Financing Water Management and Infrastructure related to Agriculture across OECD Countries

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 30 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities takes part in the work of the OECD.

Financing Water Management and Infrastructure related to Agriculture across OECD Countries

FRANK A. WARD

NEW MEXICO STATE UNIVERSITY
LAS CRUCES, UNITED STATES OF AMERICA

Note

This document, *Financing Water Management and Infrastructure related to Agriculture across OECD Countries,* by Frank A. Ward, of New Mexico State University, Las Cruces, United States, is one of the background reports supporting the OECD study (2010) *Sustainable Management of Water Resources in Agriculture,* which is available at www.oecd.org/water.

The report was carried out under the auspices of the OECD Joint Working Party on Agriculture and the Environment of the Committee for Agriculture and the Environment Policy Committee. **The report is published under the responsibility of the author and does not necessarily reflect the views of the OECD or its member countries.**

The other background reports (also available at www.oecd.org/water) are:

An Economic Analysis of the Virtual Water Concept in Relation to the Agri-food Sector
Dennis Wichelns, Hanover College, United States
http://dx.doi.org/10.1787/786736626756

Agriculture's Role in Flood Adaptation and Mitigation – Policy Issues and Approaches
Joe Morris, Tim Hess and Helena Posthumus, Cranfield University, United Kingdom
http://dx.doi.org/10.1787/786804541573

Environmental Effectiveness and Economic Efficiency of Water Use in Agriculture: The Experience of and Lessons from the Australian Water Reform Programme
Michael D. Young, University of Adelaide, Australia
http://dx.doi.org/10.1787/786732081512

Agricultural Water Pricing: EU and Mexico
Alberto Garrido, Universidad Politécnica de Madrid; and
Javier Calatrava, Universidad Politécnica de Cartagena, Spain
http://dx.doi.org/10.1787/787000520088

Agricultural Water Pricing in Japan and Korea
James E. Nickum and Chisa Ogura, Asian Water and Resources Institute, Japan
http://dx.doi.org/10.1787/787011574235

Agricultural Water Pricing in Turkey
Erol H. Cakmak, Middle East Technical University, Turkey
http://dx.doi.org/10.1787/787034266022

Agricultural Water Pricing: Australia
Seamus Parker, Council of Mayors (South-East Queensland); and
Robert Speed, Freelance Consultant, Australia
http://dx.doi.org/10.1787/787105123122

Agricultural Water Pricing: United States
Dennis Wichelns, Hanover College, United States
http://dx.doi.org/10.1787/787165082115

Table of Contents

1. Executive Summary

Many irrigated areas in the OECD countries face the problems of aging infrastructure and a declining revenue base from which to finance and sustain maintenance and repair activities. The drive toward full cost recovery arising from water reform policies around the OECD means that both water suppliers and farmers will need to evaluate infrastructure repair, maintenance, and renewal to remain viable (Bear, *et al.* 2006). Answers to a range of questions on irrigation infrastructure maintenance turn on which parts of the system can be maintained and on the consequences of a loss of function due to poor maintenance of any part. Dams, canals, and related structures should have sufficient capacities, and should be able to assure required water levels. Drainage systems should also have sufficient capacities to secure a desired level for water distribution. Proper maintenance requires information on the characteristics of the system and its elements and an understanding of which functions each contributes. Such a data base is necessary for adequate monitoring, planning, execution and control of maintenance, for cost effectiveness of the work and for its cost recovery.

This report examines the economics of irrigation projects. It identifies economic principles governing infrastructure investments for irrigated agriculture and identifies factors leading to increased demand for investment in irrigation infrastructure. It also examines both market and policy approaches that would promote rehabilitation of irrigation infrastructure and identifies needs for better information to support analysis of the economics of irrigation infrastructure improvement.

The report reviews economic factors that influence investments to maintain, renew, and sustain off-farm irrigation infrastructure, such as dams, canals and other conveyance facilities. Five factors are identified that can promote high levels of investment in irrigated agriculture. These include water pricing based on ability to pay as well as cross subsidies in which prices charged to other water users such as hydropower are used to finance irrigation development. A third factor comes from pricing irrigation water below its marginal cost of supply, which raises the demand for irrigation water and its supporting infrastructure. A fourth comes from allowing irrigators to renegotiate water supply contracts after irrigation projects are built and the water flowing. The fifth results from the incentive to invest heavily in irrigation when farmers believe they will secure a water right from use of the developed water. Next, five additional factors are identified that raise the economic value produced by irrigation infrastructure. These include a reduced price of water charged to farmers, a reduced real cost of repairing, maintaining, or improving infrastructure, a greater quantity of water saved from infrastructure maintenance, higher crop yields produced by saved water, and a lower cost of capital.

Several market approaches have the potential to influence the economic attractiveness of investments in irrigation infrastructure. These include subsidies of infrastructure, clear titles to water rights that promote market transfers of water, marginal cost pricing of water, and accurate accounting for the impact of water losses on farm income. Several policy approaches are also discussed. These include various legislative enactments requiring upkeep and maintenance on infrastructure, transboundary agreements, and water users= associations.

Barriers posed by poor data on the economics of irrigation infrastructure need attention. There are considerable needs for improved information in order that economic principles are put to best use in ensuring orderly maintenance of irrigation infrastructure. Information is needed on cost sharing arrangements between irrigators and public suppliers of irrigation, impacts on water savings at both the project and basin scales from infrastructure improvement. Good data combined with judicious use of economic principles have considerable potential to productively inform decisions on why, when, and how to develop, restore, and sustain irrigation and its infrastructure.

2. Background, Scope, Policy Debates, Objectives

The 30 OECD member countries have considerable diversity in their water demand and supply patterns. Water resources in eight member countries are subject to high water scarcity; in another eight water availability is a growing a constraint on development. Significant investments are needed to ensure adequate and safe water supplies. Other OECD member countries, though water-rich on a national scale, have large dry regions where the potential for future economic development is limited by water scarcity, made worse by recurrent droughts. A major challenge for sustainable water development and use in the OECD countries is improving the integration of environmental aims into water sector policies (OECD, 2003).

The OECD countries are the world's major food suppliers. Projected increases in OECD cereal, meat and milk production are likely to occur primarily in Australia, Canada, Mexico, New Zealand, Turkey and the United States. Much of the projected expansion in OECD farm production is likely to originate from raising yields rather than expanding the area cultivated (OECD, 2008). An important goal of agriculture for OECD is and safe food to meet the needs of a growing world population, while reducing environmental costs of agricultural production. Important challenges include internalizing environmental externalities in agriculture, promoting marginal real cost pricing to reduce environmental costs of agriculture and secure its environmental benefits. A related challenge is to increase the efficiency of water use and irrigation systems in areas experiencing growing water scarcity (OECD, 2001).

Despite the growing importance of irrigated agriculture to support food security around the world (United Nations, 2006), numerous studies show inadequate investment in the maintenance of irrigation water application and delivery systems, which can lead to water waste and leakages in many countries (Snell, 2001; Akkuzu, 2005; Aldakheel, 2007; Farmani, 2007; Mvungi, *et al.*, 2005). Some studies estimate losses of up to 25% for delivery systems, as much as 20% from on-farm pipelines, and a further 10- 15% lost from inefficient water application technologies (Parris and Legg, 2006; Snell, 2001). Some of these losses leach back into the environment, although some can transport pollutants, such as salts, into water bodies. Information is poor across OECD countries on the current levels and future needs for financing water management and infrastructure related to agriculture. The total costs for maintaining and modernizing the existing water delivery systems to farms is likely to be considerable. This is because of the need to address widespread leakages and losses from water delivery systems both on and off the farm. For the most part, few contingencies have been made for infrastructure renewal partly because publicly owned irrigation systems have only charged farmers for O&M costs and not capital renewal costs. In the face of increasing transfers of water infrastructure operation and maintenance from government to farmers or irrigation districts, this transfer of ownership raises questions about future sources of financing (Simon, 2002). The transfer of financial control and investment management into private hands may require farmers to seek private-public partnerships to raise capital to renew irrigation infrastructure (Parris, 2008). This is likely to be even more difficult in the current economic situation and credit crisis.

Irrigated agriculture in the OECD countries faces increasing pressure to transfer water to nonagricultural uses, including instream flows for fish and wildlife management (Peck, *et al.*, 2004). Improving the performance of irrigation projects including irrigation infrastructure maintenance can be an economically viable way to meet growing water demands and sustain productivity of irrigated agriculture (Howell, 2001; Islam, 2008; Renault, 2000; Rodriguez, *et al.*, 2006; Schoups, *et al.*, 2006; Alvarez *et al.*, 2005). Extreme events like droughts and floods as well as longer term outcomes of climate change provide more challenges (OECD, 2009). Both public and private infrastructure improvement options are possible (Svendsen, et al, 2003). A recent report concluded that the choice between public and private infrastructure supply should be based on cost-benefit analysis (OECD Council, 2007).

There have been a number of recent efforts to examine the performance of irrigation and its associated infrastructure in the OECD countries. For example the Spanish National Irrigation Plan (PNR) aims to help irrigated agriculture by supporting restoration of old infrastructure. Some of the program's aims include water savings, increased efficiency in water management, improved water quality, adoption of improved irrigation technologies, and increased competitiveness (Barbero, 2005). A recent study conducted in Italy identified economic, social and environmental indicators for the country's irrigated farming systems aimed at identifying impacts of various water conservation policies on sustainability (Bartolini, *et al.*, 2007). Water used for irrigation in the Netherlands is less common than in southern Europe. Still, Dutch agriculture faces challenges related to water quality especially for diverse activities in small geographic areas (Batterink, 2005). Much work in Australia has examined the economics of irrigation. A 2008 study there examined the costs and benefits of engineering investments in irrigation infrastructure to address anticipated salinity growth in Australia's River Murray. The analysis accounted for salinity impacts, time delays in benefits, and marginal cost pricing of water over a 100 year time horizon. Results showed that improved infrastructure can substitute for reduced water quality (Connor, 2008). More recent work there has examined the economic feasibility of greater on-farm irrigation infrastructure (Lisson *et al.*, 2003; White et al, 2006). A 2009 study in Greece examined the economic importance to rural economies in that country from water resource development (Sofios and Polyzos, 2009).

A 2003 Spanish study found that groundwater accounts for more than half of the total economic value of irrigated agriculture in that country while only consuming 20 percent of its total volume of water. Results show how infrastructure improvement can substitute for limited groundwater supplies (Cortina and Hernandez-Mora, 2003). A 2001 work from Portugal described the development of a decision support system to improve management of a large irrigation project in the Alentejo region of that country (da Silva, *et al.*, 2001). An analysis of irrigation in New Zealand found that irrigation contributes about 11 percent of the country's income while using less than 1% of its total water supplies. However, water is facing growing scarcity in parts of that country and there are growing demands for competing uses outside agriculture, especially for securing streamflows to support key environmental assets. In 2003, New Zealand established its Water Program of Action to promote improved freshwater management (Doak, 2005). Another analysis in New Zealand examined water transfers as a way to address growing water scarcity in the country (Lange *et al.*, 2008). One way this scarcity is being examined in New Zealand is to consider upgrading existing water infrastructure as a cheaper method to address water scarcity that provides nearly the same benefits as building ne**w** infrastructure. Some works have looked at water management options for groups of OECD countries. For example a 2002 study compared water institutions in 15 EU countries. Institutions such as basin administrations, water management associations, and private and co-operative facilities were found to have an increasing role to play in managing Europe's waters (Dirksen, 2002).

