Chapter 1

Setting the Scene: Hydrology and Economics of Water Resource Management in Agriculture

1.1. Hydrology

There is a high level of diversity in hydrological conditions and farming systems operating in a greatly varying set of political, cultural legal and institutional contexts, both across and within OECD countries. Management of water resources in agriculture includes a spectrum of options (Figure 1.1). These include totally rain-fed dependent farming systems, where on-farm conservation practices focus on storing water in the soil. As climatic conditions become drier and dry season shortages more frequent (moving from left to right along the spectrum in Figure 1.1), increasing use is made of supplemental surface water and groundwater sources to enhance crop production, and in some cases other water sources (*e.g.* recycled wastewater and desalinated water).

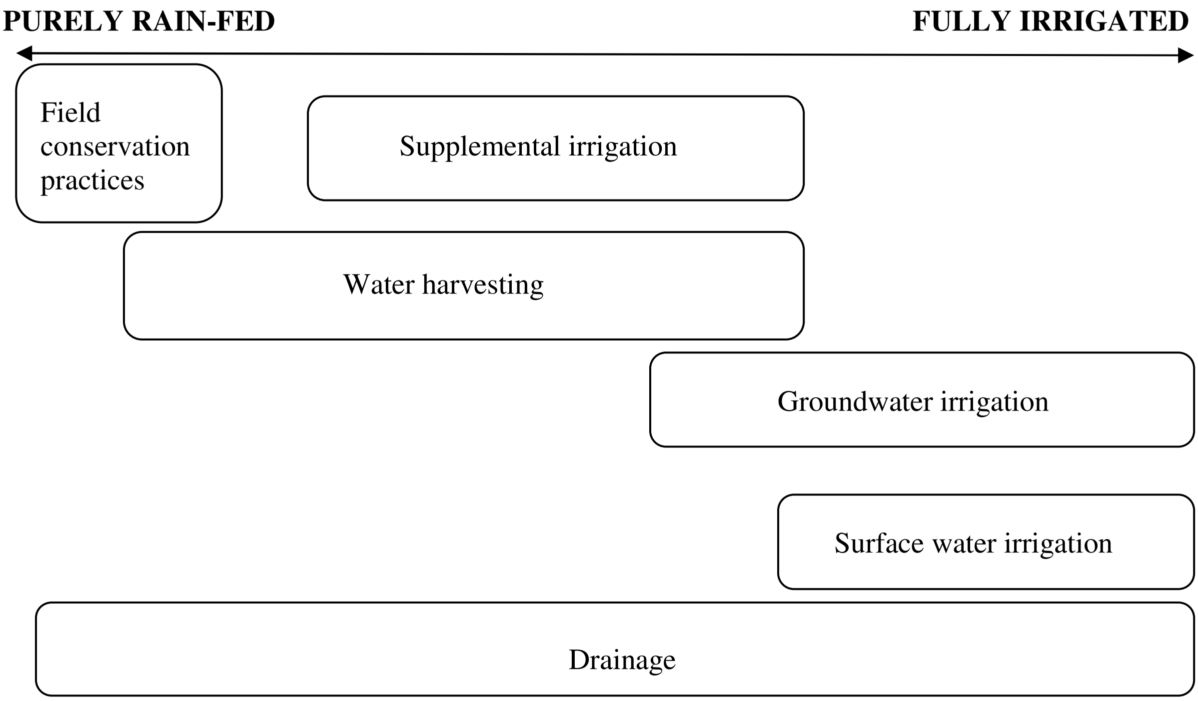
For semi-arid and arid regions agriculture maybe totally dependent (but not always) on irrigation from groundwater and stored surface water supplies (Box 1.1). Under monsoonal conditions agriculture can also be dominated by irrigated farming, but these systems are more concerned with controlling the large volumes of rainfall received during the wet season and ensuring sufficient supplies during the dry season.

Irrigated agriculture in OECD countries and globally, has been associated with bringing significant gains, not only to the private benefit of farmers, but providing a public benefit in terms of expanding food production, and positive externalities, such as contributing to rural development. Irrigation adds flexibility and competiveness to agriculture, especially in those regions where seasonal rainfall patterns would make farming extremely difficult (in some cases impossible) without irrigation. The benefits associated with irrigated agriculture need to be taken into account when considering the negative externalities and inefficiencies with inappropriate irrigation practices and system management.

Agricultural water resource management systems in OECD countries can be broadly categorised into two groups (Figure 1.2), comprising first, those countries where irrigation plays a major role in the farm sector, both in terms of the share in the total value of agricultural production and agricultural exports, and, second, countries where farming operates under predominantly rain-fed conditions. Figure 1.2 further sub-divides countries within these two broad categories, according to how rapidly the area irrigated is expanding, and with commentary on the trends over the past 20 years (or projected trends) on the incidence and severity of flood and drought events as they impact agriculture.

