The agreement of stakeholders to pursue cost recovery depends on the benefits they perceive from the recovery system (Attia 2007). The provision of a legal framework empowered the WUA to collect fees and establish a special fund financed by the recovered investment costs, which are used to finance future investment work. Establishing full cost recovery arrangements between the government and farmers or other private investors in newly irrigated lands is part of the Egyptian government's vision to achieve fiscal sustainability of the water sector (World Bank 2005).

2.5 Cost Recovery and Equity Issues

Seagraves and Easter (1983) mentioned that equity concerns include recovery of costs from users, subsidized food production, and income redistribution. Pricing polices may provide the most effective and equitable means to redistribute income between heterogeneous water users and sectors (Tsur et al. 2004). Thus,

technologies and institutional arrangements that improve cost recovery should contribute toward achieving equity among the users of the same system. Technologies that improve the accuracy of metering the water delivered to users result in greater equity among customers in terms of cost recovery, providing them with the confidence that all users are being treated equally in terms of sharing water availability and costs.

Among the case studies, the TCC™ technology (Nayar and Aughton 2007) provides the means for better control and metering of water deliveries, which gives the farmers equal opportunities to receive and pay for their water consumption. In contrast, the RS technology (Bastiaanssen and Hellegers 2007) helps assess vast irrigated areas where wells are not metered and thus provides reliable groundwater abstraction data, allowing fair charging for water use. Although it is technically feasible, the RS-based approaches have not been used yet for cost recovery purposes by irrigation agencies. It is expected that because of the low cost, independency, and reliability involved in this approach, RS has great potential for future use in large irrigated schemes.

With the institution-based approaches, cost recovery as applied in Egypt (Attia 2007) brought equity to tail-end and head-end canal users. Inequity between these users had been a chronic problem before the irrigation system was improved and management was transferred to WUAs. Cost-sharing and water user participation in the Republic of Yemen enhanced interfarm and interbeneficiary equity (Hatim and Shawky 2007). Sound water rights, rehabilitation and improvement of the irrigation infrastructure, and improved institutional arrangements contribute substantially to improving the equity of water distribution between upstream and downstream users.

2.6 Acceptability of Payment Arrangements

As mentioned earlier, farmers expect to pay their share of water charges and the related paying arrangements when they have reliable service and equitable treatment. The conversion of water from distribution loss to productive use in Australia has been particularly important to maintaining farm incomes in the district, thereby improving the ability of irrigators to pay for the infrastructure services provided (Nayar and Aughton 2007). Benefits from the TCC™ approach accrue to the different stakeholders of the water supply business and to the irrigator. Farmers became responsible for ordering the water they require, and the system responded efficiently to their demands. End users of the RS technology include a targeted set of stakeholders that would benefit from this information, such as irrigation districts, irrigation service delivery agencies, river basin authorities, and catchment's management agencies (Bastiaanssen and Hellegers 2007). Responsibilities among stakeholders begin with their identification and recognition of their interests and priorities and their role in decision making. In the case of conflict and distrust among water using groups, the RS technology provides proof of actual abstractions that cannot be manipulated, which excludes fraud. This helps farmers to confidently accept the charges based on the information provided from the satellite imagery. The Egyptian experience shows that gradually and sequentially introducing the concepts of irrigation improvement and cost

recovery with full user participation helped to build confidence and gain acceptance among users (Attia 2007). The establishment of WUAs and their participation in decision making increased farmers' sense of ownership and their willingness to share and pay.

2.7 Sustainability of Cost Recovery Institutions

A range of different governance models exists for irrigation institutions, including the following: (1) government-owned corporations (GOCs) with separate capital bases, independent revenue streams, and professional management; (2) private companies; and (3) irrigation cooperatives. Water user organizations and water boards represent the beneficiaries of the irrigation system. They operate for their own benefit and as organizations working in the field of water use, distribution, and related activities to raise agricultural productivity. Because of the formation of user organizations and the reformation of irrigation agencies, there are tests and replicable models for the sustainable self-management of local water resources by poor farming communities. Legislation is essential to empower user participation because private organizations are owned and operated by members of the watercourse associations.

The success of the TCC™ technology in Australia depends on robust corporate governance, including fully audited annual financial reporting, professionally developed asset management plans, expertise-based boards of directors, and obligations to achieve appropriate levels of financial risk management (Nayar and Aughton 2007). These elements collectively let the TCC™ operate with a high degree of financial autonomy from the government. The TCC™ relies primarily on revenue generated by selling saved or recovered water through charges billed to irrigation users. With the TCC™ technology-based approach, private companies function at arm's length from the government, sourcing the majority of their revenue base from the scheme's users. These companies are clearly accountable to their shareholders for the financial and operational performance of the irrigation system. Where the TCC™ operates, a set of laws and administrative regulations, with a register of water rights that is maintained by the government, provides legal certainty over the existence of the rights.