One information source on the scale and financing of irrigation infrastructure investments in the U.S. comes from the 100 year experience of the federal Bureau of Reclamation (Reclamation). Most large dams and water diversion structures in the American west were built by, or with the assistance of Reclamation.[1] Today, Reclamation's infrastructure provides water to 31 million people and provides irrigation water for 10 million acres of farmland that produce 60% of U.S. vegetables and 25% of its fruits and nuts. With U.S. population continuing to move west, the need for secure infrastructure to deliver greater quantities of water in future is growing. Reclamation reported in 2008 that its current infrastructure systems are in generally good condition. But it acknowledged that the long-term trend would show some decrease in reliability of its facilities in 2009. Reclamation acknowledges that it faces approximately $3 billion worth of rehabilitation needs for its aging infrastructure over the next 20 years. The agency determined in FY 2007 that 99 percent of its facilities met those standards. They stated that the reliability index may fall below 90 percent in FY 2009 and later. Much of Reclamation's current infrastructure is now 50 or more years old, and its proper operation and maintenance are important to the sustained delivery of water services.

At the inception of the reclamation program the philosophy was that all reclamation project costs should be repaid in full except interest on construction costs. However early reclamation cost-sharing policy resulted in repayments to the government falling short of planned levels. This led to a series of changes in the repayment provisions culminating with legislation in the 1930s that completely revised reclamation policy from total repayment of construction cost to repayment of those costs based on ability to pay basis. Since that time, charges for Reclamation supplied irrigation water have generally not been required to reflect the construction cost of water supply. Consequently, there has been a growing concern with the degree to which reclamation irrigation projects are subsidized, giving rise to an associated weak economic use of public resources.[2]

There have been other studies on economics of irrigation in the OECD countries.[3] A recent study from Italy examined measures to promote sustainable irrigation in Italy through use of economic optimization analysis. Results showed that for annual crops, water pricing saves water while weakening cost recovery because of price-elastic water demands. Water pricing there was found not to save water because of an inelastic demand but pricing would promote cost recovery (Bazzani, 2005). A 2000 study conducted in Spain applied farm income maximization analysis to several Spanish irrigation districts to examine effects of water pricing on farm income, crop production, and water use. Results were similar to the findings in Italy, and showed that water pricing does not promote water conservation (Berbel and Gomez-Limon, 2000; Garrido, 2005). A 2006 study examined at the contribution of irrigated agriculture to the economy of Turkey. The authors found that 308,073 ha of land are irrigated by 12 individual projects in the Turkey's Konya plain project, with growth to 617,923 acres planned for the future (Berktay, *et al.*, 2006). Other work from Turkey has examined the economic feasibility of investments in new irrigation infrastructure in Turkey as measures to cope with climate change (Evans and Zaitchik, 2008; Tilmant, *et al.*, 2008; Unver and Gupta, 2003). Work from Australia found that orchard irrigators were more interested in adopting best management practices in irrigation for their effects on farm income, and not for increased water use efficiency (Boland, *et al.*, 2006). A recent analysis of irrigated agriculture estimated irrigation demands for water in southwestern France with implications presented for water decision makers (Bontemps and Cousture, 2006).

Increased transfer of water infrastructure operation and maintenance from governments to farmer or water user associations raises questions about future sources of finance and asset management. The transfer of financial control and investment management may require water user groups to seek private-public partnerships to raise capital and develop skills in long term asset management for renewal of irrigation infrastructure. In addition, in the face of environmental considerations in large scale irrigation schemes there has been reluctance of financial institutions to engage in these projects. Overall, little attention has been given to improving performance of large-scale irrigation systems (Hervé, and Plusquellec. 2009).

In light of these issues, the aim of this report is to review the current situation regarding the financing of water management and infrastructure systems related to agriculture across OECD countries, with special focus on irrigation water application and delivery systems. A related aim is to identify some private initiatives and policy approaches to address infrastructure maintenance in cost-effective ways.

3. Methods of Analysis

3.1 Overview

This report describes current and future needs for financing water management and infrastructure related to agriculture across OECD countries to address the problem of water leakage and inefficiencies. Table 1 shows the distribution of irrigated lands for countries with more than 1 million hectares. For purposes of this report, irrigation infrastructure refers to dams, canals, pipelines, aqueducts, pumping plants, drainage and flow regulating structures. Infrastructure is expensive to build and is not cheap to maintain (Dhawan, 1997). While this study focuses on investments in developing or maintaining off-farm irrigation infrastructure, the economic performance of off-farm infrastructure investments depends considerably on how effectively the water supplied by the investments is managed on-farm.

This report includes analysis of the factors influencing investment in irrigation infrastructure, including weak incentives, complex property rights, and financial constraints. It also includes a discussion of the economically optimum level of investment. The study concludes with a discussion of the various market based initiatives and policy approaches to provide the necessary finance in cost-effective ways. In this context, consideration is given to future sources of finance for upgraded and new capital infrastructure; and private-public partnerships to raise capital and improve long term asset management for renewal of irrigation infrastructure.

3.2 *Economics of irrigation projects*

3.2.1 Enterprise budgets for irrigated agriculture

Cost and return farm enterprise budgets provide the backbone of data needed to inform decision on measures that would alter the price, availability, or reliability of the farm's irrigation water supply. Table 2 displays an example of a cost and return budget for selected crops grown in the Lower Rio Grande Basin of the U.S. state of New Mexico for 2006. Similar farm enterprise budgets are published by most U.S. land grant university colleges of agriculture.

3.2.1.1 Water management and enterprise budgets

Answers to a range of irrigation water management and use questions turn on the economics of water use in irrigated agriculture. Agriculture is a significant water user in the dry parts of the OECD countries, and water is an essential input to crop and livestock. Understanding and predicting water use patterns and economic outcomes produced by infrastructure repair and maintenance requires a comprehensive analysis of the economic factors influencing decisions by irrigators on their crop production and water use.

Irrigators face the question of how to best organize their farm operation. What outputs should they produce, and how can they produce them economically? By developing and using enterprise budgets farmers and water managers can improve the quality, reliability, and use of available information. This information can simplify analysis of the economics of alternative infrastructure development and maintenance in irrigated agriculture for the OECD countries.

Enterprise budgeting is a well-established method to develop and analyze farm management alternatives and identify impacts of policies that affect those alternatives. Used right, budgeting can provide economic information to inform numerous water management and policy debates. Transforming inputs into outputs, allocating scarce water and other resources among alternative outputs, selecting the mix of outputs, and predicting the impacts of policy changes on each of those are important choices. Outcomes of these choices have consequences that can be analyzed systematically through the use of budgeting.

3.2.1.2 Resource allocation

Irrigators in the OECD countries make decisions on resource use and allocation by applying several economic principles common to all production agriculture (*e.g.*, Berbel and Gomez-Limon, 2000; Bontemps and Cousture, 2006; Connor, 2008; Khan, *et al.*, 2009). These principles include:

- Input Use Intensity B Irrigators add units of an input whenever the value of the resulting additional output exceeds the added input cost. For example, more surface water or groundwater will be added to a field if its incremental economic value of productivity exceeds the water price (Pujol *et al.*, 2006).

- Water Use and Price B If additional water is made available through investing in infrastructure development or repair, irrigators will use that water if it adds more to farm revenue than to farm costs. If a country's institutions and policies are organized so that the water made available is priced at zero, irrigators will use all additional water made available to them as long as the additional water produces additional gross farm receipts. However the price of water charged to irrigators has a large influence on its use. The water saved by improved infrastructure is most valuable to irrigation farmers if the water has a zero price. Yet, while free water is the best deal for farmers, it produces zero cost recovery[4] as well as encouraging high irrigation water demand that must somehow be supplied to avoid shortages. This high demand can present a serious economic and political problem if the cost of supplying that water through investments in infrastructure is high. If the price of water conserved by infrastructure improvements is set to recover costs, the economic value of the water to the farmer falls (Garrido, 2005; Gastelum and Stewart, 2009; Kobayashk, 2005).

Table 1. Irrigated Land by Country, 2003

#	Country	Hectares	Acres	OECD Member
1	India	55,808,000	137,907,149	
2	China	54,596,000	134,912,176	
3	United States	22,385,000	55,315,574	x
4	Pakistan	18,230,000	45,048,153	
5	European Union	16,805,000	41,526,836	x
5	Iran	7,650,000	18,903,915	
6	Mexico	6,320,000	15,617,352	x
7	Turkey	5,215,000	12,886,787	x
8	Thailand	4,986,000	12,320,905	
9	Bangladesh	4,725,000	11,675,948	
10	Russia	4,600,000	11,367,060	
11	Indonesia	4,500,000	11,119,950	
12	Uzbekistan	4,281,000	10,578,779	
13	Spain	3,780,000	9,340,758	x
14	Kazakhstan	3,556,000	8,787,232	
15	Iraq	3,525,000	8,710,628	
16	Egypt	3,422,000	8,456,104	
17	Romania	3,077,000	7,603,575	
18	Vietnam	3,000,000	7,413,300	
19	Brazil	2,920,000	7,215,612	
20	Italy	2,750,000	6,795,525	x
21	France	2,600,000	6,424,860	x
22	Japan	2,592,000	6,405,091	x
23	Australia	2,545,000	6,288,950	x
24	Ukraine	2,208,000	5,456,189	
25	Chile	1,900,000	4,695,090	
26	Burma	1,870,000	4,620,957	
27	Sudan	1,863,000	4,603,659	
28	Turkmenistan	1,800,000	4,447,980	
29	Saudi Arabia	1,620,000	4,003,182	
30	Philippines	1,550,000	3,830,205	
31	South Africa	1,498,000	3,701,708	
32	Korea	1,460,000	3,607,806	x
33	Azerbaijan	1,455,000	3,595,451	
34	Greece	1,453,000	3,590,508	x
35	Morocco	1,445,000	3,570,740	
36	Syria	1,333,000	3,293,976	
37	Peru	1,200,000	2,965,320	
38	Nepal	1,170,000	2,891,187	
39	Madagascar	1,086,000	2,683,615	
40	Kyrgyzstan	1,072,000	2,649,019	

Source: The World Factbook, 2008

Table 2. Per Acre Costs and Returns for a 500 Acre Farm, Lower Rio Grande Basin, Elephant Butte Irrigation District, NM, USA, in $US, 2007								
	ALFALFA ESTABLISHMENT	ALFALFA HAY	PIMA COTTON	PICKER COTTON	GRAIN SORGHUM	SPRING LETTUCE	FALL LETTUCE	WHEAT
		TONS	LBS	LBS	CWT	CARTONS	CARTONS	CWT
PRIMARY YIELD		8.00	750.00	1,000.00	40.00	475.00	500.00	30.00
PRIMARY PRICE		$140.00	$0.98	$0.66	$5.75	$0.00	$5.64	$32.00
GOVERNMENT PAYMENTS		$0.00	$0.00	$143.55	$0.00	$0.00	$0.00	$0.00
SECOND INCOME		$0.00	$84.00	$112.00	$0.00	$0.00	$0.00	$0.00
GROSS RETURN		$1,120.00	$819.00	$915.55	$230.00	$2,384.50	$2,820.00	$960.00
CASH OPERATING EXPENSES								
SEED	$80.00		$22.75	$50.00	$12.20	$740.00	$6.00	$27.50
FERTILIZER	$36.00	$54.20	$82.40	$82.40		$200.00	$190.00	$156.00
CHEMICALS	$26.84	$14.40	$33.37	$98.09	$55.60	$111.09	$250.28	$30.00
CROP INSURANCE			$2.94	$0.34	$2.94			$2.94
OTHER PURCHASED INPUTS		$34.28						
CANAL WATER		$88.00	$52.00	$52.00	$40.00	$40.00	$46.67	$48.00
FUEL, OIL & LUBRICANTS-EQUIPMENT	$38.16	$28.73	$83.17	$83.72	$25.11	$48.79	$53.22	$15.20
FUEL-IRRIGATION	$0.05	$0.00	$0.00	$0.00	$0.00	$0.14	$0.00	$0.05
REPAIRS	$13.41	$6.34	$29.40	$29.62	$8.58	$18.87	$20.79	$5.42
CUSTOM CHARGES	$73.33	$60.80	$116.03	$128.30	$16.80	$1,843.90	$2,008.35	$10.00
LAND TAXES		$9.65	$9.65	$9.65	$9.65	$9.65	$9.65	$9.65
OTHER EXPENSES	$0.38	$72.44	$72.64	$72.65	$72.05	$72.54	$72.60	$71.94
TOTAL CASH EXPENSES	$268.18	$368.84	$504.35	$606.76	$242.93	$3,084.98	$2,657.54	$376.70
RETURN OVER CASH EXPENSES	($268.18)	$751.16	$314.65	$308.79	($12.93)	($700.48)	$162.46	$583.30
FIXED EXPENSES	$42.66	$147.76	$102.96	$103.37	$17.94	$53.50	$33.69	$27.47
TOTAL EXPENSES	$310.84	$516.60	$607.30	$710.13	$260.86	$3,138.48	$2,691.23	$404.17
NET FARM INCOME	($310.84)	$603.40	$211.70	$205.42	($30.86)	($753.98)	$128.77	$555.83
LABOR AND MANAGEMENT COSTS	$55.07	$137.65	$131.83	$141.67	$45.92	$233.32	$132.71	$92.04
NET OPERATING PROFIT	($365.91)	$465.75	$79.87	$63.75	($76.78)	($987.30)	($3.94)	$463.78

