WATERSHED ECONOMICS: PROPOSED METHODOLOGY FOR WATERSHED MANAGEMENT

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1. Background to Integrated Watershed Management

The scarcity of water resources in both arid and temperate countries alike is one of the most pervasive natural resource allocation problems facing water users and policy makers. In the EU this has been recognised in the recent work on the Water Framework Directive. In arid countries this problem is faced each day in the myriad of conflicts that surround its use. Water scarcity is a fact with which all countries are having to become increasingly involved.

Water scarcity occurs across many dimensions. Firstly there is growing *demand* for water in residential, industrial and agricultural sectors stemming largely from population and economic growth. Secondly, *supply* side augmentation options have become increasingly constrained, and restrictively costly in many countries. In combination demand growth and supply side interventions have stretched current water availability to its hydrological limits. In addition to these *quantity* constraints, the limits to the assimilative capacity of water resources for human and industrial waste have been reached in many places, and the *quality* of freshwater has been degraded (Winpenny 1994).

In turn water scarcity has become an important constraint on *economic development*, that has resulted in fierce competition for scarce water resources between economic sectors that rely upon it. (Winpenny 1994, World Bank/EIB 1990). Water scarcity is important for *sustainability* in economic development as well, on account of the many associated environmental/watershed services. In the face of hydrological constraints, the focus of current thinking in water resource management is on the allocation of scarce water between competing demands (Dublin Conference 1998, Winpenny 1994, UKWIR 1999).

How is it possible to allocate water between its many competing uses, all of which depend on water for their existence? Clearly water resources are necessities for many of the most important goals of every society. Firstly, water is a necessity for human existence. The absence of clean drinking water and sanitation leads to health problems, whilst the lack of access to/property rights for water resources *per se* is a significant dimension of poverty (UNDP 1998). Water is also an important input to economic activities and can be seen as both a production and consumption good (Young 1996). Furthermore water is a public good contributing to recreation, amenity and general environmental and watershed values as an input to ecosystems and habitats. How is it possible to balance such crucially important but competing uses?

The fact is that a balancing of these uses must be accomplished, and the mechanism for doing so must be carefully constructed. The existing overlay of complex hydrological, socio-economic and property rights/legal environments (in many if not most jurisdictions) predisposes water resources to open access appropriation within the watershed, and the consequence of negative environmental and economic externalities (e.g. the degradation of wetlands and coastal fisheries, depletion of aquifers, and loss of watershed services). (FAO 1987, Winpenny 1991). In short, the combination of the *arbitrariness of the prevailing property rights* structure for water resources in most jurisdictions and the *failure of markets* to capture the value of many watershed services necessarily imply that the prevailing distribution of water within most societies is not likely to be the most desirable one (e.g. Winpenny 1994).

It is our belief that a more balanced approach to water resource management must ensure that scarce water resources are allocated between competing demands in a way that maximises their contribution to societal welfare. We further believe that this approach must be constructed in a way that considers its impacts, on all of the various groups and interests affected. This requires the integration of various approaches and perspectives into a single systematic framework. We believe that a coherent watershed-based resource allocation methodology is required.

In what follows a 'watershed economics approach' is proposed which is composed of 2 important stages. In Stage I economic valuation techniques are used to establish the economic value of the competing demands for surface and groundwater, incorporating where necessary an analysis of water quality. The valuation exercise allows the objective balancing of demands based upon the equi-marginal principle to achieve economic efficiency. In Stage II a policy impact analysis is proposed which addresses issues of social equity and the value of water for environmental/ecological purposes. The analysis is undertaken within the confines of the watershed; the most natural unit for the analysis of water allocation and scarcity since it determines the hydrological links between competing users and thus the impacts of one user upon another. The methodology is encapsulated by a case study of the Kouris watershed in Cyprus.

2. INTRODUCTION TO INTEGRATED WATERSHED MANAGEMENT

The complex issue of watershed degradation and management has been the subject of wide attention in the economic and water management literature[1]. In general the focus has been on the economic costs and benefits of watershed conservation measures and the valuation of the benefits of specific 'watershed services' such as drought mitigation, flood control, water quality maintenance and water yield. This section summarises these issues, highlighting in particular the water allocation problem as addressed from the perspective of the watershed.

2.1 The Watershed as the Natural Unit for Analysis and Management

A watershed can be defined as the area drained by a river and its tributaries which naturally seek a lower level and tend to converge and unite into one main stream, which in turn discharges its flow into some large body of water, e.g., an inland lake or the sea (Winpenny, 1991)[2]. A watershed thus described may be local, regional or international. Water may be used within the stream, diverted from the stream and then returned in part to it, degraded or not, or transported elsewhere. The interconnections within the area; e.g. between the main stream and its tributaries; the ground and the surface water, give the watershed its physical and functional unity.

The physical and functional unity of the watershed has led many to suggest it is the natural hydrological unit for water resources management[3]. This implies that the most appropriate institutional arrangement to address the issues of watershed management is through the

[1] e.g. Winpenny 1991, FAO, 1987, Repetto el al 1992, Pattanayak and Kramer 2001, Groom and Swanson 2001

[2] Definitions vary in the detail. Another commonly used definition of the watershed is the drainage divide separating one river basin from another (Chow 1964), however the term 'watershed' will refer to the drainage area as described above, as is also common (Winpenny, 1991).