The Egyptian government is exploring alternative cost-sharing arrangements with decentralized service delivery institutions and the implementation of a progressive turnover of O&M to water user organizations as measures for sustainable institutional arrangements for cost recovery (World Bank 2005). District Water Boards and Integrated Water Management Districts are two new institutions being tested to implement this vision. Information and accounting system improvements are essential to extend cost recovery to higher levels (Attia 2007). A legal framework was issued in 1984 and amended in 1995 to authorize the establishment of WUAs; this framework permits the recovery of the investment cost.

In the Republic of Yemen, the new initiative brought in by the World Bank project fosters collaboration between government and water users groups to improve cost recovery. The new approach introduces financial autonomy for

the irrigation subsector within a legal and institutional framework that empowers farmer organizations and conducts comprehensive awareness programs. In the community cost-sharing approaches used in the Republic of Yemen, informal private sector and market mechanisms are recognized for irrigation water sales to water tankers and water sales between farmers. The government is working to improve groundwater governance and issued a 2003 water law that defines water rights and establishes a regulatory system of permits.

2.8 Applicability of Approach in Developing Countries

Regarding technology-based approaches, TCC™ includes a staged implementation of irrigation systems in less developed countries with an explanation of how this implementation could assist in the drive to implement cost recovery in developing countries. This approach needs to be tested in a practical situation. It is feasible to transfer RS technology to developing countries, but local universities with expertise are needed to validate the data. Regarding institution-based approaches, farmers have to participate and share in recovering all or part of the costs spent in the system O&M. Water service fees, such as volumetric water charging (water pricing), would not be economically, socially, or politically feasible in certain areas. The community cost-sharing approach promotes WUAs that integrate all water users, from big well owners to those who own no resources, on the basis of common responsibility. This approach presents a potentially high case for applicability in low-income countries.

3.0 Summary of the Analysis

The extent of coverage and implementation of the eight issues and themes listed above varies according to the novelty of each approach and the time elapsed since the initiative was launched. Table 6.1 summarizes the level of coverage of each theme by each case study. The matrix tabulates the content as relevant to each case. There is no inference nor subjective interpretation of what is not explicitly stated in the cases. The commonality of themes is presented, but there is little or no expectation that the different cases would cover the same kind of issues. This kind of analysis is required to provide answers to the questions posed for reflection in the following section. The list of issues is presented to stimulate further reflection and thinking. The levels of coverage of the common issues are depicted by the number of Xs (ranging from one to three Xs). Themes that include elaborated features are denoted with a greater number of Xs.

A glance at table 6.1 and the earlier discussions reveal potential trends in the technology- and institution-based approaches to I&D water cost recovery and highlight how each case study treats the themes and their features. For example, technology-based approaches are more private sector oriented and cover cost recovery requirements for issues of efficiency, sustainability, and accountability to improve the company owners' value. The elements covered gravitate toward for-profit-related interventions and, in some cases, seem to be less appropriate for the poor. Conversely, the institution-based approaches appear to be more oriented toward user participation and cover issues of

Table 6.1 Assessment of Level of Theme Coverage in the Four Case Studies

Theme/Issue	Coverage in the Technology-based Approaches		Coverage in the Institution-based Approaches	
	Total Canal Control™ (Australia)	Remote Sensing (Mexico, Pakistan, and Saudi Arabia)	Promoting User Participation (Egypt, Arab Repub. of)	Experiencing Community Cost Sharing (Yemen, Republic of)
1. Accurate/approximate measurement of water use	XXX	XXX	X	X
2. Water use efficiency	XXX	XX	XX	X
3. Service reliability	XXX	XX	XX	XX
4. Financial sustainability	XXX	XX	X	X
5. Cost recovery and equity issues	X	X	XXX	XXX
6. Acceptability of payment arrangements (stability)	XXX	X	XX	X
7. Sustainability of cost recovery institutions	XXX	X	XX	XX
8. Applicability in developing countries	X	X	XXX	XXX

Source: Authors.

equity for poverty reduction through I&D water cost sharing. Their strength seems to be in enhancing the equity function. Institution-based approaches are more readily applicable in developing countries. Infrastructure improvements are essential, however, if institutional arrangements are to work successfully.