There are agricultural regions within some countries that may fit all the categories shown in Figure 1.2. This is notably the case for countries with a highly varied range of climatic conditions, such as **Australia, Canada, France, Italy, Mexico, Spain** and the **United States**. The irrigated farming in the Murray Darling Basin in **Australia**, for example, accounts for around 40% Australia's total value of agricultural production, and two-thirds of Australia's total irrigated land and over 50% of national water withdrawals (Australian Bureau of Statistics, 2008).

Figure 1.1. Diverse options for agricultural water management



Source: IWMI (2007).

The ***physical water availability*** for agriculture is determined by precipitation (rainfall and snowpack melt) and the effective mean runoff that flows into surface water and groundwater stores (Productivity Commission, 2006), as well as other sources of water (Box 1.1). Globally average rainfall increased by about 2% over the period 1900 to 1998 (Huntington, 2006). But regional variations in rainfall are highly significant rising over this period, by 7-12% between 30^0N-85^0N, compared with a 2% increase for 0^0S-55^0S, but with substantial reductions in some regions.

A key issue in hydrology is that with climate warming in the future there could be an intensification of the water cycle leading to changes in precipitation and an increase in the intensity and frequency of floods and drought (Chapter 2.2). Based on a survey of OECD countries the incidence and severity of flood and droughts has been increasing for the majority of countries (Figure 1.2). Many of these countries also project that with climate change the incidence and severity of flood and drought events may continue to increase, while other research also supports an ongoing intensification of the hydrologic cycle (Huntington, 2006; IPCC 2008). This highlights the need to: improve capabilities to monitor and predict the consequences of changing hydrologic regimes; reduce current levels of scientific uncertainty; and establish longer periods of data collection, combined with enhanced understanding of the complex feedbacks involving water systems (Huntington, 2006; and Chapter 3.6).

While agriculture is affected by changes in hydrologic conditions, ***the expansion and intensification of agriculture has also altered the natural hydrology*** of surface water, groundwater and the environment (Gordon *et al.,* 2007). This applies to rain fed farming systems, but is especially relevant to irrigated areas where upstream extractions and storage reduce the quantity available for environmental services, floodplains, and other uses downstream, including irrigation (Productivity Commission, 2006). There remains a considerable policy challenge to identify ways to build resilience to the hydrologic changes caused by agriculture.

Water is used for a variety of purposes, from which society derives a range of values (FAO, 2004). Some of these use categories are defined in Figure 1.3 (Moran and Dann, 2008). Many of the uses of water are well understood and easily monitored (*e.g.* surface water), but for others the science is poorly developed (*e.g.* groundwater recharge and flows). In addition, while the economic valuation of some water uses are established (*e.g.* crop production), many of the externalities and public goods associated with water systems are inherently difficult to value (*e.g.* support for wildlife, amenity and cultural values) (Chapter 3.6).

Box 1.1. Water sources and characteristics with regard to agriculture

The ***principal sources of water supplies for agriculture*** are rainfall and "stored" sources, mainly surface water (rivers and lakes) and ***groundwater*** (shallow and deep aquifers). In some countries agriculture may draw for part of its supplies on the main water supply distribution network (mainly used by urban and industrial users), but this can be an expensive option. For some countries sharing surface and groundwater across national boundaries is important (*e.g.* Mexico-US, Portugal-Spain).

For those regions where competition for scarce water resources is more intensive, there is growing interest in using ***recycled water,*** mainly from processed drainage water or sewage water, and also ***desalinated water*** largely from seawater but also saline aquifers. But both options, recycled and desalinated water, provides only a very small and highly localised supply of water for agriculture in most situations. Moreover, use of recycled water has raised health concerns when applied to agricultural land, especially where horticultural crops are grown. Desalinated water, although once a costly option, is now a much lower-cost option, with technological improvements which have greatly reduced costs and the energy needed to produce desalinated water.

The ***physical characteristics*** of fresh water resources are well documented. In brief, for surface water these mainly include site-specificity, mobility, variability and uncertainty, bulkiness and solvent properties. Groundwater shares similar characteristics but has other attributes setting it apart, including relative immobility, security and divisibility. Surface water and groundwater are components of a water catchment, an area of land supplying water to a common watercourse which is host to a variety of socio-ecological systems. The interdependent components of a catchment – land, vegetation, fauna, human – are linked together by the water component (*e.g.* rivers, lakes, dams, reservoirs, irrigation networks or systems, groundwater, stormwater and wastewater). The concept of water catchment is also referred to as a watershed, water or drainage basin.

Source: Adapted from Molle and Berkoff (2007a); Syme *et al.* (2008).