- Input Substitution – Irrigators substitute one input for another as long as the cost of the added input is less than the cost of the input that is replaced and the output is maintained. For example, on farm infrastructure improvements like drip or sprinkler irrigation will be substituted for water, which promotes water conservation, if output can be maintained and if the on-farm improvements cost less than the value of the water saved. For another example, adoption of more uniform sprinkler systems involves a trade off between increased capital expenditure on equipment and the benefits associated with reduced water application. Infrastructure improvements can be a substitute for low or unreliable water supply or high demands in uses outside agriculture (Brennan, 2008). In Australia, ongoing water reforms encourage irrigators to adjust farming practices by substituting water-saving irrigation infrastructure for growing water scarcity brought on by climate change or drought (Khan, *et al.*, 2009). The potential for input substitution assigns high importance to measures such as technological advances that reduce the cost to farmers of water conserving technologies. Recent work in Turkey examined the economic feasibility of investments in new irrigation infrastructure in that country as a way to cope with climate change (Evans and Zaitchik, 2008).

- Output Substitution B Irrigators substitute one product for another as long as the value of the incremental output exceeds the value of the output replaced and the cost is unchanged. For example, U.S. rice irrigators in the Texas Gulf Coast substitute waterfowl habitat production for rice production if a given amount of water can be applied to either and the added waterfowl habitat produces more revenue than the losses incurred from reduced rice production. A 2005 analysis found similar substitution among agricultural outputs in Spain (Custa *et al.*, 2005).

- Resource Allocation B Irrigators use each unit of resource where it gives the greatest returns when resources are scarce. This economic behavior has implications for choices in which surface water versus groundwater infrastructure could each be improved or restored.

- Optimizing Over Time B Irrigators base comparisons on discounted values when considering choices made in different time periods. For example, irrigators will invest $1000 today in a water conserving land improvement like drip irrigation if net farm income increases by more than $1000 over time, in present value terms. If not, irrigators will avoid making the investment. A range of resource allocation management decisions faced by farm managers can be addressed by applying one or more of these budgeting economic principles. For example a recent study from Australia showed the importance of current versus future tradeoffs in a 100 year analysis (Connor, 2008).

- Overall B Where correctly defined and used, the budget format permits a manager or policymaker to use economic principles and data to answer questions of which resource, how many resources, and at what time resources are best used to achieve the farm's goals.

3.2.1.3 Farm management questions

Irrigators in OECD countries face several challenges when managing available farm resources to maximize economic returns. Resources include land, capital, buildings, labor, and of course, water. Much of that water is supplied through investments in irrigation infrastructure maintenance. The manager is responsible for combining available resources, buying additional resources, and applying knowledge to maximize net farm income. With information provided by budgets, farm managers and water policymakers can pose, address, and answer these kinds of questions:

- How can the farm operator=s available resources best be used?

- What enterprises (*e.g.*, cotton v. lettuce v. alfalfa) can potentially be produced and which mix of those will contribute most to net farm returns?

- How much land should be devoted to each enterprise and in what time periods?

- What equipment, land, and machinery are needed to produce each potential enterprise?

- Which production practices (*e.g.* water management, pesticides, fertilization, weed control) should be used to produce each enterprise?

- How much labor (hired and family) is needed on the farm and to produce each enterprise?

- What are the capital requirements for each enterprise?

3.2.1.4 Knowledge gaps

Answers to the resource allocation and farm management questions posed above are central to decisions on the most economic measures to promote water use in the dry parts of the OECD countries. These answers can come partly from information provided by reliable cost and return enterprise budgets. The U.S. land grant university colleges of agriculture have historically published enterprise budgets for major crops, limited budgets have reduced the support for this type of work in recent years.

3.2.1.5 Function and structure of enterprise budgets

Enterprise budgets are essential elements of farm planning. They can be used to

- Identify profitability of various enterprise mixes

- Examine impacts of changing the scale of each enterprise, and

- Identify impacts on costs and productivity of each production technology
- Identify impacts on profitability of measures that would increase water supply through irrigation infrastructure maintenance. An equivalent impact is the loss in farm income produced by measures that avoid such maintenance.[5]

The best data on irrigated farm enterprises come from the particular farm being examined. That farm produces the most accurate indication of costs, efficiency in resource use, resource quality, and the individual farm manager's personal characteristics and attitudes. While individual farm data are the most accurate, they are not the most comprehensive. Using only data from a particular farm, the range of future potential enterprise combinations and technologies is limited to the historical experience of that farm. Harnessing the full potential of the budgeting approach to promote profitable farm planning requires securing data from other sources and adapting those data to the unique conditions of that farm.

It is for this reason that enterprise budgets are developed for use in farm planning and associated water management and policy analysis. Carefully developed, these budgets provide a standard set of costs and returns associated with a particular enterprise. They give producers and policymakers an estimate of input requirements and potential net income for enterprises not within their experience. So, farm enterprise budgets provide managers a way to:

- Organize effectively
- Improve the existing organization
- Experiment with the process and outcome of a proposed organizational change before committing large amounts of resources to support it
- Identify cost items otherwise missed
- Secure credit

Farm managers and water policymakers rarely have enough information needed to make ideal decisions. Still, they must make decisions using available information, and then they must live with the outcomes associated with their implementation. Correctly developed, an enterprise budget provides information in a structured format to use so that the economics of alternative enterprises and alternative production systems, and alternative water supply conditions arising from investments in irrigation infrastructure can be consistently appraised. Information provided by an enterprise budget summarizes what generally can be expected from a set of particular production practices when producing a specified amount of output. It consists of a statement of revenues from and the expenses incurred in the production of a particular output.

3.2.1.6 Roles of budgets

For an irrigated farm, an enterprise budget

- is a plan for a course of action, including estimated costs and returns for one enterprise.
- presents a single combination, from among many available, of inputs such as water, land, chemicals, labor, and fertilizer to produce a single level of output, typically on a per unit land basis. Hundreds of other input combinations could produce the same output.[6]
- provides a structure for developing alternative enterprise budgets targeted to a different farm situation.
- does not mean that a producer with costs or returns different from the published base budget has poor records. Variations in local input and output prices, land grading, different soil types, and fertility levels, are all examples causing variation in price, cost, and net income.

- does not mean that all producers can achieve these costs and yields. Different soil types, different land grades, different fertility levels, and different weather or climate from one place or time to another all can cause the actual net returns to vary greatly from what is presented in the budget.

3.2.1.7 Gross revenue

The gross revenue part of an enterprise budget shows projected gross revenue from the crop to be sold, and in some cases can include revenue from related activity, such as revenues from wildlife habitat provided. When enterprise budgets are developed before the production period begins, producers must estimate sales prices one period before the products are sold. For the case of crop production, payments de-coupled from production, *i.e.*, those that occur whether or not production occurs, are excluded from the budget because they are received regardless of whether the crop is produced or not.

3.2.1.8 Gross cost

When enterprise budgets are developed, costs are typically categorized in ways to make the information more useful to the decision-maker. Costs are sometimes broken into two groups, namely variable and fixed costs, described below.

Variable costs vary with the scale of the enterprise (*e.g.*, acres) and with the management decisions made, such as the type of field and tillage operations. They also vary with the intensity of any single input on a given parcel of land (*e.g.* one acre). Variable costs occur because of the decision to purchase additional inputs for use in production. In the long run all costs are variable in the sense that given a long enough period of time, they can be varied. In the long run, all costs must be covered or that agricultural enterprise is not an economically viable use of the land.

In the short run, such as a single year, however, revenues must exceed variable costs, or it is more profitable to cease production. At one point in time near the end of the production period, nearly all costs are fixed in the sense that they have already been incurred, so the incremental revenue coming in from a crop sold is likely to be considerably higher than the additional variable costs needed to make the crop available for sale. For example, it can be useful to separate variable costs for an irrigated farm into pre-harvest and harvest costs. Facing the added cost of harvesting a crop, a producer with a low yield or a poor commodity price outlook faces the painful decision of deciding whether the value of harvesting the crop will pay for the harvest costs alone. At this point late in the planning period, costs already incurred (pre-harvest costs) are sunk costs. Sunk costs are irrelevant when deciding whether or not to harvest a crop already planted.

Fixed costs are cost the farm must pay for all decisions made over the current period. Producers who have already paid fixed costs such as those on machinery, buildings, and land are committed to owning these resources for the forthcoming period. The producer incurs some fixed costs associated with these resources regardless of whether any production occurs. Fixed costs include depreciation and insurance on machinery, equipment and buildings, interest on machines, land, equipment, and buildings and land taxes.

Both fixed and variable costs have an influence on whether or not a producer continues to produce. Many producers sooner or later confront the problem of failing to recover all their costs for an irrigation enterprise. In the short run, quantities of some inputs can be altered, while others cannot. All inputs, including land and water, can be varied in the long run. In the short run, the period over which some costs are fixed, the producer continues production if expected revenue cover variable costs. However, if variable costs cannot be paid for by revenues in the short run, continued production only increases losses.

3.2.1.9 Return over variable cost

Return over variable cost (gross margin) is defined as gross revenue minus variable cost. Gross margin can be used to compare the profitability of competing enterprises in the same business. In the short run, the producer's gross revenue must at least cover total variable costs or production will be discontinued. The breakeven commodity price for covering variable cost shows what commodity price is needed, given the yield, efficiency, and input price assumptions, to produce adequate revenue to pay for variable costs.

3.3.2 Economic efficiency in irrigation projects

The development and use of water resources for irrigation is usually accompanied by one or more of the classic cases of market failure. These include externalities, public goods, decreasing marginal costs, common property resources, and uncertainty (Young, 1978). The presence of these market failures gives rise to an inefficient allocation of water and related capital resources under competitive market conditions. Economic analysis of public water resource management has long emphasized market failure as justification for public intervention into the development and allocation of water for irrigation. Externalities can result from either the development of water or its allocation. Economies of large scale and decreasing marginal costs are often found in water development measures. Both create problems for financing systems large enough to capture economies of scale. It also presents challenges in establishing economically efficient water pricing mechanisms.

Recreational and environmental uses that benefit from irrigation projects rarely deplete water at the expense of other users. In these cases an irrigation project has the characteristics of a public good, in which several water users can simultaneously consume the services of the project. Finally, the flowing nature of water and its changing physical characteristics as it passes among states in the hydrologic cycle produce high transaction costs in establishing and enforcing property rights to develop, allocate, and use water. In these cases, water services, especially environmental values produced by leaving water in its natural state, may emerge as a common property resource, for which the complete opportunity costs of its use may not face the user.