4.0 Synthesis of Issues

The analytical overview presented in the previous section provides a consolidated set of issues that form the basis for integration and synthesis. The following perspectives and questions were revealed by the analytical work.

4.1 The Different Perspectives

From the technology perspective: Promising advances in technology improve information accuracy about water consumption and enhance opportunities to improve water use efficiency and service reliability. These advances help to improve the methods to charge for the services, which results in financial sustainability. Because some new technologies are still in their infancy, they are prone to problems with practical application, affordability, ability to use and maintain, and user confidence. Over time, new technologies could be

improved and become more affordable and user-friendly. Technological contributions to improve cost recovery would be one by-product among many other benefits in water resources management.

From the institutional perspective: Ensuring financial sustainability of the I&D sector is a growing concern and cost recovery is an important mechanism for its realization. Governance and institutional arrangements that promote user participation and empowerment are prerequisites to successfully implement cost recovery policies. Establishment of user organizations combined with infrastructure improvement and rehabilitation provide a sound basis and good incentives to implement cost recovery. Scaling up of cost recovery to higher system levels and to nonagricultural users requires efficient information and accounting systems.

From a broader and more general perspective: There are several models and mechanisms to apply cost recovery, and choices for a specific situation should address economic and social dimensions as well as pay special attention to poverty. In developing countries with a long history of central government dominance, extra time and effort are needed to encourage reforms that allow farmers to participate in management, contribute to investments, and pay for the O&M costs. It is rather an evolutionary process.

4.2 Guiding Questions

How far has the objective of exploring the effect of technology and institutions on improving cost recovery been realized? In broader terms, how far have they come to improve water resources management and sustain its financing? A synthesis of the common themes and issues, along with the outcome of discussion among experts, may provide the answers to these questions. To provoke such feedback, the following questions were proposed. Although the questions are not comprehensive and do not fully cover the scope of the study, they were a starting point. They questions are as follows:

Affordability: How can modern technologies become pro-poor (affordable) and more user-friendly to support and improve cost recovery in I&D in developing countries?

Applicability to World Bank operations: What are the modifications and adjustments that could be explored to make the proposed technical and institutional approaches more applicable to the World Bank's operations?

Improved cost recovery: Did the case studies determine whether technology and institutions could improve cost recovery in I&D projects?

Scaling up: What recommendations and advice could be given to scale up proposed approaches by promoters of the innovations presented through the different approaches; end users; and the World Bank staff?

4.3 The Synthesis

The cross-cutting issues highlighted in the four case studies and the deliberations among experts were explored to generate answers to the proposed questions. Discussions among experts went beyond the four questions

and included broader objectives as well as scope of cost recovery in I&D. Paradoxically, while synthesizing, more questions unfolded than answers to the questions posed. Although these new questions remain to be answered, some elements have been identified for integration and synthesis. They are presented as follows:

The context: Although cost recovery is an important strategic element in improving I&D management, it was suggested that it is important to question first the prevailing conditions underlying each situation. For example, should costs recovered include inflated office administration costs and excessive investment costs that result from prior neglect of infrastructure maintenance? Or, should it be introduced in the context of overall policy and institutional reform package?

The level: It was proposed that discussion on cost recovery should be more specific about the targeted level of the irrigation system. Because any I&D costs can be disaggregated along the lines of the headwork, main canals, diversion infrastructures, distribution canals, and on-farm systems, it is important to identify which system level is targeted for cost recovery. Furthermore, it is important to know whether cost recovery targets only the infrastructure expenditure (financial objective) or the broader water resource management improvement (water use efficiency objective).

Data accuracy: Is there a need for perfectly accurate measurements of water volumes delivered? If so, what is an appropriate level of measurement accuracy? Should cost recovery be based on factors that are highly "economically correct"? If so, are there any agreed benchmarks for cost recovery?

Land tenure: It was suggested that cost recovery for irrigation services, at least for the investment cost component, should be linked to land ownership. This prompted the need to issue land titles as part of the reform process to promote accountability through confirmed ownership.

Cost of technology: Although the modern technologies involve potential improvement of cost recovery, their cost cannot be justified only for this purpose. Technologies such as TCC™ are better suited to middle-income countries and above rather than to low-income countries. This is possible when the incremental cost of adopting a modernized system is generally small and users are able to pay for it, given the higher income expected from better water delivery and higher productivity. More realistically, the rationale for using or scaling up relatively expensive technologies could be made on the merits of service improvement and water saving.

Volumetric pricing: Although some discussions recommended that volumetric pricing should be pushed in all situations, doubts were raised about the effectiveness of volumetric pricing, particularly in terms of achieving demand management objectives.