Figure 1.2. Typology of agricultural water resource management systems across OECD countries

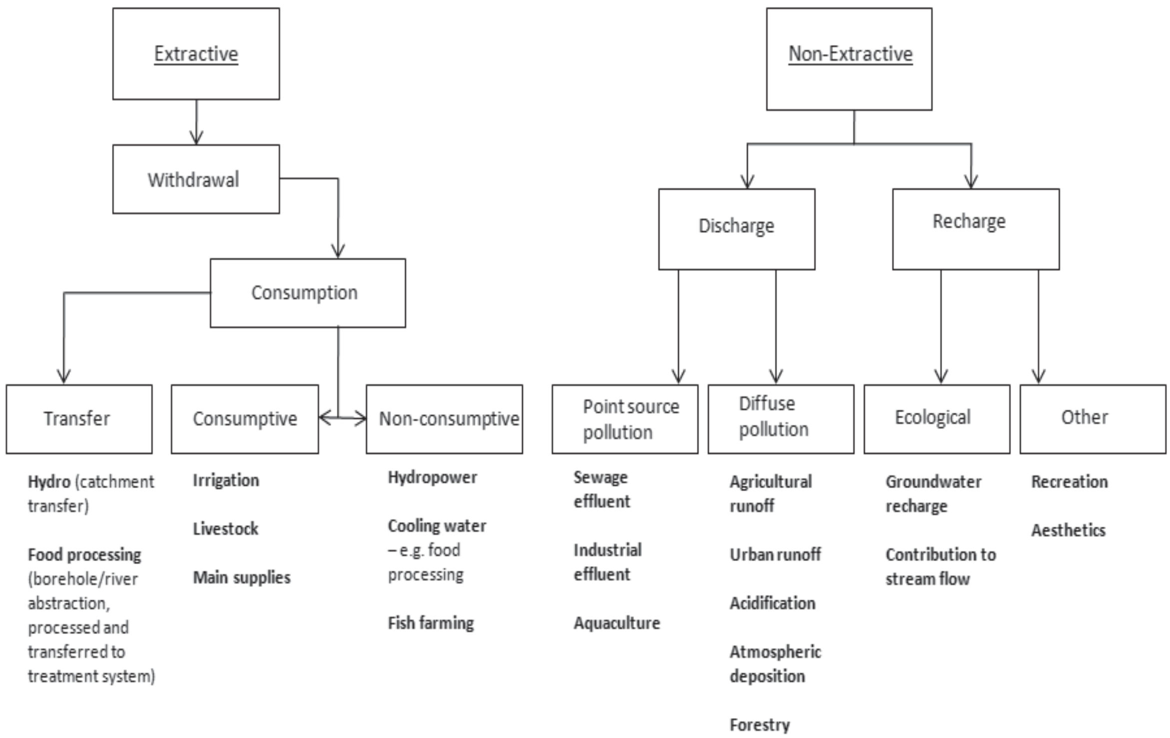
OECD COUNTRIES WHERE IRRIGATION PLAYS A MAJOR ROLE IN THE AGRICULTURAL SECTOR					
A major share of agricultural production operating under climatic conditions requiring irrigation during seasonal dry periods				**Irrigation operating in largely monsoon conditions, dominated by paddy farming**	
Area under irrigation has grown rapidly since 1990		**Area under irrigation has grown slowly or declined since 1990**			
	Comments		*Comments*		*Comments*
Australia	Drought events increasing	**Italy**	Drought events increasing	**Japan**	Flood events increasing
Greece	Flood/drought events increasing	**Mexico**	More prolonged drought events		
Spain	Drought events increasing	**Portugal**	Drought events increasing	**Korea**	Flood events increasing
Turkey	Flood/drought events increasing	**United States**	Drought events increasing		

OECD COUNTRIES WHICH HAVE PREDOMINANTLY RAIN-FED AGRICULTURAL SYSTEMS					
Agricultural systems predominantly rain-fed, but requiring irrigation in some regions during the summer dry period				**Agricultural systems almost entirely rain-fed, with little or no irrigation**	
Irrigated agriculture is rapidly expanding		***Irrigated agriculture is expanding slowly or declining***			
	Comments		*Comments*		*Comments*
Canada	Drought events increasing	**Denmark**	Flood events increasing	**Austria**	Drought events increasing
New Zealand	Flood/ drought events increasing	**France**	Drought events increasing	**Belgium**	Flood/drought events increasing
		Germany	Projected increase in area irrigated	**Czech Republic**	Flood events increasing
		Hungary	Flood/drought events increasing	**Finland**	Flood events increasing
		Netherlands	Flood/drought events increasing	**Iceland**	No information
		Slovak Rep.	Drought events increasing	**Ireland**	Flood events increasing
		Switzerland	Projected increase demand for irrigation	**Luxembourg**	No information
				Norway	No clear evidence
				Poland	Flood/drought events increasing
				Sweden	Flood events increasing
				United Kingdom	Flood/drought events increasing

Trends in drought/flood events for most countries reflect regional trends, rather than a nationwide pattern.

Source: OECD Secretariat, based on Figure 2.2, and responses from member countries to an OECD questionnaire at www.oecd.org/water.

Figure 1.3. Defining uses of water



Source: This figure does not provide exhaustive coverage of the uses of water use and mainly focuses on uses related to agriculture, and is adapted from Moran and Dann (2008).

The characteristics of ***water use in agriculture*** set it apart in many ways from its use in domestic household and industrial sectors. Diversions for consumptive use are invariably larger than the fraction actually consumed with the balance returning to the water system (Molle and Berkoff, 2007a). Agriculture usually accounts for the major share of water withdrawals for consumptive use in most OECD countries (over 40%), with evapotranspiration accounting for 40-60% of agricultural withdrawals rising to 70% with repeated reuse in modern irrigation systems. Agriculture can also contribute positively to the hydrological cycle in some irrigation systems, for example, through groundwater recharge and water purification functions, but also have negative impacts through pollution or excessive pumping.