3.2.3 Economic framework for irrigation investments

Sustainable financing for irrigation infrastructure ultimately comes from additional incomes earned by the farmer or from added net national economic benefits resulting from that improved infrastructure. Farmers will not invest in irrigation improvements unless their discounted net present value of income is expected to be greater than zero (Carey and Zilberman, 2002; Merriam and Freeman, 2007; Molden and Gates, 1990). There is a long history of irrigation subsidies by various government agencies in many countries, and these subsidies are likely to continue (Sur *et al.*, 2002; Malik, 2008). However, unless maintenance of the infrastructure adds sufficient resources to farm income by a large enough amount to pay for the cost of the infrastructure, the economic benefits produced by a public subsidy are unlikely to be sustained. Governments and donor organizations rarely assign high priorities or large budgets to irrigation maintenance (Pitman, 2006).

The equations below present an economic framework that can be used for evaluating investments in irrigation infrastructure. Similar to the analyses presented by Young (1978) and later by Singh (1994) and by many others more recently, it shows the economics of irrigation investments from two views: private farm income and national economic benefit. Economic performance for each view is shown without infrastructure maintenance, with low maintenance, and with high maintenance. This table can be used to evaluate the economic performance of investments in maintaining irrigation infrastructure. Several features of the table stand out. The standard of private farm income earned attempts to evaluate impacts of irrigation and its infrastructure maintenance on private income earned by irrigators. It assumes that irrigators ultimately are charged for the cost of infrastructure maintenance. That farm income is measured as:

(1) $NY_i = [P\,Y_i - C_i - Pw\,W_i - M_i]\,L_i$

where

NY = Net farm income

P = crop price

Y = crop yield per unit land (*e.g.* acre)

C = production cost per unit land excluding cost of water and infrastructure

Pw = price charged for irrigation water

W = crop water applied per unit land

L = amount of land in production

M = cost of infrastructure repair per unit land

i = index for level of infrastructure investment (0 = none; 1 = low; 2= high)

Like farm income, net national benefit also accounts for the economic performance of an irrigation project, but that performance is measured from a wider point of view. Several factors included in net national economic benefits are excluded from private farm income: the opportunity cost of water displaced from other uses is typically higher than water=s price charged to irrigators; urban values of water associated with a multiple use irrigation project can be quite high (Meijer, *et al.*, 2006; Turner, 1997) depending urban populations and incomes; environmental values of water can be significant, especially so in environmentally sensitive areas that have received little historical attention to environmental assets (Chakravorty and Umetsu, 2003).

Equation (1) provides an important framework for assessing investments in infrastructure. Several terms are directly influenced by the level of infrastructure: These include crop yield, production cost per unit land, crop water applied per unit land, cost of infrastructure itself, and the amount of land in production. For example if a reservoir that is partly silted up is dredged or if its storage capacity is increased in some other way, crop yields would likely increase in the face of a more reliable water supply, the crop mix could change in favor of higher valued crops, production costs may fall, and the amount of land in production could be expected to increase. If the value of these improvements exceeded the cost of the infrastructure improvement, then equation (1) shows that the investment pays for itself.

Bearing in mind the distinction between farm income and net national benefits, net national benefits of an irrigation project or an investment in infrastructure maintenance are measured as:

(2) $NB_i = [P\,Y_i - C_i - Po_i\,W_i - M_i]\,L_i + U_i + E_i$

where

NB = Net national benefit

P = crop price

Y = crop yield per unit land (*e.g.* acre)

C = production cost per unit land excluding cost of water and infrastructure

Po = opportunity cost of irrigation water

W = crop water applied per unit land

L = amount of land in production

M = cost of infrastructure repair per unit land

U = urban value of water complementing an irrigation project

E = environmental value of water made possible by an irrigation project

i = index for level of infrastructure investment (0 = none; 1 = low; 2= high)

While equation (1) views irrigation infrastructure as limited to irrigation benefits, equation (2) recognizes that related benefits (and costs) can be produced by this infrastructure. For example hydropower, recreation, and flood control, and urban water supply can result from the storage and delivery systems designed for irrigation. More generally, water-related infrastructure normally serves many purposes related to water services, and not only for agricultural use of water, but water delivery to urban areas, water accumulation for environmental uses, hydropower production, as well as drought and flood protection. In fact water infrastructure limited to irrigation uses may be less frequent in many of the OECD countries than infrastructure supplied for multiple uses.

The framework described above can be applied to evaluate irrigation decisions for a wide range of economic, technical, agronomic, climatic, and institutional conditions. Equation (2) also shows that any investment in infrastructure that increased national benefits by more than the cost of the investment is justified economically. In fact the economic value of these improvements are what can be used to pay for the investments.

3.2.4 Causes of over-investment in irrigation

The optimum level of irrigation infrastructure investment is that level that produces a maximum value of discounted net present value of services that flow from that investment. From the private financial view, it is the net present value of additional net farm income minus the cost of developing the infrastructure. For a national economic view it is the net present value of additional benefits from all water users minus the cost of developing the infrastructure. In irrigated systems, the optimum level of irrigation infrastructure differs for different levels of water availability, but only one level of irrigation capacity can be maintained in the short run once that capacity has been established.

3.2.4.1 Cost allocation and water pricing

The method to finance irrigation projects is widely debated in many countries. For example, in the U.S. financing was widely debated beginning with the inception of the Reclamation Act of 1902. For the U.S. case, one outcome of those debates was that numerous changes were made by the Congress, all which separated beneficiaries of irrigation development from incurring its full cost. The original intent of the Act was to promote settlement of the western US. When it was found that settlers inexperienced with irrigation would not earn enough farm income from the water for several years, the repayment period was soon extended to 20 years and later to 40 years.

Amendments to the U.S. Reclamation Law enacted in the 1930's effectively separated repayment requirements from the real cost of developing and delivering the water. Water prices charged to irrigators on reclamation projects were originally based on a cost recovery basis. So irrigation water was priced at its marginal cost of supplying the water. However the price of water was later changed from marginal cost to "ability to pay", based on the principle of repayment capacity. Price was no longer based on marginal cost, but on marginal benefits of water used in irrigation (Moore, 1991; Easter and Liu, 2005).[7] Irrigators were charged prices they could afford to pay unless their repayment capacity was greatly overstated. Beneficiaries paid only a fraction of construction costs,[8] so even if benefits were considerably overestimated, the ratio of local benefits to local costs paid is likely to be much larger than 1.0. Such a low fraction of repayment required gave rise to historically high local support for federally financed irrigation projects, giving rise to what has been called the "iron triangle" of bankers, real estate interests, and farmers[9] who have shared economic interests in development of irrigation projects. Not surprisingly, vigorous support of irrigation projects by iron triangles has strong incentives to limit the use of rigorous economic principles in the conduct of irrigation project appraisals.[10]

3.2.4.2 Financing and cross subsidies

In the US, despite the weak economics of irrigation development, Congress adopted the ability to pay principle described above, and authorized the difference between the cost of development and repayment charges received from farmers to be paid from cross subsidies paid by hydroelectric power revenues. Electricity sales turned out to be the effective source of finance supporting the reclamation program, offsetting the typically weak economic performance of irrigation. That part of irrigation development not repaid by farmers were financed by Basin Accounts, which allows deficits from one project to be made up from surpluses from others in the same river basin. The power beneficiary paid most (80 percent or more) of the irrigation water costs. This cross subsidy of irrigation by power also avoids government subsidies of public power production that competes with private electric utilities.

3.2.4.3 Pricing irrigation water below marginal cost of supply

Again for the US, in the face of low water prices charged to irrigators, farm income gains from irrigation expansion could be considerable, and therefore politically supported by irrigation interests. In some cases the irrigation supporters have successfully negotiated a project evaluation framework in which farm income is substituted for net national benefit. In that case, considerable overinvestment in irrigation has occurred from the view of net national benefit. That is, the gain in farm incomes would be very high. Still a national economic view would have rejected the project because of high environmental costs such as minimum streamflows required to keep an endangered from going extinct or from other opportunities lost that were ignored.

3.2.4.4 Potential to renegotiate irrigation water delivery contracts

Even when contract price of water is high, and the market test of an irrigation project is weak, irrigators may still show strong support for irrigation projects. If farmers believe they can renegotiate the contract after the system is built and the waters is flowing, their support may be greater than would be predicted by calculations of discounted net present value of the project, For example, Martin and his coauthors found that by the early 1980's, irrigators in Arizona who would receive water from the Central Arizona Project (CAP) had signed long-term contracts amounting to 70% of the CAP water allocated for agricultural use (Martin, Ingram, and Laney, 1982; Martin, 1988). Many were surprised that so many farmers had committed to purchase CAP surface water at the high price of $65 per acre foot. In fact, many of those same farmers had installed their own groundwater wells and pumps, and their cost of pumped groundwater was a much lower $30-50 per acre foot. An important question centered around why these Arizona farmers showed such strong support of CAP by signing contracts for delivered water at prices considerably higher than they could afford to pay. The farmers= attitudes seemed irrational in that the purchase of CAP water seemed to violate their own self-interest.

The authors surveyed farmers supplied by CAP water to answer this question. They found that the farmers had learned to play the water development game. Under that game, farmers kept their options open. As long as the costs of playing the game are minimal and there is a good chance of a benefit in the future, farmers need take no action now to reduce uncertain future costs. Even if future contracted irrigation water prices are greater than farmers can rationally afford to pay, historical experience with Reclamation showed them that once the water project and its water are in place, the price of the water would be negotiable.

Moreover, since the Arizona farmers had cheap substitute groundwater available for use after CAP was built, they would be in a strong position when re-negotiating contracts with Reclamation. Reclamation would have spent millions of taxpayer dollars building CAP, and after its completion they would be searching hard to find willing buying customers. Farmers believed they would be able to buy CAP water on their own terms at low prices. In short, the farmers were willing to play what the authors described as the water development game. Their readiness to sign contracts for CAP water they could never afford signaled a willingness to play, not a willingness to pay. Their willingness to play gave rise to overinvestment in irrigation compared to what the market could bear.

3.2.4.5 When irrigators expect to secure water rights

Even if the economics are weak, potential irrigators may see contracting to buy project water as a good method to secure a water right just in case that water might be needed for the future. Where water rights are based on historical and sustained beneficial use, irrigators often believe that investments in water conservation measures, such as lining ditches with concrete, fallowing fields, or placing water into a water bank for cash, may cause them to forfeit their saved or deposited water. The fear is that water conservation could be perceived as failure to demonstrate current beneficial use (Ward, 2007b). For example, in recent years, some legislators in the U.S. state of New Mexico found farmers spilling their water rather than trying to conserve it as a way to guard against the risk of forfeiting any of their water right for lack of demonstrated beneficial use. High current water use, even if not needed, is a common method to demonstrate beneficial use in case the water might be needed in the future. Property rights in water have an important effect on the incentive on water conservation, as shown in a study of Korean agriculture in 2007 (Labadie, *et al.*, 2007).

Securing control of the natural flows of a river basin through irrigation developments in parts of the American west has succeeded in blocking a city or an environmental user from claiming the right to use the water. Through heavy investment in irrigation, other beneficial uses, such as environmental uses, are lost along with the opportunity for the farmer to earn an income by marketing that water to the other user. So the simple act of getting control of unused water, even through non-performing irrigation projects, is perceived is an attractive measure for landing a property right that may have considerable future value. And indeed urban uses continue to grow in many of the world's dry places, and cities are typically the buyer of water from willing farmers who wish to sell.[11] Growing cities can typically pay prices 2-5 times higher than the economic value in irrigated agriculture.[12]

3.2.5 Factors leading to a higher value of infrastructure maintenance

Table 3 and equations (1) and (2) show factors that influence the economic performance of irrigation projects for each of several levels of maintenance of irrigation infrastructure. The economic value of food produced in addition to the cost of supplying the water, the price charged for water, and urban and environmental values of water all play a part. This formula is quite general, and can be applied to any country, river basin, climate, economic or political system, or set of institutions that govern irrigation and irrigation infrastructure maintenance. It can be adapted to agricultural enterprises that specialize in grains, fruits and vegetables, or fodder. It can account for farming operations for which irrigation is a supplemental activity to reduce risk of intermittent rainfall or for irrigated agriculture in desert regions that receive almost no rain. Several factors described below influence the value of irrigation infrastructure maintenance.