[3] There are many that dispute this proposition. Winpenny (1994) suggests that the watershed is not always the most relevant scale for water resources development planning, nor does it justify the use of centralised institutions for solving the problems associated with water resources planning. The hydrological relevance of the watershed is also questionable on occasion. In Namibia, for example, there are only ephemeral (seasonal) rivers within the country, and although the watershed areas can be defined for these rivers the relevance of this hydrological unit for planning and resource management purposes has been questioned (NWRMR 2000). Similarly the lack of coincidence of political jurisdictions and watershed boundaries has lead others to comment on their preference for the former as the planning and decision making unit (FAO 1986, Turton et al 1998). Furthermore the demands for water resources in a watershed need not be confined to the watershed, nor should the development of watersheds necessarily be restricted by local hydrological constraints. Water may be imported or exported via inter basin transfers to satisfy growing demands internal or external to the watershed in question. Similarly external (regional, global) demands for *in situ* environmental values associated with water may impact upon water allocation decisions within the watershed.

development of centralised watershed authorities (e.g. river basin committees) focussing on individual watersheds[4].

Ultimately, water and land users and the environmental (and other) services provided by the watershed are inexorably interconnected by the hydrological characteristics of the watershed. Consequently the impact of one water or land use on another is determined by the nature of the hydrological cycle. In this sense the many of the problems of land and water resource management and allocation arise directly from the nature of the watershed and are thus sensibly analysed and approached from this perspective. By extension the watershed is a useful unit for water resources management, since institutions representing the watershed can bring together and consider the plight of all interconnected parties and balance the costs and benefits of interventions (FAO, 1987). Indeed, despite the criticisms of the use of the watershed as the natural unit for water planning and management (in particular see footnote 3), the recent evolution of water policy in many countries has lead to the creation of water management areas and institutions based on the watershed[5]. Such an approach is described from hereon as the *watershed approach*.

2.2 Watershed Services, Watershed Degradation and Economic Costs and Benefits

The interconnected nature of the water and land users within the watershed, and the core issues of watershed management are exemplified by the well-documented degradation of watersheds world-wide. For example, changes in land-use in upstream areas such as deforestation, increased grazing, a change from deep to shallow root crops etc., can lead to a wide variety of inter-related impacts downstream (FAO, 1987). Increased exposure of the earth to rain and run-off leads to soil erosion, reduced fertility of soil (loss of nutrients and soil structure) and reduced agricultural productivity. Increased run-off can lead to gully erosion and flooding. In addition reduction in local retention of water reduces groundwater recharge and stocks, whilst the transport of sediment causes siltation in irrigation works and water storage schemes, reducing water supply potential and/or hydropower production. Furthermore, the transport of Non Point Source pollution arising from increased runoff, overgrazing, road building and recreational activities etc. is another source of potential degradation (Rilla, 1996). At the furthest reaches of the catchment the productivity of fisheries may be impinged upon by sedimentation and pollution, whilst wetland areas and other ecosystems such as coral reefs may become degraded (Winpenny 1991, Swanson et al 2001).

Simultaneously the direct appropriation of water resources by upstream sectors either through the consumptive extraction of surface water flows or through the use of conjoined groundwater and surface water, can deprive downstream economic sectors access to water resources (Howe, 2000). This may manifest itself in reduced yields in reservoirs, reduced groundwater recharge and stocks and alterations to the preferred time profile of water resource flows (Groom and Swanson, 2001). In sum, an inefficient intra and inter-temporal allocation of water resources can result.

[4] There is an issue of watershed scale here. Although some hydrologists describe the watershed in terms of scale: river-basin, sub-basin, watershed, and others refer to 'micro-watersheds' (Turton et al 1999, Farrington, 1999), we use the term very broadly here to refer to a variety of scales. Thus the extent to which watershed management institutions are considered to be truly 'centralised' and governmental, or more reflect participatory watershed committees is largely a question of watershed scale. In sum we do not make a prior distinction between these approaches, nor do we advocate one over the other, the suggestion is that the institution represent the watershed.

[5] South Africa provides the most recent example, having created 19 water management areas under the provisions of the National Water Act of 1998. Namibia has followed this lead in the development of its new Water Act (NWRMR, 2000). New Zealand and Australia have also developed catchment management policies as part of their respective natural resource management programmes (Rhoades, 1999), whilst the EU Water Framework Directive advocates the creation of 'River Basin Districts' for integrated water resource management (Grimeaud, 2001).

The economic cost of these interconnected water quality and quantity perturbations highlights the benefits that can be obtained from watershed management and the watershed approach. Since the direction of the aforementioned impacts is generally the same as the direction of water drainage: largely upstream-downstream, watershed management interventions target largely the upstream areas to alleviate the costs and risks to both upstream and downstream areas. Therefore the specific benefits of watershed management can be generally categorised as occurring either upstream or downstream. By extension the benefits arising from watershed management provide examples of 'watershed services'. Table 1.1 describes some of the benefits derived from the associated watershed conservation strategies; reforestation, afforestation, gully control, pasture management etc., and the resultant watershed services.