Water losses from agriculture are an important water policy concern, especially in situations of water stress. Depending on site-specific factors, some water is irretrievably lost to the hydrologic system. What returns to the water system (as surface return flow and groundwater percolation) is often altered in time, location, and quality. In particular, the characteristics of irrigation losses have important implications for the effectiveness of water-efficiency improvement in achieving net water savings. While improvements in the physical efficiency of water use may indeed result in a decline in water consumption, actual water saved is less clear, due to changes in area irrigated and water use per hectare.

1.2. Economics

In the past to address some of the hydrologic challenges focus was typically placed on influencing the performance of farmers by the manipulation of the hydrologic cycle through engineering solutions, such as building new dams and canal networks. Increasingly, however, emphasis is being placed by many countries to improve the economic and environmental performance of the water system through providing economic incentives by taking into account the cost, value, price and demand for water in agriculture (Molle and Berkoff, 2007a).

With growing intersectoral competition for water and increasing emphasis on environmental externalities associated with agriculture, from around the late 1980s the policy agenda shifted to considering the economic and environmental dimensions of water. A key turning point was the ***Dublin International Conference on Water in 1992***, which stressed that "managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources" (Molle and Berkoff, 2007b).

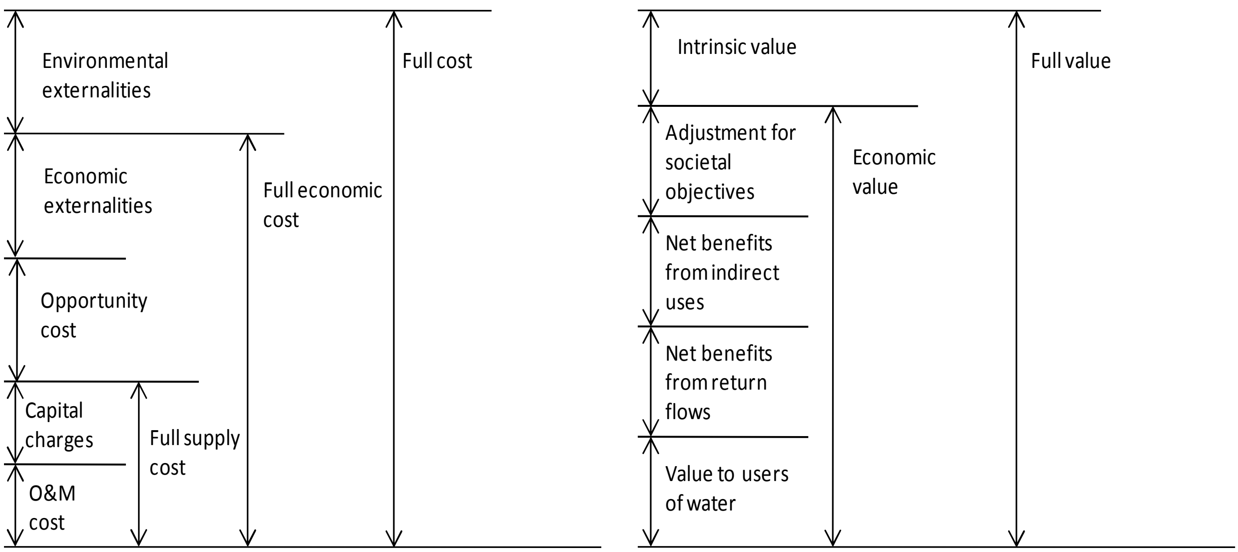
There are some distinctive economic features that make the supply and demand for water more complex than other economic goods and services, including (Hanemann, 2006; Thompson, 2006):

- Private (extraction) and public good (stewardship) characteristics of water imply different allocation mechanisms. When water is used on a farm it is a private good, but when left in situ, such as a lake or wetland, it is a public good for which private markets are generally absent. Moreover, water is largely used by the private sector (farms, households, industry) but its ownership and delivery is normally in the public domain;
- Mobility of water, in that it flows, leaches, evaporates, and has the opportunity to be reused, which makes it distinctive as a commodity compared to land, for example. Moreover, agriculture can contribute positively to the hydrological cycle, for example, through groundwater recharge and water purification functions; it can, however, also contribute to surface water and groundwater pollution and through excessive extraction may lead to diversion of water from supporting ecosystems;
- Heterogeneity of water in terms of space, quality and variability over time (seasonal and annual), which presents challenges in terms of matching supply and demand and structuring legal and institutional arrangements, as a given quantity of water is not the same as another available at a different location, point in time, quality and probability of occurrence;
- Critical nature of water is evident in terms of sustaining human life and agricultural production, but beyond minimum thresholds to maintain life and farming this notion conveys no information on the productivity or value of water, for example, the marginal value of applying 80 or 90 cm of water to irrigate cotton; and, the

- Complex and multi-layered institutional and governance arrangements for water resources, reflected in the national institutions and governance of water resources (and in some cases cross national border structures) and sub-national regional and local governments (water user associations) management of water, while the governance of surface water and groundwater are often separated.