3.2.5.1 Lower water prices

A lower price of water charged to irrigators increases farm income and increases the value of investments made in infrastructure maintenance. Lower water prices also increase the economic incentive for farmers to produce heavy water-using crops like alfalfa and orchards. These low prices discourage farmers from growing water-saving crops. Finally, lower water prices encourage greater water use and will encourage farmers to substitute water for other resources, such as land, labor, capital, and water-conserving technology. For the case of net national benefits the opportunity cost of water occupies the place in equation (2) held by the price of water in the farm income analysis in equation (1). A lower opportunity cost of water increases the net national benefits of measures that maintain irrigation infrastructure. A higher opportunity cost does the opposite. For example, in a region where values of water outside agriculture are high, due to water-sensitive or high-valued environments, or possibly due to growing cities, then investments in infrastructure maintenance will perform weakly. In fact it is in cases such as these where opportunity costs of water outside irrigation are considerable that it may pay to never renew irrigation infrastructure, and let it depreciate to the point of zero value in irrigation.

3.2.5.2 Lower infrastructure cost

Governments rarely assign high priority to using taxpayer resources to maintain irrigation infrastructure. A common belief by governments is that even if the government subsidizes the development of irrigation initially, they are less willing to assign adequate budgets to keep its infrastructure in top form. The high cost of maintenance is a major reason. Another reason is that since the farmer or other water user is the main beneficiary, they should be able to pay for its upkeep out of the additional income it produces. It is unlikely that the debate will soon be resolved on who should have the responsibility of maintaining infrastructure. Nevertheless a considerable amount can be said about the economic feasibility of maintaining infrastructure based on its cost.

A lower price of infrastructure maintenance increases its quantity demanded, since its demand is derived from the demand for its final services, summarized as additional irrigation farm income for the case of irrigation infrastructure. Table 3 and equation (1) both show that the gain in farm income from infrastructure maintenance is higher when the real cost (per unit land) of that maintenance is lower. With no maintenance needed, farm income is unaffected by changes in the price of maintenance. However a given level of maintenance required provides a greater boost to farm income as the maintenance price charged to farmer is lower. What this means is that advances in technology, labor supplies, or institutions that make it cheaper to restore or maintain existing infrastructure all are translated into greater farm income produced. There is a greater farm income produced from a given planned level of infrastructure maintenance when repair costs fall. Also the planned level of maintenance increases because of the added farm income induced by those cost economies.

There are similar forces affecting measurement of net national benefits associated with a reduced cost of infrastructure maintenance, summarized in equation (2). Where infrastructure maintenance costs are low there are greater net national benefits to be secured by investing in infrastructure renewal. Where the opportunity cost of water is high for environmental or urban uses that compete with agriculture, those net national benefits will be higher than where opportunity costs are low. For example, consider the case when a reduced cost of investments in drip irrigation technology occurs. That cost savings will raise the net national benefits from the farmer's saved water by a greater amount when that water has a value in urban or environmental uses than when there are few competing demands for the saved water.

Table 3. Economic Framework for Evaluating Investments in Irrigation

Data	Viewpoint	Without Infrastructure Maintenance	With Infrastructure Maintenance: Low Level	With Infrastructure Maintenance: High Level
Farm				
Crop Price	farmer	P	P	P
Crop Yield/Acre	farmer	Yo	Y1	Y2
Production Cost/Acre	farmer	Co	C1	C2
Crop Water Applied/Acre	farmer	Wo	W1	W2
Acres in Production	farmer	Lo	L1	L2
Non Farm				
Urban Value	nation	Uo	U1	U2
Environmental Value	nation	Eo	E1	E2
Irrigation Water Price	farmer	Pf	Pf	Pf
Irrigation Water Opportunity Cost	nation	Po	P1	P2
Annual Cost/Acre Infrastructure Maintenance	nation	0	M1	M2
Net Income	farmer	{[P*Yo-Co] - [Pf*Wo]}*Lo	{[P*Y1-C1] - [Pf*W1] - M1}*L1	{[P*Y2-C2] - [Pf*W2] - M2}*L2
Net Economic Benefit	nation	{[P*Yo-Co] - [Po*Wo]}*Lo + Uo + Eo	{[P*Y1-C1] - [P1*W1] - M1}*L1 + U1 + E1	{[P*Y2-C2] - [P2*W2] - M2}*L2 + U2 + E2

3.2.5.3 Greater water savings from infrastructure maintenance

Investments that maintain irrigation infrastructure include improvements in dams, canals, pipelines, aqueducts, pumping plants, drainage and flow regulating structures. These investments are generally for the purpose of improving the quantity, quality, timing, or reliability of water itself at the place where the farmer needs it. In much the same way as a reduced cost of maintaining infrastructure improves farm income, greater amounts of water saved from that investment that is made available for irrigation use on the farm have a similar economic effect.[13] However, depending on the price of water charged to irrigators, additional water saved may or may not end up getting used. There is only additional farm income resulting from saved water if water demand exceeds supply at the going price charged to farmers. If there is an excess supply at the going price, the additional water will not be used for irrigation and there is no farm income gained.

Net national benefits and farm income impacts have similar effects from higher levels of water savings. Greater amounts of water saved from infrastructure renewal will produce greater impacts on net national benefits. Where opportunity costs of water for urban and environmental uses are higher than water prices charged to irrigators, impacts on net national income will be smaller than impacts of farm income.

3.2.5.4 Higher crop yields

Greater crop yields produce larger farm incomes, raise the value of water in irrigated agriculture, and increase the economic productivity of measures that maintain or improve irrigation infrastructure. When a given measure to maintain infrastructure is applied to a place where crop yields are higher, the farm income benefits are higher. However, even if existing crop yields with and without the infrastructure investment are the same, if the investment occurs where there are higher yields, the farm income benefits will be higher. That is either higher existing yields where an infrastructure investment occurs or higher yield improvements produced by the investment will improve the economic performance of infrastructure investments. A good example of this finding is a 2005 study found that the weak state of the water distribution network in Spain's Lemos Valley Irrigation District forced farmers to abandon irrigation because they lack economic motivation to irrigate. The authors found greater incentives to invest in irrigation infrastructure where its economic return are highest. This occurred where the infrastructure increased crop yields, saved more water, or was able to substitute for effects of unreliable water supply (Custa, *et al.*, 2005).

The economic principles described above point to the comparative experience of irrigators in investing in infrastructure maintenance in different parts of the world. We would expect high performance both for farm income and for net national benefit from infrastructure improvements when crop yields are already high, but much weaker incentives to invest where crop yields are low. This set of economic forces gives rise to the cycle of low yields (giving rise to current poverty) causing low investments in sustaining infrastructure (which can contribute to increased future poverty).

3.2.5.5 Lower cost of capital

An important element that affects the decision to invest is the cost of capital needed to sustain and support the investment B the interest rate. While not stated, the formulas presented in Table 4 and equations (1) - (2) refer to the economics of irrigation for a single period. Most investments in irrigation infrastructure last for several years, so the added costs and returns need to be summed up for all relevant times in the planning horizon. A lower interest rate makes any investment in infrastructure maintenance more attractive, since most costs are incurred in the first few periods, while benefits are reaped over many future periods. The lower interest rate that is applied to those future benefits (additions to farm income or national water-related benefits) the higher they will count in the evaluation of current investments. Where a lower interest rate reflect a greater effective supply of investable capital for infrastructure, that greater supply will make it easier to support greater growing farm income as well as supporting more additions to net national income. Lower capital supplies, and a corresponding higher interest rate contribute to perpetuating the cycle of poverty, since both farm incomes and net national incomes will be more expensive to sustain through resources available to sustain infrastructure.

4. Results

4.1 Market approaches to irrigation infrastructure

Several market approaches could influence the economic attractiveness of investments in irrigation infrastructure. These include subsidies of infrastructure, clear titles to water rights that promote market transfers of water, and marginal cost pricing.

4.1.1 Subsidies

Measures that subsidize the capital cost of infrastructure repair have been tried with some success. For example the U.S. City of San Antonio, Texas, has partnered with the Lower Colorado River Authority to pay for on- and off-farm water conservation measures by rice irrigators in the Texas Gulf Coast. A considerable part of these subsidies are paying for repairing aging infrastructure and modernizing and improving water conveyance systems. Similar arrangements have been agreed to between San Diego, California, paying to repair leaky infrastructure in the Imperial Irrigation District (IID). In paying for the infrastructure to reduce water losses, San Diego hopes that the water made available for their urban needs is cheaper than finding it from alternative sources, such as desalting sea water. IID has agreed to transfer up to 67,000 acre feet per year of water conserved by lining of the All-American Canal to the City of San Diego in exchange for financing the canal lining costs.

4.1.2 *Water rights, water transfers, and water markets*

Water markets can be an economically efficient institution for implementing marginal cost pricing and for establishing the right incentives that support maintenance of infrastructure. When a price is paid for water that would be gained by repaired infrastructure that price seller signals the marginal cost of leaving the infrastructure unrepaired.

Water markets in Europe have been advocated to cope with this growing water shortages and quality problems (Pujol *et al.*, 2006).

The development or improved efficiency of water banks, water rentals, water leasing, water trading, or other market forms of water transfers provide an excellent set of economic incentives to restore or repair aging irrigation infrastructure. The presence of these water markets provides a way to harness the power of market incentives to self-finance irrigation infrastructure improvements. To the extent that these water markets can be developed that reflect the income value of infrastructure improvements, considerable burdens of searching for external finance by governments or other external organizations are reduced.[14]

The price charged by the seller in a water market transaction reflects the marginal cost of existing water uses that are displaced (opportunity cost) by the transaction. The market price established by a competitive water market encourages the water resource to move to its highest valued use, producing economic efficiency as long as all incremental costs are incorporated in the market price. Nevertheless, implementation of water markets often requires investing a considerable cost of administrative, institutional, and technical support. These costs include the high cost of measuring and defining property rights with variable and random streamflows. Water rights adjudications can take on an important role to support establishing water markets.[15] The high cost of engineers and lawyers typically required for adjudications, has presented a financial barrier to many places around the world from conducting stream adjudications. For example, as of the year 2009, the U.S. state of New Mexico has finished only about one-quarter of its planned stream adjudications.

One of the biggest problems related to development of water markets is the high cost of initiating the change produced by the transition from existing regulatory or traditional water allocation mechanism to a market environment. A good example is the high cost of discovering historical water use patterns in the face of poor or absent records documenting historical use. This information typically is required prior to adjudicating water rights and may be a necessary prerequisite for establishing a market system, which itself may be needed to economically justify irrigation infrastructure improvements. Where irrigation infrastructure needs repair, and water losses result, it is clear who has the incentive to bear responsibility for taking care of it only when the water rights are adjudicated. Without adjudicated rights and clear titles, infrastructure repair has all the well-known problems of a common property resource, with little incentive for anyone to contribute their share of the financing (Herrera, 2006).