Full cost recovery: The rationale for full cost recovery from irrigators was questioned. When discussing cost recovery, not only incremental cost of system modernization as well as operating costs (such as energy) should be considered but also the costs to repair or replace damaged structures and

equipment, environmental costs, and so on. In some situations, an important feature that must be given attention is the risk of vandalism and its related costs. If all these costs are included, then cost recovery may not be affordable in all cases. The "principled pragmatism" approach promoted by the Water Sector Strategy (World Bank 2004) applies well in this case. Solutions should be tailored to the specific cultural, economic, and political circumstances.

Technical assistance: Technical assistance for building capacity for cost recovery is important and should be ensured not only during project design and implementation but also during the post-project operation phase.

Capacity building: Approaches to improve cost recovery require certain skills to use and operate the systems, especially in situations in which new technologies are proposed. Local capacity should be sufficiently improved to use technologies and institutional arrangements to avoid hiring consultant services every time a new technology is used (for example, for the implementation of RS-based approaches). It is extremely difficult to introduce new institutional arrangements that change long-standing practices that are part of the local culture and way of doing business. Acceptance of new arrangements requires special capacities that can deal with this challenge.

Standardization: With respect to the introduction of new technology, it was recommended that standard methods and equipment be used without trying to save costs through using cheap copies or homemade products. Otherwise, the risk of failure would be multiplied.

In summary, the synthesis reveals that country-specific circumstances may be responsible for determining the modalities for I&D water cost recovery. A balanced combination of technological and institutional capacity will lead to agreement among stakeholders about appropriate cost recovery approaches. The 10 elements of the synthesis pose additional questions, which demonstrate the need for I&D water cost recovery to be explored further, because cost recovery affects water use stakeholders differently across societies. For example, societies that consider water as a natural gift (a public good) would respond to the concept of cost recovery differently than those that consider water to be a commodity for wealth generation.

5.0 Conclusion and A Way Forward

Cost recovery in I&D is still a work in progress. It is part of a bigger policy and institutional reform package that has achieved varying degrees of success in many countries around the world. Basic irrigation sector reform and improvement initiatives (management transfer, decentralization, modernization, and so on) help to improve the implementation of cost recovery. The four case studies and the expert discussions are indicators of the complexity involved in establishing certain cost recovery strategies. They confirm, however, the dynamics in the sector toward accelerating the pace of reform, including cost recovery. Innovations and success stories similar to those reported here would also motivate the I&D community and the concerned governments to make the right choices and seek answers to those unanswered questions. The role of the World Bank and the rest of the development

community is to act as brokers and agents to promote reforms and provide support and incentives to those who are willing to move forward and make changes.

Technology and institutions are two important factors for advancing cost recovery as much as they are able to improve service delivery, reliability, and equity among irrigators. The willingness of farmers to pay is a function of these three parameters. The four case studies reported in this document are typical examples. More cost recovery is achievable when suppliers become more accountable to users and, as a result, charging for services becomes a principal tool to ensure mutual obligations. The more cost recovery is realized, the more financial and resource sustainability can be achieved. The implication from the point of view of financial cost recovery is to promote an institutional framework in which service providers are accountable and efficient (World Bank 2006). Experience shows that user participation and irrigation system improvements are prerequisites to make this happen. This is where institutions and technology play their vital role and complete the circle. This reform circle can stop the vicious circle of public finance deficiency, deferred maintenance, costly operation, and poor performance.

To move from wishful thinking to the reality of achieving full cost recovery, solutions need to be tailored to specific, widely varying, natural, cultural, economic, and political circumstances. Artful reform accepts and achieves this possibility (World Bank 2004). Objectives must be clear, and governments must set their priorities to design appropriate service charges that meet financial and efficiency objectives. Ultimately, someone has to pay for these services. Given the multiple public benefits of I&D (for example, food security, economic growth, poverty reduction, social and environmental development benefits) and the cultural attitudes toward the public nature of water, governments should consider paying for the cost of I&D at the level of the headworks and main infrastructure. They should consider subsidizing technologies that lead to improved water management and water saving. At the lower level of water supply to the farms, farmers should contribute their fair share, following the "user pay" principle that those who directly benefit from investment and scarce resource should pay. This will achieve the double benefits of increasing revenues and signaling opportunity costs. If constraints mean that a full cost recovery policy cannot be introduced, then an alternative needs to be clear. Cost sharing is one such alternative. It is important to be clear about who is paying for what and to ensure commitments. The ability to pay will determine this share, which likely will range from 5 percent to 30 percent of net revenue (Attia 2007; World Bank 2006).