Understanding the economics of water can help inform decision makers of the full social costs of water use in agriculture and the full social value or benefits that agriculture's use of water can provide (Hanemann, 2006). The usefulness of understanding these concepts for policy analysis is the transparency they bring in terms of how the value of water to society is more that just as an agricultural input, and to clarify what the costs are of agriculture's use of water resources (Malik, 2008; Rogers *et al.,* 1998; Rogers *et al.,* 2002). The value and cost of water can be summarised as follows (Figure 1.4):

Figure 1.4. General principles for cost and value of water



Source: Rogers et al. (2002).

- ***Value of water,*** is the sum of the economic and intrinsic value.
  - The ***economic value*** includes the:
    - *Value to users* of water for productive activities, such as irrigated farming;
    - *Net benefits of return flows* of water diverted for agriculture and other users, which may also include groundwater recharge, although these benefits will depend on the lost to evapotranspiration;
    - *Net benefits from indirect use,* such as drinking water for domestic purposes and providing habitat for flora and fauna, although these benefits can be offset by various negative environmental externalities, such as salinisation of soils and pollution of water from farm chemicals used in irrigation; and,

    - *Adjustment for social objectives and values,* such as the additional increase in commodity production gained from irrigation, higher employment and benefits for rural development.

  - The ***intrinsic value*** of water is linked to the attributes of water that are the most difficult to assign values, for example, the aesthetics of waterscapes and recreational attributes.

- ***Cost of water,*** consists of three elements, full supply cost, full economic cost, and the full cost:

  - The ***full supply costs*** are the costs associated with supplying water to consumers without considering either the externalities of water consumption (positive or negative) or alternate uses of water (opportunity costs). These costs consist of two elements, which are also important in terms of measuring agricultural support for irrigation (Chapter 3.2), including:

    - *Operation and maintenance costs,* associated with daily running of the water supply system, such as electricity for pumping, labour and repair costs;

    - *Capital costs,* covering both capital for renewal investment of existing infrastructure and new capital investment costs, such as building a new dam and canal network.

  - The ***full economic costs*** are the sum of the supply costs, plus the:

    - *Opportunity (or resource) costs,* which address the cost of one consumer depriving another of the use of the water if that other use has a higher value for the water, although opportunity costs are zero when there is no alternate use, that is no shortage of water, while opportunity costs also apply to issues of environmental quality already discussed; and, the

    - *Economic cost of externalities,* consisting of positive externalities, for example the groundwater recharge benefits from irrigation; and negative externalities, typically upstream diversion of water or the release of pollutants downstream within an irrigation system.

  - The ***full costs*** are the sum of full supply and economic costs, plus environmental externalities. While economic externalities cover costs to producers and consumers upstream and downstream, environmental externalities are associated with costs to public health and ecosystems.

Usually the value of delivering water is easily determined from the charges made by water companies in supplying water to farms, but valuing the opportunity cost of water can be extremely difficult. The economic value of water, however, covers goods and services that are not usually marketed, such as the net benefits from return water flows (*e.g.* groundwater recharge) and indirect use (*e.g.* wetlands or pollution); social values (*e.g.* rural employment); and intrinsic values (*e.g.* recreational, scenic, and cultural attributes). While economists have tools to provide proxy values for these non-marketed goods and services (*e.g.* contingent valuation) there application to guide policy decisions can be difficult.

The cost of supplying water has several distinctive features compared to other commodities:

- Water is bulky and expensive to transport relative to its value per unit of weight, unlike electricity, where there is usually a national grid;
- There are significant economies of scale in water supply, such as the use of a dam to store surface water, while the physical capital in the water industry is typically long-lived, for example, irrigation canals; and,
- Water supply projects are usually designed to meet multiple needs (*e.g.* agriculture, hydroelectric power, urban use), which makes defining the marginal benefit very difficult, as in many uses an additional unit of water may have little value at certain times, but considerable value at others.

The capital intensity, longevity and economies of scale of irrigation infrastructure mean that fixed costs dominate. As a consequence the short-run marginal cost of water supply for irrigation systems can be very low except for the costs of pumping water through the delivery system. These characteristics of water supply make it likely that there will be a monopoly supplier in any given area, requiring a high degree of managerial and social control. Also because of the capital lumpiness in water supply this provides an incentive to expand the capacity in surface water storage at a single point in time rather than spread out over time, which can mean that it may be a considerable duration before demand materialises to use this capacity.

A distinction needs to be made between the marginal and average or total value of water, in policy related applications of the economic valuation of water. Policy interventions in agriculture regarding water commonly involve changing the quantity and/or quality of access, as usually farmers have some access to water. Hence, to measure the benefit from an increment in water supply for farming in the receiving areas it is necessary to estimate the marginal value of water (marginal net profit) in the agricultural uses that would go out of production without the new increment of water.