Table 2.1: Examples of the Benefits of Watershed Management and Watershed Services

Location of Benefits	Economic Benefit	Watershed Service[6]	Economic Valuation Study
Upstream	**Reduced crop losses**	**Soil quality maintenance**: Reduced soil erosion, and loss of soil depth and fertility	**Morocco**: Loukkos Watershed. Brooks et al (1982)
	Value of e.g. forest products	**Land/Water Productivity**: conservation strategies: e.g. afforestation, provide livelihoods	
	Improved livestock and produce	**Land/Water Productivity**: conservation strategies: e.g. pasture management, provide livelihoods	**Nepal**: Phewa Tal Watershed. Fleming, Hufschmidt et al (1986)
	Increased crop yields	**Soil quality maintenance**: ecological benefits: increased soil organic matter, moisture retention etc.	**Mali**: Bishop & Allen (1989)
Downstream	**Improved Water Availability**	**Water Yield**: inter-sectoral reallocation of surface water yield from surface water management or optimal control of groundwater coupled to surface water	**USA, Colorado**: Howe (2000)
	Irrigation Benefits	**Water quality maintenance**: Improved yields through water quality improvement and reservoir yield	**Java**: Repetto et al (1989)
	Hydropower generation	**Water quality/sediment retention and water yield**: Reduced siltation of storage dams, increased inflow	**El Salvador**: Acelhuete Catchment. Wiggins and Palma, (1980)
	Flood damage prevention	**Water flow smoothing**: Reduced runoff in high rainfall periods	**USA**: North Carolina. Freund & Tolley (1966)
	Drought Mitigation	**Water storage**: increased groundwater for drought years	**Indonesia**: Manggarai watersheds. Pattanayak & Kramer (2001)
	Fisheries Benefits	**Water quality**: Increased yields from improved water quality	**Australia**: New South Wales. Sinden (1990).
	Domestic and other Industrial	**Water yield and quality**: Improved water quality, reduced treatment costs, reduced siltation of storage dams, increased yield	**Morocco**: Loukkos Watershed. Brooks et al (1982)
	Amenity	**Environmental/ecological**: Recreation, tourism, ecological/habitat	**Cyprus**: Kouris Catchment. Swanson et al (2001)

Adapted from Winpenny (1991) and FAO (1987)

[6] The observant reader will notice that soil quality maintenance upstream translates by and large to water quality improvements downstream. The same process provides benefits both upstream and downstream. However, the authors are aware that there are some benefits to irrigation from the transport of nutrients in sediment from one area to another that may occur with 'soil erosion'.

The economic costs of watershed conservation or water reallocation vary from one watershed to another and the decision by water management authorities to intervene must rest upon the appraisal of the costs and benefits of these actions compared to the status quo[7]. Watershed conservation strategies such as those included in the studies cited in Table 1.1 should not be considered desirable *a priori* (Aylward et al, 2000)[8].

Decisions concerning the (re-) allocation of scarce water resources between competing economic sectors, environmental demands and other watershed services require structured analysis. Water allocation decisions not only require consideration and understanding of the hydrological cycle of the watershed and the associated pattern of interconnection between agents, but also the evaluation of demands in a coherent and objective manner so as to balance demand and supply and meet social welfare goals (Young 1996, Koundouri 2000).

In essence it is the balancing the societal benefits and costs of competing demands for water and the watershed services, such as those in Table 1.1, which defines the watershed allocation problem.

2.3 The Watershed Allocation Problem

The widely accepted objectives of water resource management can be broadly summarised as economic efficiency, equity and sustainability[9]. There are a number of reasons why the unregulated behaviour of agents within the watershed will fail to allocate water resources in an economically efficient, equitable or sustainable manner. These reasons relate to the overlying layers of hydrological, socio-economic and legal interaction within the watershed. Firstly, the array of watershed services is vast (see Table 1.1), whilst the hydrological connection between water and land using agents within a watershed is complex, often ill defined and uncertain (Ward and Robinson 2000, Boronina et al 2001). Secondly, the property rights to water resources, which are a major determinant of their pattern of allocation, are typically incomplete, absent or unenforceable (Young, 1996). Thirdly, and perhaps consequently, the economic behaviour and interaction of interconnected agents is similarly complicated. The complex nature of the resultant watershed dynamics can lead to a situation in which agents are a) unaware of every service that watersheds provide both to themselves and to others, whilst b) ignorant of, or apathetic to the implications of their actions upon other agents within the watershed (Groom and Swanson 2001).

In effect many of the services that the watershed provides are non-marketed, whilst the nature of the hydrological connection between agents leads to negative (and positive) externalities arising from **market failures** and the **open access** or **public good** characteristics of watershed services and water resources. In addition **missing markets** for watershed services help create an environment ripe for externalities leading to economically inefficient and/or unsustainable allocations of water resources. Where resources are allocated inefficiently there is potential for increased social welfare derived from water resources and a strong case for intervention in water resources/watershed management.