4.1.3 *Marginal cost pricing*

Many cultures treat water as a free resource. While free water has desirable equity properties, it can damage incentives to repair aging infrastructure. Economic analysis faces major challenges in the search for institutions that encourage more efficient use of high-cost water. Responding to the problem of weak financial incentives to repair aging irrigation infrastructure some have called for incentives promoting economically efficient use of water in irrigation. One way to promote economically efficient water use by sending the right signals to repair infrastructure that would increase water supply is to establish institutions that confront all water users with the real cost of their actions. For example, irrigation water pricing in France aims to recover costs and reduce the cost of public financing for operation and maintenance costs for irrigation projects. A large part of the capital cost of irrigation infrastructure, ranging from 15 to 60 percent is charged to farmers, with heavy reliance on volumetric pricing (Rieu, 2005; Tardieu, 2003).

Economically efficient water supply requires clear price signals that provide incentives for economically efficient use of water by individual consumers, resulting in total benefits of the water exceeding costs. One method for promoting that economic efficiency is marginal cost pricing in which each water user pays a price that reflects the incremental cost of their use on the system. When irrigation water is underpriced, there is little incentive to repair aging infrastructure as long as supplies can be obtained from alternative sources. Still, even if the price is zero, when irrigators suffer shortages from lack of infrastructure repair, they still have some incentive to invest in needed repairs, as long as the saved water produced by the repairs reduces those shortages accordingly.

The irrigator=s location in the system influences the marginal cost of repairing infrastructure as well as the cost of ignoring repairs. Farmers located at higher elevations, for example, impose significant added pumping costs compared to those on level ground. Also, farms located at the lower end of the system may have lower costs of infrastructure repair. One way to find the needed information to implement marginal cost pricing is through the development and application of integrated basin scale models that account for the economic value of water in its several uses, locations, and time periods (Malek-Mohammadi, 1998; Scheierling *et al.*, 2006).

4.2 Policy approaches to irrigation infrastructure

4.2.1. Regulatory solutions

Governments have a potential role in influencing water allocations and affecting economic efficiency by establishing requirements for upkeep in irrigation infrastructure. Market failures, such as the potentially common property nature of benefits produced by maintained infrastructure serve to block economically efficient infrastructure maintenance, so in that case regulations can be an important way to maintain infrastructure. Regulations have been tried for many dimensions of water benefits, including water use levels, timing of use, place of use or water transfers, and control of environmental pollution (Weinberg, 1997). Supported by an underlying legal framework, regulations require, permit or restrict particular activities or prescribe specific results in connection with water use. For an existing regulation to be economically efficient and to achieve community support, the economic benefits of the regulation need to outweigh its costs. Involvement in regulation redesign would be targeted and concentrated on the major areas of the problem and where the highest economic efficiency (additional net benefits) could be produced. Especially in places where water rights are not clearly defined to water saved from infrastructure maintenance, regulations could be an economically efficient measure for sustaining infrastructure.

4.2.2 Water user associations

Water user associations are composed of stakeholders who get together collaboratively to manage water, sometimes at the scale of a watershed (Ashraf *et al.*, 2007; Marshall, 2004). There is growing increasing interest in using these associations to provide information for water resource managers (Dinar, 2004). There is considerable variability in terms of water user associations= goals, their effectiveness, stakeholder composition, their involvement in the real decision-making process, types of participation allowed, leadership, financing, decision-making procedures, economic efficiency and temporal scale. Several analyses have identified a rapid growth of watershed associations in the 1990s. These associations are a response to historical and political trends that have resulted in increasingly ineffective forums and processes of water management decision making and that have subordinated the role of local stakeholders in problem-solving efforts. In most cases, watershed user associations provide a pragmatic vehicle for resource managers and stakeholders to address common concerns in a more economically efficient manner than is otherwise possible.

4.2.3 Compacts, treaties, and transboundary agreements

Transboundary waters shared by two or more nations occur in some irrigated areas of the OECD countries. One way of reducing the cost of infrastructure maintenance as well as increasing the size and scope of its benefits is for two or more nations jointly to develop, finance, manage and use common rivers, where elements of responsibility are assigned to each nation based on comparative advantage. This permits all nations to gain from trade (Ward, 2007a).

The Columbia River Treaty between the U.S. and Canada, signed in 1961, provides an excellent example. The treaty fosters a coordinated plan that manages the multiple uses of the Columbia River Basin as a trans-national system for mutual benefit. Storage dams built in Canada meant that downstream users were no longer dependent on seasonal river flows. The dams ensured the necessary amount of water would be in the river to meet water demands regardless of season, within the basin and beyond its borders. The U.S. had a comparative advantage in capital and engineering expertise, but suffered from floods. Canada had a comparative advantage in endowments of water but was limited by absolute capital shortages. Both nations secured what they needed most at a lower cost than either nation could have financed on its own. When total benefits from an agreement exceed total costs, this is a signal that there is a potential for all parties in a transboundary basin to share in the benefits.

Trans-boundary rivers pose major economic and political challenges in policy design. Designing an economically efficient, fair, and sustainable measure to allocate scarce and random supplies that meets the needs of all parties is a major challenge, particularly when two or more political units share a water source. One way to allocate these supplies that could be tried out in the OECD countries is the water sharing agreement. In the US, for waters extending beyond borders of one state, interstate compacts have been used with success. An interstate compact is a negotiated agreement among the states that, once ratified by Congress, becomes both a federal law and a contract between the signing states. Beginning in 1922 with the signing of the Colorado River Compact, 22 such compacts currently divide the waters of western American rivers.

4.3 The information challenge: Data availability and gaps

There are considerable needs for improved information in order that economic principles are put to best use in informing orderly maintenance of irrigation infrastructure. Information is needed on cost sharing arrangements between irrigators and public suppliers of irrigation, impacts on water savings at the project level as well as at the basin scale from infrastructure improvement. Good data combined with judicious use of economic principles have considerable potential to productively inform decisions on why, when, and how to develop and sustain irrigation and its infrastructure.

5. Conclusions

Many irrigated regions in the dry parts of the OECD countries face the challenge of aging infrastructure and a limited revenue base from which to fund maintenance and repair activities. The drive toward full cost recovery for storage and delivery services arising from emerging water reform policies means that both water suppliers and irrigators will need to consider the strategic evaluation of infrastructure renewal to remain viable.

This report has examined the economics of irrigation projects. It identified economic principles governing infrastructure investments for irrigated agriculture and described factors leading to increased demand for investment in irrigation infrastructure. In describing the economics of irrigation projects, the report characterized the optimal level of investment in irrigation and in irrigation infrastructure maintenance. It examined both financial and economic views of the optimal level of investment in irrigated agriculture. It also examined some of the historic causes of overinvestment in irrigation compared to investments that limited to ones passing a rigorous economic analysis. While the motivation for this report was a better understanding of the economics of maintaining off-farm irrigation infrastructure, the economic performance of those investments depends essentially on how the additional water produced is managed on the farm.

This report identified five factors that have promoted overinvestment in irrigated agriculture. These include water pricing based on ability to pay rather than marginal cost, financing mechanisms in which cross subsidies from hydropower charges finance irrigation development, pricing irrigation water below the marginal cost of supply, the potential for irrigators to renegotiate contracts after projects are built, and the incentive to overinvest in irrigation when irrigators believe they will secure a water right. Five factors were also identified that lead to a higher value of infrastructure maintenance. These include a lower price of water charged to irrigator, a lower real cost of repairing infrastructure, a greater water savings from infrastructure maintenance, higher crop yields produced by saved water, and a lower cost of capital.

Several market approaches were identified that could influence the economic attractiveness of investments in irrigation infrastructure. These include subsidies of infrastructure, clear titles to water rights that promote market transfers of water, and marginal cost pricing of irrigation water. Several policy approaches are also discussed. These include various regulatory solutions requiring infrastructure maintenance, development of water user associations, and river basin compacts, treaties and transboundary agreements.

Water markets as a source of financing for irrigation infrastructure improvement received special attention. Water markets provide an economically efficient measure for establishing the economic incentives to support maintenance of irrigation infrastructure. When a price is paid for water that would be gained by repaired infrastructure, that price seller signals the marginal cost of leaving the infrastructure unrepaired. So the development or improved efficiency of water banks, water rentals, water leasing, or other market forms of water transfers provide an important set of incentives to restore or repair aging irrigation infrastructure. The development of these water markets provides a way to harness the power of market incentives to self-finance irrigation infrastructure improvements. Where some kind of water market can be developed that reflect the income produced by infrastructure improvements, the burdens of searching for external finance can be reduced.

There is a considerable scarcity of available data are that can be used to formulate and implement plans to renew infrastructure economically. Important data needs would focus on assembly of detailed cost and return enterprise budgets for irrigated agriculture that account for financial and economic impacts of greater water supply and increased water supply reliability. Other important data needs would focus on the cost and productivity of measures that would maintain dams, canals, pipelines, aqueducts, pumping plants, drainage and flow regulating structures. Improvements in models of water supply and demand in alternative uses would be even more valuable.

There is considerable need for improved information in order that economic principles be put to best use in ensuring orderly maintenance of irrigation infrastructure. Information is needed on cost sharing arrangements between irrigators and public suppliers of irrigation, impacts on water savings at the project level as well as at the basin scale from infrastructure improvement. Research conducted for this report found almost no data on who owns what part of irrigation infrastructure in any of the OECD countries. Good data combined with judicious use of economic principles have considerable potential to productively inform decisions on why, when, and how to develop and sustain irrigation and its infrastructure.

Notes

[1] The U.S. Army Corps of Engineers (Corps) also operates and maintains a considerable inventory of dams and other water control infrastructure throughout the U.S. The Corps indicated that in FY2006 it had USD 1.8 billion in deferred maintenance for its civil works activities.

[2] Concerns remain, but they were higher before the early 1980s prior to the enactment of the Reclamation Reform Act of 1982 which set upper bounds on use of subsidized federal water.

[3] Important work has been conducted outside the OECD on connection between irrigation infrastructure and poverty. For example a study from Pakistan examined impacts on reduced poverty from irrigation infrastructure development. The major problem of agricultural production in Pakistan was shortage of irrigation water, affecting more than 60 percent of surveyed farm households. Results suggest that (1) access to irrigation infrastructure reduces the incidence of poverty; (2) upgrading watercourse lining helps save water, resulting in higher cropping intensity, higher crop productivity and improved farm incomes (Hussain *et al.*, 2007).

[4] While cost recovery is widely-embraced principle throughout the OECD countries it has to take into account that water infrastructure produces public goods, such as environmental benefits. The costs associated with these public goods should be recognised when calculating the cost recovery.

[5] Where enterprise budget data are available that summarise alternative water application rates against a background of other inputs that are fixed, budgets can accurately identify marginal income gained from the additional water. But budgets are rarely available in this form. More typically, budgets are built for one irrigation technology and water application rate per unit land. For this case, budgets well predict impacts of scale changes, but can say nothing about marginal impacts of higher water application rates.

[6] An important question centers on how to assign an economic value to any single resource such as irrigation water when several resources like land and water act jointly produce a single output. Average values of water in agriculture do not inform decisions in the debate over whether or not to develop a new water supply. The debate is properly informed economically only by the marginal value of water. However, the correct assignment of a marginal economic value to water is information on how physical crop yield changes with changes in only water, holding land, capital, and other inputs constant. That is, a production function is needed in which input proportions vary. Complete empirical production functions are difficult to estimate, requiring careful experimental conditions in which input mixes are varied. This kind of experimentation is expensive, and for that reason rare. Moreover, results often translate poorly to conditions outside where the experiment occurred.

[7] Regardless of the real cost of the irrigation project, such costs have little direct bearing on the cost-sharing arrangement and ultimately on the water charge negotiated between the government and the irrigators. The cost sharing arrangement is a political decision. Pricing water at a proportion of its marginal benefit encourages the development and use of water no matter how low those benefits are to the cost of development. If marginal benefits (additional farm incomes) are low because the water is used to grow alfalfa in a region with a 60 day season, then a percentage of that low farm income will give rise to a very low charge, no matter how high the cost of developing the water may be. It should be noted that in discussing the ability to pay concept, the share of water supply costs refer to the repayment of infrastructure development costs, not operation and maintenance of water delivery systems. It should also be noted that the U.S. Congress and not Reclamation establishes the rules for pricing water for federal reclamation projects. Finally, it should be noted that many of the irrigation districts have repaid in total the construction cost debt to the federal government.