The fact that more questions are generated than answers can be supplied demonstrates the need for more comprehensive policy analysis, research, and testing of options under practical conditions. The process should start with an analysis of the full range of services and benefits produced and should allocate project costs among all beneficiaries, including those outside the irrigation and drainage scheme who would benefit from positive externalities (Abdel Dayem et al. 2004; World Bank 2006). Research needs to focus on the types of technology, particularly those most appropriate for the poor. A key area to pursue is the

adaptation of technology to become affordable and adequate to conditions in low-income countries. The challenge will be to promote partnerships between research institutions and the private sector to bring research and technological innovation to the needs of smallholders in developing countries. The Bank should push for a bigger lending share for technical assistance because the budget for such assistance for cost recovery is lacking in many Bank I&D projects. Although the World Bank increased its role in advancing the reform agenda in the I&D sector, a greater effort is needed in the vital area of technical assistance to build capacity for improved cost recovery.

Finally, some unanswered questions remain. This indicates that the file of cost recovery is not closed and more work is required. At the same time, the available knowledge base and lessons learned from past experience and recent innovations pave the way for greater progress to implement cost recovery in the I&D sector.

Notes

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[3] A one-day workshop was organized by ARD on June 9, 2006, to share the knowledge brought in by the four case studies and discuss their applicability in future Bank operations.

References

Abdel Dayem, S.; Hoevenaars, J.; Mollinga, P.; Scheumann, W.; Slootweg, R.; and van Steenbergen, F. 2004. "Reclaiming Drainage: Toward an Integrated Approach." Agriculture and Rural Development Report 1, World Bank, Washington, DC.

Attia, Bayoumi. 2007. "Cost Recovery in the Irrigation and Drainage Sector: User's Participation as a Mechanism for its Promotion." In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington, DC: World Bank. Paper presented at one-day workshop on the "Cost Recovery Assessment Study in Irrigation and Drainage Systems," World Bank, Washington, DC, June 9, 2006.

Bastiaanssen, W.G.M., and P. J.G.J. Hellegers. 2007. "Satellite Measurements to Assess and Charge for Groundwater Abstraction (Draft)." In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank. Paper presented at one-day workshop on the "Cost Recovery Assessment Study in Irrigation and Drainage Systems," World Bank, Washington, DC, June 9, 2006.

Dinar, A. 2007. Cost Recovery of Irrigation and Drainage Projects: Wishful Thinking or Difficult Reality? In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank.

Gambarelli, G. 2006. "Review of Agricultural Water Projects' Quality at Entry (FY02-05 portfolio)." Agriculture and Rural Development Department, World Bank, Washington, DC.

Hatim, N.A., and A. Shawky. 2007. "Advancing Irrigation Cost Recovery in the Republic of Yemen: A Community Cost-Sharing Approach (Draft)." In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank. Paper presented at one-day workshop on the "Cost Recovery Assessment Study in Irrigation and Drainage Systems," World Bank, Washington, DC, June 9, 2006.

Nayar, M., and D. Aughton. 2007. "Canal Automation and Cost Recovery—Australian Experience Using Rubicon Total Channel Control(TM)." In *The Role of Technology and Institutions in Cost Recovery of Irrigation and Drainage Projects*, ed. Ariel Dinar, Safwat Abdel Dayem, and Jonathan Agwe. Washington DC: World Bank. Paper presented at one-day workshop on the "Cost Recovery Assessment Study in Irrigation and Drainage Systems," World Bank, Washington, DC, June 9, 2006.

OED. 2002. "Bridging Troubled Waters: Assessing the World Bank Water Resources Strategy." World Bank Operation and Evaluation Department, Washington, DC.

Seagraves, J.A, and Easter, K.W, 1983. Pricing Irrigation Water in Developing Countries. Water Resources Billetin, 4, 663–671.

Tsur, Y., T. Rooe, R. Doukali, and A. Dinar. 2004. "Pricing Irrigation Water: Principles and Cases from Developing Countries. Resources for the Future." Washington, DC.

World Bank. 2006. "Reengaging in Agricultural Water Management: Challenges and Options." Direction in Development. Washington, DC: World Bank.

World Bank. 2005. "Cost-Effectiveness and Equity in Egypt's Water Sector." Egypt Public Expenditure Review. Policy Note 3, Social and Economic Development Group, Middle East and North Africa Region. Washington, DC: World Bank.

World Bank. 2004. *Water Sector Strategy*. Washington, DC: World Bank.

World Bank. 1993. "Water Resources Management." A World Bank Policy Paper. Washington, DC: World Bank.