In order to achieve economic efficiency in the face of water scarcity characterised by supply constraints, the emphasis is clearly on the balancing of demands for water with supply. Therefore

[7] Column 4 of Table 1.1 provides examples of Cost Benefit Analyses of watershed interventions which have been undertaken throughout the world and found to be economically viable for the reasons mentioned.
[8] Aylward et al (1999) found that there were considerable downstream hydrological yield benefits, as well as production benefits, from maintaining current ranching and dairy industries in upstream areas of the Arenal watershed in Costa Rica, rather than implementing a reforestation/afforestation programme.
[9] These terms are defined in more detail below.

problem for the watershed management institutions is to establish the social/economic values of the multifarious demands for water resources and non-marketed watershed services, and implement policies which will allocate scarce water resources between these demands to maximise societal welfare. Equity considerations; consideration of the distribution of policy impacts and access to water resources, contribute to social welfare and the political expedience of policy implementation and should enter into the policy analysis (Dinar et al 1996, Boland and Whittington 2000). Similarly, environmental/ecological sustainability is also a necessary component of any water allocation analysis. In what follows a concrete methodology to evaluate and balance water demands with supply in a watershed context is expounded.

3. BALANCING THE DEMANDS FOR WATER RESOURCES: METHODOLOGY

3.1 The Management Unit: Watershed

The watershed is a natural unit of analysis for addressing the balance of supply of and demand for water, and the issues of efficiency, equity and sustainability for the following broad reasons:

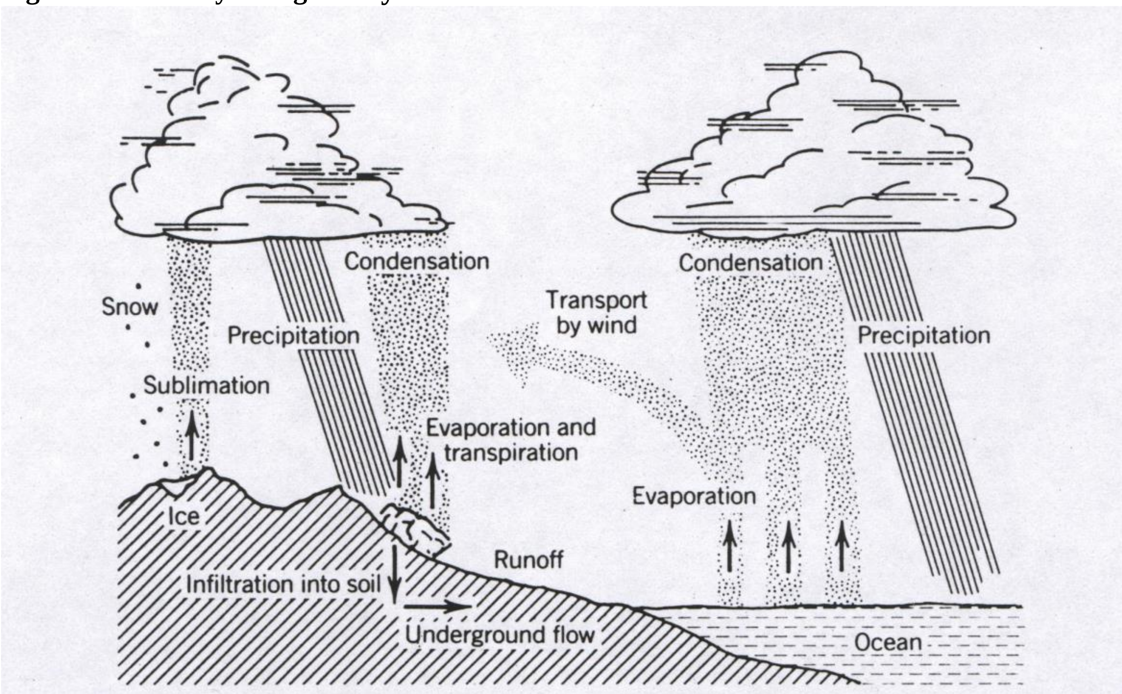
- **Water Resource Availability**: The aggregate availability of water resources, including sustainable yields is bounded by the hydrological cycle of the watershed; Figure 3.1

- **Conjunctive Water Sources**: The interaction of different sources: e.g. groundwater and surface water, is confined by the watershed

- **Interaction of Demands**: The demands for water interact within the watershed and the hydrological impacts of one water user upon another and upon environment; **externalities**, are defined by the watershed.

An understanding of the hydrological cycle in the watershed area in question is a pre-requisite for the determination of efficient, equitable and sustainable water resource allocation.

Figure 3.1. The Hydrological Cycle



3.2 The Allocation Objectives

Sections 1 and 2 described the conflict between natural constraints to water supply and an uncoordinated pattern and growth of demand resulting from arbitrarily determined property rights and governmental policies. Given the natural water resource constraints there is a clear need to address the pattern and growth of water demands in order to address the imbalance.

The methodology proposed provides the policy maker and planner with an objective approach to balancing the competing demands for water subject to the natural constraints. The approach is based on the comparison of the economic value of water in different sectors, in terms of quantity and quality, in comparable units of measurement. The overall objective of public policy is to maximise societal welfare from a given natural resource base subject to those valuations. The key objectives of public policy in the allocation of resources are as follows:

- **Efficiency**: Economic efficiency is defined as an organisation of production and consumption such that all unambiguous possibilities for increasing economic well being have been exhausted (Young 1996). For water, this is achieved where the marginal social benefits of water use are equated to the marginal social cost of supply, or for a given source, where the marginal social benefits of water use are equated across users.