This is because the profit from farming is not exclusively a return on water as an input, but also a return on labour, land, other fixed assets and variable inputs. Moreover, the return to water is not constant and declines as more water is supplied, because farmers are likely to alter their cropping patterns with varying supplies of water. In a number of irrigated areas there is usually some substitutability between surface and groundwater supplies, although in the **United States**, for example, less than 20% of the farms, accounting for less than 25% of the total US irrigated area, have access to multiple water sources.

Water charges can, in principle, be used to recover the full costs or value of water (Figure 1.4). This embodies the "user pays principle" in that the opportunity costs, economic and environmental externality costs and benefits should be fully reflected in the charges paid by water users, and not just the supply costs (*i.e.* operation, maintenance and capital costs). The principle of full cost recovery is evoked in a number of OECD countries water policies, but in reality few countries practice full cost recovery through water charges or even achieve full supply cost recovery. In recognition of the difficulties for countries in moving toward full cost recovery, OECD has endorsed the concept of *sustainable cost recovery* which recognises the need to establish the water sector on a financially sustainable basis, finding the right mix between the main revenues for the water sector, the so-called "3Ts": tariffs, taxes and transfers (Box 1.2).

In nearly all cases the water charges paid by agricultural users reflect only a part of the full costs for water (Chapter 3.4.3). This is partly due to the difficulty of evaluating opportunity costs and environmental costs and benefits. Moreover, there is usually a sharp difference in the water charges paid by agriculture compared to urban water users, which can be explained for a number of reasons as listed below.

- Where water is supplied through the same network to agriculture and other users, it may be under charged to all users because most water agencies set charges to cover the historic cost of a water delivery system rather than the future replacement costs. Frequently there is a large gap between historic and future costs because of the lumpiness and longevity of surface water supply systems.
- There is a strong incentive to cover only the short-run marginal cost of a new water supply project, since initially the supply capacity of such projects often exceeds current demand. As demand grows and the capacity is more fully utilised it is optimal to switch to a charging system based on long-run (*i.e.* replacement) marginal cost, but often public water agencies get locked 'politically' into only recovering historic costs.
- Historically, water supplied to irrigate agriculture in most OECD countries has been provided through public irrigation schemes, and, as such, has been frequently supplied covering only operation and maintenance costs of water deliveries (Chapter 3.4.3).
- Agriculture water, unlike urban water, is usually not treated and generally not available on demand via a pressurised system, making price comparisons difficult.
- In many circumstances irrigators do not have the opportunity to trade their water entitlements with other users: as no markets exist to do so; there are often legal and administrative restrictions to developing such markets; the transactions costs of water markets can be high; there is uncertainty about the supply and demand for water at a given point in the future; and also the water delivery systems supplying agriculture, urban and industrial users are rarely physically interconnected.
- Agriculture can be a secondary objective of water supplied from a project where water has been provided to meet other primary objectives, such as supplying a hydroelectric scheme.

The use of financial instruments to cover costs of supplying water to irrigators is necessary to maintain or develop the physical infrastructure and avoid degradation of the water delivery system. There are also equity considerations in recovering financial costs in that farmers might be expected by society to repay the benefits they receive where public investment has been involved. But governments may justify financing the capital costs of irrigation projects for a variety of reasons other than economic optimisation, such as rural development and for water and food security objectives (Molle and Berkoff, 2007a).

Box 1.2. Full cost recovery and sustainable cost recovery for water supplied to agriculture

The conventional wisdom regarding ***full cost recovery*** through water tariffs (or charges), including for the agricultural sector, is that water tariffs should be sufficient to cover the full supply costs of water (including the operation and maintenance costs and the capital costs for renewing and extending the water system), and ultimately opportunity costs (scarcity value) and externality costs (economic and environmental), as shown in Figure 1.4.

The principle of full cost recovery is evoked in a number of OECD countries water policy frameworks, for example the **EU** *Water Framework Directive* requires member states to take account of the principle and ensure adequate contributions by all users after accounting for the social impacts of cost recovery (see the example of **Greece** in Box 3.11), while the same is true in **Australia** (Box 3.8). In reality, very few countries practice full cost recovery through water charges, even if this definition is limited to full supply costs, as shown in Figure 3.1.

In recognition of the difficulties for countries in moving toward full cost recovery, and even recovery of full water supply costs, the concept of ***sustainable cost recovery*** was formulated by the Camdessus Panel* and later endorsed by OECD (see sources below). The panel's report identified three main characteristics of sustainable cost recovery:

1. An appropriate mix of tariffs, taxes and transfers (the 3Ts) to finance recurrent and capital costs, and to leverage other forms of financing;
2. Predictability of public subsidies to facilitate investment (planning); and,
3. Tariff policies that are affordable to all, including the poorest, while ensuring the financial sustainability of service providers.