[8] Where environmental values displaced are high, those costs can be considerably higher than the monetary cost of developing the irrigation.

[9] In U.S. water politics, an iron triangle describes the policy-making relationship between the Congress, federal agencies, and interest groups. For irrigation projects, the interest groups have organized around their own iron triangles consisting of banking, real estate, and farmers. This association has historically been strengthened considerably by federal irrigation subsidies.

[10] Responding to the problem of heavy use of water in irrigated agriculture promoted by underpriced water, reforms were enacted in the early 1980s. With the passage of the Reclamation Reform Act of 1982, the U.S. Congress increased the number of acres that a legal entity, such as a partnership or corporation, could irrigate with water from federal projects from 160 acres to 960 owned or leased acres. However, owned land above this limit could not be irrigated with federal water, and the act required irrigators to pay the full supply cost for water delivered to leased land over the limit. The concept of full supply-cost pricing enacted in this legislation, presented a significant departure from prior reclamation law. The full supply-cost rate is an annual rate intended to repay over time the portion of the federal government's expenditures for project construction allocated to irrigation, including the operation and maintenance expenses, with interest. Since the 1982 Reclaimation Act, the 1986 statutory requirement and the 1992 Central Valley Project Improvement Act have generated notable increases in irrigation prices in California's Central Valley (Wichelns, 2010b).

[11] Communicating water's value in agriculture to urban interests presents its own challenges. For example, the Australian irrigation sector has found it harder to communicate to the wider population the economic benefits of irrigation. So irrigation water suppliers are examining better ways to communicate. These include financial, environmental, and cultural elements. This triple bottom line evaluation attempts to provide a more balanced view of water use with economic benefits and environmental consequences (Christen, *et al.,* 2005).

[12] The comparison to urban water prices requires careful analysis. In general, urban values are higher than those for irrigation. However, urban costs are also higher because they must pay for (1) water treatment, (2) sewage and (3) urban delivery infrastructure, in addition to the price of the raw water. In many of the world's river basins, urban water deliveries also require considerable additional pumping costs. Common denominator comparisons between urban and irrigation marginal values require subtracting urban production costs from the gross marginal value of urban treated water. Moreover, while the marginal value of water in urban uses is usually higher than the same water used for irrigation, this value represents a correct opportunity cost of water use by agriculture for only a small share of irrigation water currently in use. The very large quantity of water used by agriculture compared to water used in urban areas suggests that a transfer of, say 10% of irrigation water to urban uses, represents a large percent increase in urban water supplies. Such a transfer considerably drives down the marginal value of water in urban uses.

[13] Water lost to failure to maintain infrastructure at one point in a river basin can end up flowing to greater water supply at another point or another time period in the same basin, as described by Ward and Pulido-Velazquez (2008). Similarly increased maintenance of irrigation infrastructure that makes more water available at the point of repair can take water away from other users in a hydrologically connected basin.

[14] Water markets have other advantages, too. For example recent work from Australia found water markets to be an good institution for managing uncertainty of future water supplies in Australian irrigated agriculture (Bjornlund, 2006). In dry places a more highly developed or advanced infrastructure can substitute for water supply risks and can help cope with future climate change. A recent Spanish study examined effects of water markets as an institution that can substitute for growing economic risk caused by unreliable water in the Gaudalquivir Valley District in southern Spain (Calatrava and Garrido, 2005). Recent work from Mexico found considerable benefit in the use of water markets to promote water transfers from irrigators to urban users to address growing water scarcity in that country (Gastelum and Stewart, 2009). More recent work from both Spain and Mexico found that either water markets or reservoirs or both can reduce the risks of unreliable of water supply (Iglesias and Garrido, 2003; Unver and Gupta, 2003).

[15] In the US, general stream adjudications are judicial proceedings to determine the extent and priority of all water right claims in an entire river basin. Most of the western states have started general stream adjudication for their important river basins. A water rights priority determines who has the better water right in periods of drought when streamflows are low or when supplies are reduced from failure to maintain infrastructure. Adjudications are necessary to provide legal clarity for all those who have water right claims. When a court of law confirms a water right, that right becomes enforceable against other water users and can be protected from impairment by illegal users. When a stream has been adjudicated, the right divert water is regulated in favor of senior water right holders during times of drought. Adjudications also provide information necessary for decision-making regarding the impact of granting new rights and proposed changes to existing rights.

Bibliography

Akkuzu, E., H. B. Unal, and B. S. Karatas. 2007. Determination of Water Conveyance Loss in the Menemen Open Canal Irrigation Network. Turkish Journal of Agriculture and Forestry. 31: 11-22.

Aldakheel, Y., and F. Zeineldin. 2007. Improving Conveyance and Distribution Efficiency through Conversion of an Open Channel Lateral Canal to a Low Pressure Pipeline at Al-Hassa Irrigation Project, Saudi Arabia. Arabian Journal for Science and Engineering. 32: 77-86.

Alvarez, C. J., J. J. Cancela, and M. Fandino. 2005. Characterization of Irrigated Holdings in the Terra Cha Region of Spain: A First Step Towards a Water Management Model. Water Resources Management. 19: 23-36.

Ashraf, M., M. A. Kahlown, and A. Ashfaq. 2007. Impact of Small Dams on Agriculture and Groundwater Development: A Case Study from Pakistan. Agricultural Water Management. 92: 90-98.

Barbero, Á. 2005. The Spanish National Irrigation Plan. OECD Workshop on Agriculture and Water: Sustainability, Markets, and Policies, Session 5. Adelaide, South Australia. 14-18 November.

Bartolini, F., G. M. Bazzani, V. Gallerani, M. Raggi, and D. Viaggi. 2007. The Impact of Water and Agriculture Policy Scenarios on Irrigated Farming Systems in Italy: An Analysis Based on Farm Level Multi-Attribute Linear Programming Models. Agricultural Systems. 93: 90-114.

Batterink, M. 2005. Allocation of Costs and Benefits in the Water Framework Directive: A Dutch Exploration. OECD Workshop on Agriculture and Water: Sustainability, Markets, and Policies, Session 2. Adelaide, South Australia. 14-18 November.

Bazzani, G. M. 2005. A Decision Support for an Integrated Multi-Scale Analysis of Irrigation: DSIR. Journal of Environmental Management. 77: 301-314.

Bear, S., A. Hall, and L. Pechey. 2006. Irrigation Infrastructure Charging: Non-Rival Access, Cost Sharing, and Exclusion. 50th Annual conference of the Australian Agricultral and Resource Economics Society. Sydney, Australia. February 8-10.

Berbel, J., and J. A. Gomez-Limon. 2000. The Impact of Water-Pricing Policy in Spain: An Analysis of Three Irrigated Areas. Agricultural Water Management. 43: 219-238.

Berktay, A., B. Nas, and A. Demirbas. 2006. Contribution of Konya Plain Projects to the National Development in Turkey's Water-Related Energy. Energy Exploration & Exploitation. 24: 87-94.

Bjornlund, H. 2006. Can Water Markets Assist Irrigators Managing Increased Supply Risk? Some Australian Experiences. Water International. 31: 221-232.

Boland, A. M., D. Bewsell, and G. Kaine. 2006. Adoption of Sustainable Irrigation Management Practices by Stone and Pome Fruit Growers in the Goulburn/Murray Valleys, Australia. Irrigation Science. 24: 137-145.

Bontemps, C., and S. Couture. 2002. Irrigation Water Demand for the Decision Maker. Environment and Development Economics. 7: 643-657.

Brennan, D. 2008. Factors Affecting the Economic Benefits of Sprinkler Uniformity and Their Implications for Irrigation Water Use. Irrigation Science. 26: 109-119.

Calatrava, J., and A. Garrido. 2005. Spot Water Markets and Risk in Water Supply. Agricultural Economics. 33: 131-143.

Carey, J. M., and D. Zilberman. 2002. A Model of Investment under Uncertainty: Modern Irrigation Technology and Emerging Markets in Water. American Journal of Agricultural Economics. 84: 171-183.

Chakravorty, U., and C. Umetsu. 2003. Basinwide Water Management: A Spatial Model. Journal of Environmental Economics and Management. 45: 1-23.

Christen, E. W., W. S. Meyer, N. S. Jayawardane, M. Shepheard, D. Robinson, A. Marshall, and H. Fairweather. 2005. Triple Bottom Line Reporting to Promote Sustainability of Irrigation in Australia. OECD Workshop on Agriculture and Water: Sustainability, Markets, and Policies. Adelaide, South Australia. 14-18 November.

Connor, J. 2008. The Economics of Time Delayed Salinity Impact Management in the River Murray. Water Resources Research.

Cortina, L. M., and N. Hernandez-Mora. 2003. The Role of Groundwater in Spain's Water Policy. Water International. 28: 313-320.

Cuesta, T. S., J. J. Cancela, J. Dafonte, M. Valcarcel, and X. X. Neira. 2005. Social Aspects Influencing Water Management in the Lemos Valley Irrigation District, Spain. Irrigation and Drainage. 54: 125-133.

da Silva, L. M., J. R. Park, J. D. H. Keatinge, and P. A. Pinto. 2001. I. A Decision Support System to Improve Planning and Management in Large Irrigation Schemes. Agricultural Water Management. 51: 187-201.

Dhawan, B. D. 1997. Large-Scale Canal Irrigation - How Cost Effective? Economic and Political Weekly. 32: A71-A77.

Dinar, A., and J. Mody. 2004. Irrigation Water Management Policies: Allocation and Pricing Principles and Implementation Experience. Natural Resources Forum. 28: 112-122.

Dirksen, W. 2002. Water Management Structures in Europe. Irrigation and Drainage. 51: 199-211.

Doak, M. 2005. Value of Irrigation in New Zealand. OECD Workshop on Agriculture and Water: Sustainability, Markets, and Policies. 14-18 November.

Easter, W., and Y. Liu. 2005. Cost Recovery and Water Pricing for Irrigation and Drainage Projects. World Bank: Agricultural Rural Development Discussion Paper 26, Washington, D.C.

Evans, J. P., and B. F. Zaitchik. 2008. Modeling the Large-Scale Water Balance Impact of Different Irrigation Systems. Water Resources Research. 44:

Fais, A., R. Napoli, P. Nino, P. Bazzoffi, and N. Laruccia. 2005. Irrigation Sustainability in the Land Use/Soil System in South Italy: Results from a G.I.S. Simplified Approach and Future Methodological Developments. OECD Workshop on Agriculture and Water: Sustainability, Markets, and Policies, Session 4. Adelaide, South Australia. 14-18 November.

Farmani, R., R. Abadia, and D. Savic. 2007. Optimum Design and Management of Pressurized Branched Irrigation Networks. Journal of Irrigation and Drainage Engineering-ASCE. 133: 528-537.

Garrido, A. 2005. Using Good Economic Principles to Make Irrigators Become True Partners of Water and Environmental Policies. OECD Workshop on Agriculture and Water: Sustainability, Markets, and Policies, Session 1. Adelaide, South Australia. 14-18 November.

Gastelum, J. R., J. B. Valdes, and S. Stewart. 2009. An Analysis and Proposal to Improve Water Rights Transfers on the Mexican Conchos Basin. Water Policy. 11: 79-93.

Herrera, P. A., G. Van Huylenbroeck, and R. L. Espinel. 2006. Asymmetric Information on the Provision of Irrigation through a Public Infrastructure: The Case of the Peninsula of Santa Elena, Ecuador. Water Resources Management. 20: 431-447.

Hervé, and Plusquellec. 2009. Modernization of Large-Scale Irrigation Systems: Is It an Achievable Objective or a Lost Cause. Irrigation and Drainage. 58: S104-S120.