- **Equity**: Social welfare is likely to depend upon the fairness of distribution of resources and impacts across society, as well as economic efficiency. Equal access to water resources, the distribution of property rights, and the distribution of the costs and benefits of policy interventions, are examples of equity considerations for water policy.

- **Environment and Sustainability**: The sustainable use of water resources has become another important aspect in determining the desirable allocation of water from the perspective of society. Consideration of intergenerational equity and the critical nature of ecological services provided by water resources provide two rationales for considering sustainability. In addition the *in situ* value and public good nature of water resources should enter into water allocation decisions.

3.3 Assessing the Economic Value of Water

For physical, social and economic reasons, water is a classic non-marketed resource. Even as a direct consumption good, market prices for water are seldom available or when observable, often are subject to biases; subsidies, taxes etc. Similarly, environmental and ecological water values are rarely explicitly marketed and priced. Thus the economic value of water resources is seldom observed directly.

The balancing of demands to resolve the resource conflicts described above requires the identification and comparison of the benefits and costs of water resource development and allocation among alternative and competing uses. In addition, water management policies have widespread effects on the quantity and quality of water within a watershed, and the timing and location of supplies for both in- and off-stream uses. In general, these impacts have an economic dimension, either positive or negative, which must be taken into account in policy formulation. Again, the value of these impacts is seldom observed directly.

Fortunately economists have refined a number of techniques to value water resources and address objectively the balance of demands and evaluate the impacts of water management policy. The first step towards the evaluation of economic benefits requires the identification of the demands for the resource. Water is needed for all economic and social activities, so the evaluator is faced with the problem of identifying a multi-sectoral demand curve. The dimensions of demand include:

- Municipal and Industrial
- Agricultural
- Tourism
- Environmental (recreation, amenity and ecological)

The valuation of each of the identified demands calls for a different approach for two main reasons, a) the specific economic and hydrological context: data availability etc and b) because the use of the resource is sector-specific. The residential and tourist sectors exploit the **use value** of water and use it as a consumption good; the agricultural sector derives use value from water as an input in production. The value of water related environmental goods can be a use value or a **non-use value**, e.g. existence value. The overall evaluation strategy is shown in Figure 3.2 below.

3.3.1 The Outputs of the Demand Valuation

The valuation techniques allow the estimation of the following desirable parameters:

- **Marginal Value of Water**: The efficient balance of demands from a given source is found where the marginal value (benefit) of water is equated across users. In any given context efficiency is achieved where the marginal value of water is equated to marginal social cost

- **Price Elasticities of Demand (PED)**: Measures the responsiveness of demand to price changes. Characterises the demand function and tells the policy maker the extent to which prices must change to cause demand to fall to a particular, e.g. efficient, sustainable, level.

- **Income Elasticity of Demand (IED)**: Measures the extent to which the demand for water varies with income. Tells the policy maker whether water is a necessity or a luxury good and provides one way in which to assess the fairness of pricing policies. In combination with PED can be used to estimate welfare changes resulting from policies.

- **Marginal/Average Willingness to Pay for Public Goods (WTP)**: Estimates the strength of demand for water as an environmental good. This determines in part the efficient environmental allocation of water

- **Marginal Willingness to Pay for Quality Changes of Common Access Resources:** Estimates the value of quality attributes of the resource, which are particularly important, if the resource is used as a productive input.

- **Risk Parameters**: Measurement of preferences towards risk and uncertainty. Useful for establishing policies which reduce producer/consumer risk

3.3.2 Balancing Water Demands in the Watershed

The outputs of the demand analysis allow the economically efficient allocation of water resources by the equi-marginal principle. As defined in Section 3.2 above resources are allocated efficiently where the marginal social benefit of their use is equated to the marginal social cost. This suggests water resources should be priced at the **marginal social cost**, and has the following implications:

- Where competing demands are being supplied by the same water source at the same marginal social cost the efficient allocation occurs where the marginal social benefits of resource use are equated

- Where the marginal social cost of water supply includes scarcity rents, as is frequently the case with groundwater resources, this should be included in the optimal price

- Similarly where scarcity rents exist in the form of intra-temporal opportunity costs, water should be rationed to the highest value user: e.g. industry, residential or environmental, i.e. marginal units of water should be allocated to the highest value marginal user