Sustainable cost recovery recognises the need to establish the water sector on a financially sustainable basis, finding the right mix between the ultimate revenues for the water sector, the so-called "3Ts": tariffs, taxes and transfers Revenues from these sources need to increase to cover the costs of achieving agreed policy objectives for the provision of water supply, including to agriculture. This approach, which on the basis of country experience, is now considered a more realistic and practical policy principle than "full cost recovery" based on water charges alone. Covering costs solely on the basis of water charges may not take sufficient account of the burden this would place on the poorest consumers, or of the merit or public goods character of some ecosystem services provided by agriculture.

Every country must find its own balance among the three basic sources of finance (the 3 Ts), but typically for OECD countries, with most of the agricultural sector (and domestic/industrial sectors) connected to a water infrastructure network, they largely rely on water tariffs to cover operation and maintenance costs for water supplies to agriculture, as described in Chapter 3.4 of this report. However, public budgets based on taxes often continue to play a role in covering capital costs of water infrastructure. Indeed public budgets have historically played the major role in financing initial investments in water infrastructure in virtually all countries.

The path to improved cost recovery may involve a phased approach, with tariffs increasing in stages to cover operation and maintenance costs, and thereafter depreciation of assets, new investment and, eventually – where relevant – the externality and opportunity (resource) costs of water. Where tariffs are extremely low relative to full cost recovery or sustainable cost recovery, a gradual approach may not be sufficient and more drastic action may be called for. Increasing cost recovery rates through water tariffs, also requires a comprehensive approach, which includes reforming tariff levels and structures and increasing bill collection rates, but also improving levels of service and establishing social protection measures where necessary.

Where a phased approach is adopted, the water tariff-setting process becomes a vital consideration. Many countries have decentralised responsibilities for services, including those for tariff setting (Chapter 3.4). This can delay tariff reform and the regular adjustments necessary to account for inflation. In some countries the central government determines the tariff structure and level, for local governments to implement. A realistic central-local balance of obligations and responsibilities is the key to tariff reform.

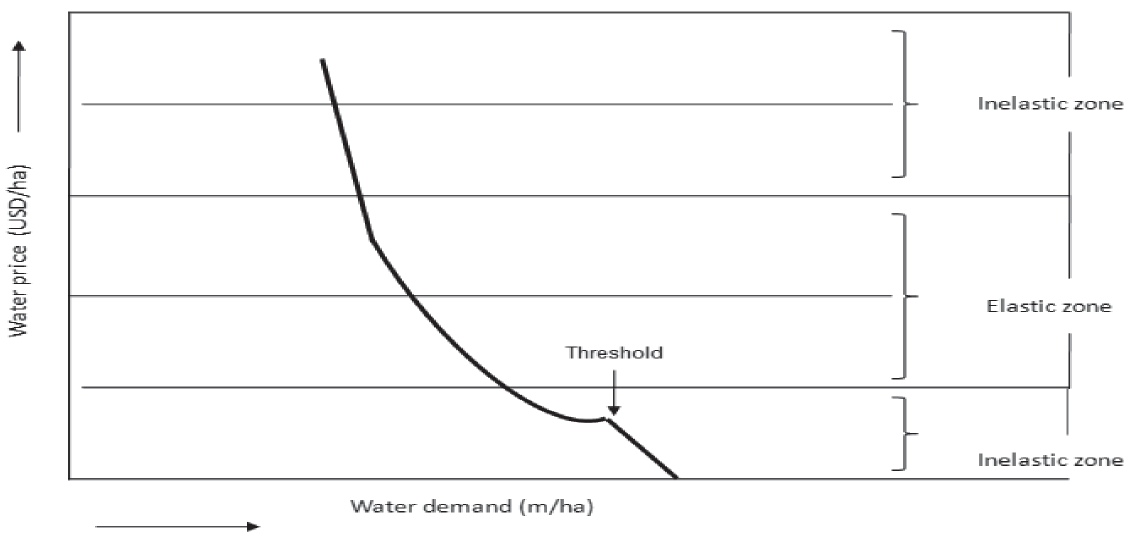
* The Camdessus Panel Report is available at Winpenny, J. (2003), *Financing Water for All, Report of the World Panel on Financing Water Infrastructure,* chaired by Michel Camdessus at www.financingwaterforall.org.
Source: Adapted from OECD (2009a; 2009b).

Raising water charges can reduce pressure on water resources by inducing greater efficiencies in the use of water, bringing both economic and environmental benefits through water conservation, especially where water stress is an issue. The possibilities for water conservation in agriculture can potentially release supplies for other users and to meet environmental demands, especially as agriculture tends to account for the major share of national water withdrawals (Figure 2.1). But raising water charges will not improve water use efficiency where water supply constraints are binding, a situation common in many OECD countries and as discussed above.

But the ***responsiveness of farmers to changes in the price of water*** (the elasticity of demand) is complex (Figure 1.5). At low price ranges demand is unresponsive to price, inelastic, and hence, is not a determining factor affecting application efficiency or water application technology choice (de Fraiture and Perry, 2007; OECD, 1999; Rieu, 2006). At a certain threshold demand for water becomes elastic in the short run, more responsive as prices rise, but becomes inelastic again at higher price ranges as water quantities approach the minimum needed for plant growth. In general farmers responsiveness to price requires that water charges comprise a volumetric component, they have control over the water they take from the irrigation system, and that the price is sufficiently high to correspond to the elastic range of their demand curve.