Howell, T. A. 2001. Enhancing Water Use Efficiency in Irrigated Agriculture. Agronomy Journal. 93: 281-289.

Hussain, I., W. Jehangir, M. Mudasser, A. Nazir, and M. Ashfaq. 2007. Impact Assessment of Irrigation Infrastructure Development on Poverty Alleviation: A Case Study from Pakistan. Japan Bank for International Cooperation.

Iglesias, E., A. Garrido, and A. Gomez-Ramos. 2003. Evaluation of Drought Management in Irrigated Areas. Agricultural Economics. 29: 211-229.

Islam, A., N. S. Raghuwanshi, and R. Singh. 2008. Development and Application for Irrigation of Hydraulic Simulation Model Canal Network. Journal of Irrigation and Drainage Engineering-ASCE. 134: 49-59.

Kahlown, M. A., and W. D. Kemper. 2004. Seepage Losses as Affected by Condition and Composition of Channel Banks. Agricultural Water Management. 65: 145-153.

Khan, S., S. Mushtaq, and C. Chen. 2009. A Decision Support Tool for Irrigation Infrastructure Investments. Irrigation and Drainage (forthcoming).

Knapp, K. C., M. Weinberg, R. Howitt, and J. F. Posnikoff. 2003. Water Transfers, Agriculture, and Groundwater Management: A Dynamic Economic Analysis. Journal of Environmental Management. 67: 291-301.

Kosgei, J. R., G. P. W. Jewitt, V. M. Kongo, and S. A. Lorentz. 2007. The Influence of Tillage on Field Scale Water Fluxes and Maize Yields in Semi-Arid Environments: A Case Study of Potshini Catchment, South Africa. Physics and Chemistry of the Earth. 32: 1117-1126.

Labadie, J. W., D. G. Fontane, J. H. Lee, and I. H. Ko. 2007. Decision Support System for Adaptive River Basin Management: Application to the Geum River Basin, Korea. Water International. 32: 397-415.

Lange, M., A. Winstanley, and D. Wood. 2008. Drivers and Barriers to Water Transfer in a New Zealand Irrigation Scheme. Journal of Environmental Planning and Management. 51: 381-397.

Lisson, S. N., L. E. Brennan, K. L. Bristow, B. A. Keating, and D. A. Hughes. 2003. Dam Easy - Software for Assessing the Costs and Benefits of on-Farm Water Storage Based Production Systems. Agricultural Systems. 76: 19-38.

Machingambi, M., and E. Manzungu. 2003. An Evaluation of Rural Communities' Water Use Patterns and Preparedness to Manage Domestic Water Sources in Zimbabwe. Physics and Chemistry of the Earth. 28: 1039-1046.

Malek-Mohammadi, E. 1998. Irrigation Planning: Integrated Approach. Journal of Water Resources Planning and Management-Asce. 124: 272-279.

Malik, R. P. S. 2008. Towards a Common Methodology for Measuring Irrigation Subsidies. The Global Subsidies Initiative of the International Institute for Sustainable Development, http://www.globalsubsidies.org/files/assets/pdf/irrigation__methodology.pdf.

Marshall, G. R. 2004. Farmers Cooperating in the Commons? A Study of Collective Action in Salinity Management. Ecological Economics. 51: 271-286.

Martin, W. E. 1988. Back to the Future: A Willingness to Play Reexamined. Western Journal of Agricultural Economics. 13: 112-120.

Martin, W. E., H. Ingram, and N.Laney. 1982. A Willingness to Play: Analysis of Water Resources Development. Western Journal of Agricultural Economics. 7: 133-139.

Meijer, K., E. Boelee, D. Auqustijn, and I. van der Molen. 2006. Impacts of Concrete Lining of Irrigation Canals on Availability of Water for Domestic Use in Southern Sri Lanka. Agricultural Water Management. 83: 243-251.

Merriam, J. L., and B. J. Freeman. 2007. Operational Cost Benefits Study of Flexible on-Farm Irrigation Supply Systems. J. Irrig. and Drain. Engineering. 133: 12-16.

Molden, D., and T. K. Gates. 1990. Performance Measures for Evaluation of Irrigation-Water-Delivery Systems. Irrigation and Drainage Engineering. 116: 804-823.

Moore, M. R. 1991. The Bureau of Reclamation's New Mandate for Irrigation Water Conservation: Purposes and Policy Alternatives. Water Resources Research. 27: 145-155.

Mvungi, A., D. Mashauri, and N. F. Madulu. 2005. Management of Water for Irrigation Agriculture in Semi-Arid Areas: Problems and Prospects. Physics and Chemistry of the Earth. 30: 809-817.

North, R., and W. P. Neely. 1977. A Model for Achieving Consistency for Cost-Sharing in Water Resources Programs. Water Resources Bulletin. 13: 995-1007.

OECD. 2001. OECD Environmental Strategy for the First Decade of the 21st Century. Paris, http://www.oecd.org/dataoecd/33/40/1863539.pdf.

OECD. 2003. Environmental Performance Reviews: Water Performance and Challenges in OECD Countries, Paris.

OECD. 2008. Environmental Performance of Agriculture at a Glance. Paris, http://www.oecd.org/dataoecd/61/28/40953155.pdf.

OECD. 2009. Managing Water for All: An OECD Perspective on Pricing and Financing, Key Messages for Policy Makers. Paris, http://www.oecd.org/dataoecd/53/34/42350563.pdf.

OECD Council. 2007. OECD Principles for Private Sector Participation in Infrastructure. Paris, http://www.oecd.org/dataoecd/41/33/38309896.pdf.

Parris, K. 2008. Irrigation Infrastructure Financing across OECD Countries (Personal Communication with Author).

Parris, K. and P. K. Jung, editors. 2003. *Agricultural Water Quality and Water Use Indicators in the Context of the OECDd Work on Agri-Environmental Indicators*. OECD Secretariat, Paris, France, Gyeongju, Republic of Korea.

Parris, K., and W. Legg. 2006. Water and Farms: Towards Sustainable Use. *OECD Observer*, OECD Directorate for Food, Agriculture and Fisheries, www.oecdobserver.org/news/fullstory.php/aid/1801/Water_and_farms:_Towards_sustainable_use.html.

Peck, D. E., D. M. McLeod, J. P. Hewlett, and J. R. Lovvorn. 2004. Irrigation-Dependent Wetlands Versus Instream Flow Enhancement: Economics of Water Transfers from Agriculture to Wildlife Uses. Environmental Management. 34: 842-855.

Pitman, G. T. K. 2004. Project Performance Performance Assessment Report: Armenia Irrigation Rehabilitation Proejct. World Bank.

Pujol, J., J. Berbel, F. Ramirez-De-Cartagena, D. Viaggi, and M. Raggi. 2006. Evaluation of Markets for Irrigation Water in the Internal River Basins of Catalonia, Spain. Spanish Journal of Agricultural Research. 4: 3-16.

Renault, D. 2000. Operational Sensitivity of Irrigation Structures. Journal of Irrigation and Drainage Engineering-Asce. 126: 157-162.

Rieu, T. 2005. Water Pricing for Agriculture between Cost Recovery and Water Conservation: Where Do We Stand in France ? OECD Workshop on Agriculture and Water: Sustainability, Markets, and Policies, Session 2. Adelaide, South Australia. 14-18 November.

Rodriguez, L. B., P. A. Cello, and C. A. Vionnet. 2006. Modeling Stream-Aquifer Interactions in a Shallow Aquifer, Choele Choel Island, Patagonia, Argentina. Hydrogeology Journal. 14: 591-602.

Scheierling, S. M., R. A. Young, and G. E. Cardon. 2006. Public Subsidies for Water-Conserving Irrigation Investments: Hydrologic, Agronomic, and Economic Assessment. Water Resources Research. W03428 doi:10.1029/2004 WR003809: W03428-W03428.

Schoups, G., C. L. Addams, J. L. Minjares, and S. M. Gorelick. 2006. Sustainable Conjunctive Water Management in Irrigated Agriculture: Model Formulation and Application to the Yaqui Valley, Mexico. Water Resources Research.

Simon, B. M. 2002. Devolution of Bureau of Reclamation Constructed Water Facilities. Journal of the American Water Resources Association. 38: 1187-1194.

Singh, R. 1994. Social Cost-Benefit-Analysis of Investment in Irrigation. Economic and Political Weekly. 29: 1210-1217.

Snell, M. 2001. Lining Old Irrigation Canals: Thoughts and Trials. Irrigation and Drainage. 50: 139-157.

Sofios, S., and S. Polyzos. 2009. Water Resources Management in Thessaly Region Greece and Their Impact on the Regional Development. Journal of Environmental Protection and Ecology. 10: 244-265.

Sur, M., D. Umali-Deininger, and A. Dinar. 2002. Water Related Subsidies in Agriculture: Environmental and Equity Consequences. OECD workshop on Environmentally Harmful Subsidies, Nov.7-8, 2002. Paris. November 7-8.

Svendsen, M., F. Gonzalez, and S. Johnson. 2003. Privatizing Canal Irrigation. Irrigation and Drainage. 52: 95-108.

Tardieu, H. 2003. Irrigation, Economic Regulation and Sustainability. Houille Blanche-Revue Internationale De L Eau. 86-91.

Tilmant, A., D. Pinte, and Q. Goor. 2008. Assessing Marginal Water Values in Multipurpose Multireservoir Systems Via Stochastic Programming. Water Resources Research.

Turner, B., and G. M. Perry. 1997. Agriculture to Instream Water Transfers under Uncertain Water Availability: A Case Study of the Deschutes River, Oregon. Journal of Agricultural and Resource Economics. 22: 208-221.

United Nations. 2006. Enhancing Regional Cooperation in Infrastructure Development Including That Related to Disaster Management. www.preventionweb.net/english/professional/publications/v.php?id=8981.

Unver, O., and R. K. Gupta. 2003. Water Pricing: Issues and Options in Turkey. International Journal of Water Resources Development. 19: 311-330.

Velez, E. P., and L. F. Perez. 2000. Reservoir Operating Policies for Irrigation Districts in Mexico. Ingenieria Hidraulica En Mexico. 15: 127-132.

Ward, F. A. 2007. Decision Support for Water Policy: A Review of Economic Concepts and Tools. Water Policy. 9: 1-31.

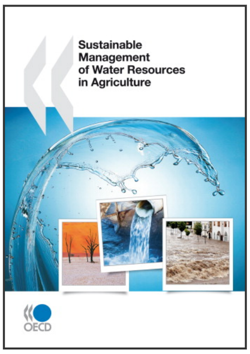
Ward, F. A., and M.Pulido-Velazquez. 2008. Water Conservation in Agriculture Can Increase Water Use. Proceedings of the National Academy of Sciences. 105: 18215-18220.

Ward, F. A., A. M. Michelsen, and L. DeMouche. 2007. Barriers to Water Conservation in the Rio Grande Basin. Journal of the American Water Resources Association. 43: 237-253.

White, D. H., N. Beynon, and O. Kingma. 2006. Identifying Opportunities for Achieving Water Savings Throughout the Murray-Darling Basin. Environmental Modelling & Software. 21: 1013-1024.

Wichelns, D. (2010), *Agricultural Water Pricing: United States*, OECD, Paris.

Young, R. A. 1978. Economic Analysis and the Federal Irrigation Policy: A Reappraisal. Western Journal of Agricultural Economics. 3: 257-267.



From:

Sustainable Management of Water Resources in Agriculture

Access the complete publication at:

https://doi.org/10.1787/9789264083578-en

Please cite this chapter as:

Ward, Frank A. and Alberto Garrido (2010), “Financing Water Management and Infrastructure related to Agriculture across OECD Countries”, in OECD, *Sustainable Management of Water Resources in Agriculture*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264083578-11-en