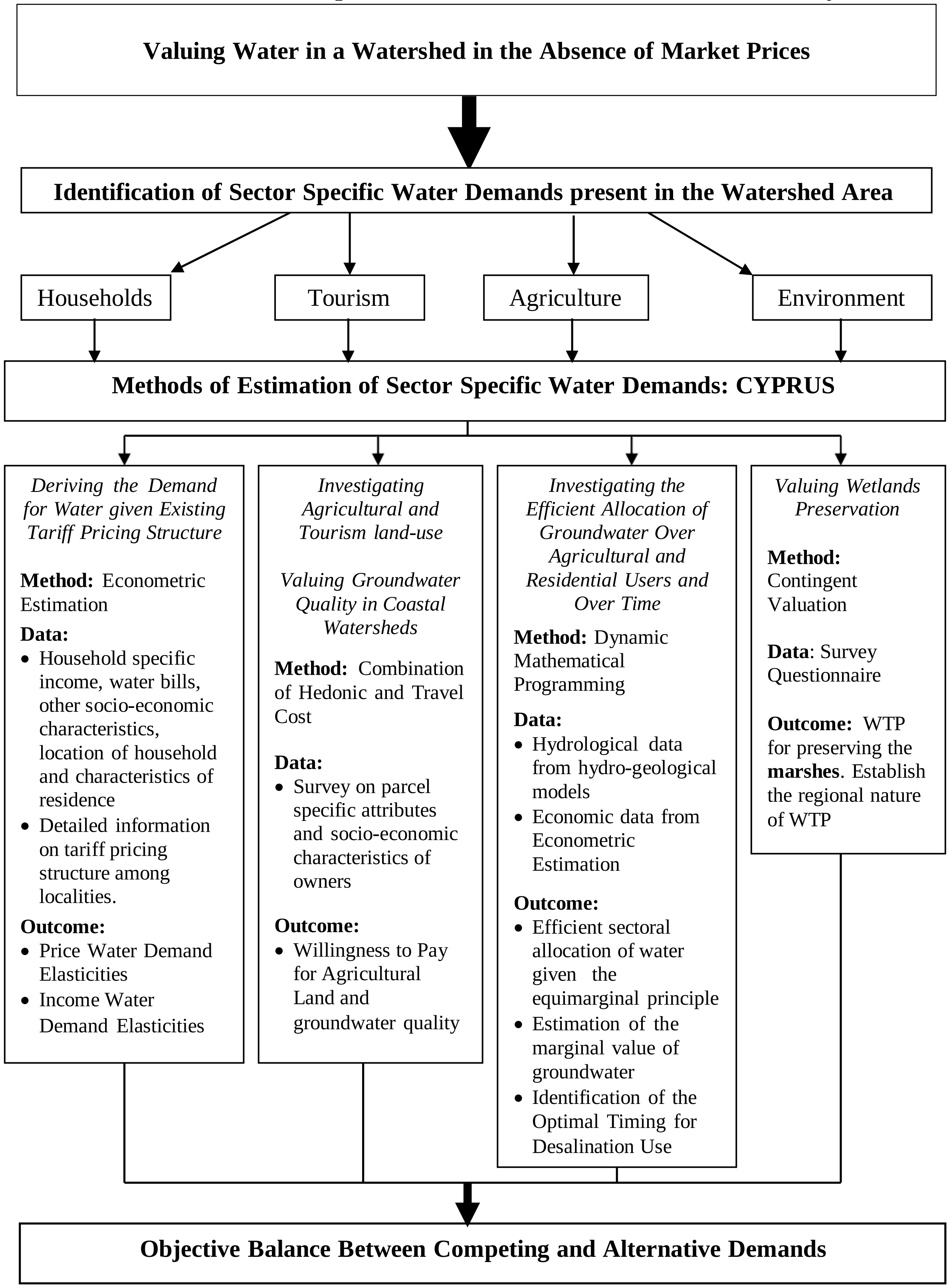
The discussion here has largely been in terms of the water price as the allocation mechanism. There are many different approaches to enable the efficient allocation of water resources (Dinar 1996, Winpenny 1994, Easter et al 1999). Pricing is advocated here as the conceptual allocation mechanism, despite its inappropriateness in certain circumstances. Ultimately the policy maker must determine the most appropriate allocation mechanism once the economic valuation has determined the efficient allocation.

3.3.3 Deriving Policies from the Methodologies

The economically efficient allocation is not necessarily equitable or sustainable. Firstly additional analysis is required to determine the distributional impacts of the (re-) allocation recommended by the equi-marginal principle. Secondly, the hydrological impacts of one demand upon another that result from the proposed allocation need to be assessed. Thirdly, the effects on environmental sustainability, the existence of regional and perhaps global environmental goods and their demands need to be considered. In sum, the watershed needs to be double checked for unforeseen externalities and for missing markets for watershed services to ensure intra and inter-temporal efficiency is achieved and that equity and sustainability considerations are properly considered.

In effect Section 3.3.2 and 3.3.3 can be thought of as two complementary stages in the methodology, the latter phase can be described as the **policy impact analysis phase**.

Figure 3.2. The Methodology for Water Demand Valuation in a Watershed Area: Examples from the Kouris Watershed Case Study



3.4 Summary of Methodology

3.4.1 **STAGE I**: Objective Approach to Balancing Water Demands

I. Evaluate Demands

Appropriate economic methodologies assess the demand for water and derive the desired parameters: Marginal Value, PED, IED, WTP, and risk parameters for the relevant dimensions of demand. The evaluation process should be undertaken in accordance with the economic methodologies, and be independent of the prior rights to water resources

II. Determine Allocation

Policy maker defines an allocation of water resources in accordance with the principles that determine economic efficiency: demands should be balanced according to the equation of marginal social value (benefit) to the marginal social cost of supply.

III. Implement Allocation

The policy maker chooses instruments to effect the desirable allocation using the information contained in the valuation exercise.