Over the long run irrigators may respond to rising water charges by adopting water saving technologies, altering the mix of irrigated activities or shifting to non-irrigation activities (Appels *et al.,* 2004). A major problem for water providers is estimating the price responsiveness of demand for irrigation water, as there is little published information on the relationship, although with increasing water trading more data could become available (Appels *et al.,* 2004; de Fraiture and Perry, 2007). Moreover, while water demand in generally inelastic, as shown in Figure 1.5, this does not imply that water demand is necessarily stable. Hence, water demand by irrigators may be highly responsive to agricultural and agri-environmental policies and also technological changes.

Figure 1.5. Agricultural water demand curve



Source: de Fraiture and Perry (2007).

Trading in water entitlements can encourage investment by farmers in water saving technologies and promote agricultural production diversification, especially toward higher value commodities. But as water is just one of the inputs for agricultural production, adoption of water saving technologies or production diversification is seldom driven by water prices or water scarcity alone (Cai *et al.,*, 2008; Molle and Berkoff, 2007a). Instead changes in farm technology choice and production patterns are likely to be driven by substitution between water and other inputs (*e.g.* farm chemicals, labour) and market opportunities (i.e. changes in commodity prices). Also farm input and output markets are also influenced in most OECD countries by the level and form by which governments provide support to agriculture.

Trading can provide a scarcity price in the market and help allocate water among competing users (urban and industrial) ***and uses*** (environmental). By this reasoning higher water prices would release water from use in low value agricultural activities to high value uses, such as for higher value agricultural commodities, and urban and industrial users, and raise social welfare (Molle and Berkoff, 2007a). While fully functioning water markets might be able to achieve such an outcome there are a number of obstacles in reaching such a result, as already discussed in this chapter.

Transfers of water entitlements between different users can also depend on government policies (*e.g.* water expropriation, investment in desalinisation), and the strength of market regulations. ***Surface water allocations can be traded***, within season, between seasons or permanently, or where the market is regulated the regulator can set the price, price limits, and serve as a broker, for example, to facilitate market operations. For tradable water markets to operate effectively between agriculture and other users requires having a robust knowledge and monitoring of hydrologic conditions; a modern and comprehensive hydraulic infrastructure; well defined water property rights; and established legal, institutional and regulatory arrangements (Chapter 3.5).

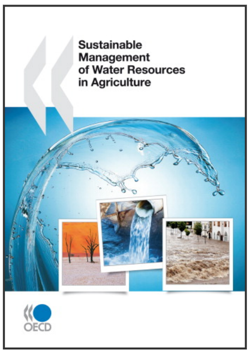
In terms of using ***water charges and trading for groundwater management***, there are some important differences compared to the discussion above which has largely focused on water charges and trading for surface water irrigation. Farmers commonly have the right to exploit any aquifer lying below the surface of their properties, but usually subject to a system of permits and regulations to control groundwater abstractions (Chapter 3.4.3 and the OECD questionnaire at www.oecd.org/water).

But the lack of enforcing groundwater regulations and illegal groundwater pumping, has led to the fall in groundwater tables and consequently a rise in the costs of pumping water, while over the longer term the resource can become unsustainable. This implies that the farmer has no incentive to limit extractions since others may continue to pump the resource. In saline groundwater areas the farmer also has no incentive to install drainage facilities since all farmers would have to install facilities to be effective. The over exploitation of saline groundwater can lead to a complexity of threats to aquifers, including waterlogging and secondary salinity, involving salinity intrusion in coastal areas (Hellegers *et al.,* 2007).

The use of groundwater rather than surface is attractive for farmers because it can allow farmer control over the resource, and offsets the risks and uncertainties where entitlement and allocation systems are poorly defined. Moreover, use of groundwater allows water on demand and can support crop diversification and high value farming. In contrast to surface water, however, the transaction costs to regulate the sustainable use of the resource can be high, hence, the long term degradation of groundwater resources represents a major policy challenge (Molle and Berkoff, 2007a).

In principle raising water charges to farmers (or trading water entitlements) can ensure demand is consistent with the supply needed to meet environmental demands, if externalities (positive and negative) are included in the traded price (Molle and Berkoff, 2007a). The user-pays and polluter pays principles embody the idea that water quantity and quality externalities should be reflected in the charges paid by water users as an incentive to reduce adverse environmental impacts (Box 1.2) (OECD, 1999).

A major obstacle in using water charges and trading to address environmental issues in agriculture is the difficulty in valuing the environmental externalities associated with agricultural use of water resources. While there has been a burgeoning literature on valuing the environment assets associated with ecosystems (see the review in FAO, 2004), there is less research on how these values can be incorporated into the costs of production and resource use, and few examples where this has been implemented in practice. This reflects, as in the case of opportunity cost pricing, problems of estimation, implementation and enforcement, plus the social and political challenge of farmers who commonly consider these externalities are the responsibility of society more widely (Molle and Berkoff, 2007a).



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