3.4.2 **STAGE II**: Policy Impact Analysis

I. Welfare Distribution

The impact of the allocation policy options should be evaluated to establish the resulting distribution of the costs and benefits to society. That is, the change in social deadweight loss resulting from resource allocation changes should be determined, together with the actual distribution of this change. This is important both from the perspective of equity and often for reasons of political economy.

II. Market Failures and Missing Markets

Consideration of sectoral demands in isolation may be insufficient to ensure efficient outcomes. Where water users are conjoined by the underlying hydrology of the watershed there are a number of potential impacts/externalities that may arise from the chosen allocation. For example, policies implemented in upstream areas of a watershed will impact upon downstream users where the water resources are conjoined. Ignoring these effects will lead to inefficient allocations of water. In effect all the following **facets** of water demand should be considered:

- **Sectoral Allocation**: Water demands should be balanced between sectors
- **Spatial Allocation**: Spatial variability and the conjoined nature of surface and groundwater.
- **Temporal Allocation**: Conjoined users may impose externalities upon each other relating to allocation over time and the timing of resource use.

III. Public Spending, Public Goods

The demand for public goods may extend beyond the watershed. Global and regional environmental goods for which existence, bequest and option values are held provide an example of this. Similarly, where water scarcity is extreme, demands for water outside the watershed may induce investments in inter-basin transfers.

3.5 Conclusion

The methodology described above addresses the problem of water resource allocation at the level of the watershed and provides policy makers and resource managers with a concrete procedure for attaining economic efficiency targets whilst considering equity and environmental sustainability.

The methodology proposes that competing demands, including the environment, are traded off against one another and balanced against extant hydrological constraints using the of notion of economic efficiency, the marginal valuation of water and the equi-marginal principle. The valuation exercises are undertaken independently of prevailing property rights regimes for water resources and hence allow the characterisation of efficient/optimal allocations of water, rather than those tainted by property rights uncertainties, open access and missing markets.

However, economic efficiency itself must be traded-off against the contributions to social welfare derived from equitable distributions of resources and policy impacts such as employment. Similarly the complex nature of hydrological linkages requires additional analysis to establish the value of water resources in non-marketed watershed services such as drought mitigation/risk reduction and coastal wetlands. In addition demands for *in situ* environmental services external to the watershed need to be considered along with other potentially subtle market failures. Where not addressed in Stage I, these considerations are captured by Stage II of the methodology.

In sum, the watershed economics approach provides a coherent procedure for overcoming the water resource allocation problem addressed at the level of the watershed.

4. PROJECT STUDY: THE KOURIS WATERSHED IN CYPRUS

The following study illustrates how the economic watershed appraisal methodology described above has been implemented in Cyprus. It uses the Kouris watershed as an example of a watershed in which resource conflict exists, describes how valuation exercises have been undertaken in Cyprus for the sectoral demands, and the policy implications.

4.1 Overview of Human and Physical Aspects: Hydrology and Water Supply

Cyprus is an arid island state situated in the north-eastern Mediterranean in which renewable freshwater resources are highly constrained. The hydrological cycle of Cyprus is characterised by spatial and temporal scarcity in water quality and quantity (See Figure 3.1). Precipitation is between 300 and 1100mm per annum, the long-run annual average (1916-1999) being 510mm. Precipitation is highly seasonal, with 82% confined to the period between April and November, and surface water flows are correspondingly ephemeral (World Bank, 1996). Similarly, precipitation varies regionally within Cyprus from 300mm/a in the eastern plains to 1200mm/a in the westerly Troodos Mountains. This variability is reflected in the underlying distribution of water resources: groundwater aquifers, water courses etc. 80% of rainfall is lost through evapo-transpiration, the remaining 20% can be considered as the available annual water resources in Cyprus.

In 1970 the limit to water resource availability was calculated to be 900Mm^3/a, 600Mm^3/a of which manifested itself as surface water flow and the remaining 300Mm^3/a infiltrated and contributed to aquifer recharge Socratous (2000). It is estimated that of the surface water 130-150 Mm^3/a are diverted to dams, 150Mm^3/a are diverted directly from rivers for irrigation, with the remainder flowing into the sea. Of the 300 Mm^3/a aquifer recharge, $270Mm^3/a$ is pumped or extracted from springs and $70Mm^3/a$ flows into the sea in the form of sub-surface flow (MITWRG, 1999), implying the use of groundwater stocks in addition to flows. Since the estimation was undertaken in 1970 a 30% reduction in the overall water availability has been witnessed, highlighting the need for a reassessment of strategic water resources (Socratous 2000).

A number of different water supply investments and interventions have been made in Government controlled Cyprus. In addition to surface water dams and groundwater exploitation, these have included recycling, desalination, and even evaporation suppression, cloud seeding and importation of water. Table 4.1 shows the contributions to water supply of the most important water resources and investments.

Table 4.1. Water Resource Assessment, Cyprus

Water Source	Average Quantity (Mm^3/a)	Description
Surface Water	130-150	Diverted to storage dams; subject to evaporation
	150	Diverted direct from rivers for irrigation
Groundwater	270	Pumped or extracted from springs
Desalination	6.5	Supplies residential areas: capacity to increase
Recycling	4	Soon to be increased to 13 Mm^3/a

Source: Socratous (2000) and MITWRG(1999).

The most significant investments have been those contributing to the Southern Conveyor Project (SCP). This scheme forms an interconnected water supply system which allows the transfer of water resources throughout the southern part of the island, and also to and from the capital Nicosia. The scheme was designed to supply water to irrigated agriculture and residential areas, alleviating the spatial and temporal scarcity of water supplied in the country. The SCP effectively links all groundwater and surface water sources from the Diarizos River (near Paphos) in the west to Paralimni (south of Famagusta) in the East. The management of individual catchments is of national consequence for Cyprus as a result (World Bank, 1996). See Figure 4.1 in Section 4.4.

Currently all aquifers are exploited beyond their safe yield, with the excess of use over natural recharge estimated to be $40Mm^3/a$. The storage of ephemeral surface water flows supplies approximately $150Mm^3/a$ on average. However in recent years the yields of the major storage dams of the SCP have not been as high as the predictions upon which the investment decisions were based had suggested. In the last 25 years mean annual inflows have been $62Mm^3$, compared to $87Mm^3$ in the preceding years, for three possible reasons: a) the previous hydrological modelling may have been optimistic, b) water use and storage in the upper parts of the Kouris watershed may have increased, c) there has been a reduction in rainfall (World Bank, 1996).

The possibilities for additional exploitation of surface water have been largely exhausted and this has necessitated the consideration and/or use of costly unconventional sources such as desalination, recycling, and evaporation suppression.

4.2 Sectoral Water Demands

The inter-sectoral demand for water is shown in Table 4.2 for the three major water schemes in Cyprus. It can be seen that approximately 75% of current water use is in irrigated agriculture. The majority of the remaining demand is in urban areas including municipal, tourist and industrial demands.

Table 4.2. Water Consumption in the Major Water Schemes in Cyprus, Mm^3/a (1994)

Water Scheme	Municipal, Industrial and Tourism	Irrigation	Total
Southern Conveyor System	42.7	45.9	88.6
Paphos System	4.2	23.2	27.5
Khrysokhou System	0.4	6.3	6.7
Other	8.1	84.5	92.6
TOTAL	**55.4**	**160.0**	**215.4**

Adapted from World Bank (1996)

There is a distinct seasonality to the demands for water from both of these water consuming sectors. Urban demands are clearly higher in the tourist season, whilst the demands for agriculture also vary according to the growing season. Economic growth has averaged 6% over the past 15 years, driven largely by up to 10% annual growth in the tourist sector. There has also been nominal economic growth in the industrial sector. Under current Government plans, the irrigation sector will be expanded in the coming years, having grown at a rate of 2.2% over 1980-1992 period. Coupled with an expected aggregate population growth rate of 0.9% and rapid urbanisation, these different components of sectoral growth will place further pressure on water resources in the years to come. These factors describe the inter- and intra-temporal aspects of water demand.

Price is a significant determinant of water consumption. The consumption of water resources by irrigated agriculture is subsidised to the tune of 70% of the unit production cost on average (World Bank, 1996). Current pricing strategies in urban areas differ significantly between municipalities, but generally involve significant cost recovery.

4.3 The Water Balance and Rights to Resources

4.3.1 The Water Balance

A quick comparison of the estimated water resource availability and demand predictions contained in Table 4.1, 4.2 and 4.3 suggests that the overall water balance in Cyprus is favourable on average. However, given the spatial and temporal variability of water resources and demands described above, the water balance itself varies from one watershed and/or water scheme to the next, and from one year to the next. The scarcity of water resources in Cyprus is thus characterised by extreme fluctuations over time and space of water supply and demand: including droughts, and not in general by the average hydrological parameters.

Of the water schemes shown in Table 4.2 above the SCP has been shown to have the least favourable water balance (World Bank, 1996). Using recorded levels of consumption for the area supplied by the SCP, and comparing these to the water supplied from desalination, recycling and the recorded surface water inflows for the period 1969-1994 the water balance in Table 4.3 is constructed.

The SCP caters for 40% of the aggregate demand; 80% of all urban demand and 25% of all agricultural demand. Clearly, the average water balance for the SCP scheme is negative based on the surface water flows witnessed over the 25 year period and the observed water demands. It is the deficit of surface water flow where the main shortfall occurs. Given the yearly fluctuations in precipitation and the resultant surface flow, the picture of scarcity and the severity of the deficit varies from year to year. With demands at 2000 levels, the pattern of surface water flows observed over the past 25 year period would lead to several years of water deficit, many of which would be severe. Indeed the droughts of 1989-91 and 1995-99 illustrate the immediacy of the water balance deficits and the potentially unsustainable path of water resources management under the current system.

Table 4.3. Water Balance for the Southern Conveyor Project

Demand and Supply		1995	2000
Water Supply	Surface Water	61.8	61.8
	Groundwater	28.0	28.0
	Diversions	16.3	16.3
	Desalination	-	6.5
	Reuse	1.0	7.0
TOTAL SUPPLY*		**101.1**	**109.6**
Water Demand	Urban	42.7	48.9
	Irrigation	45.9	61.2
TOTAL DEMAND		**88.6**	**110.1**
WATER BALANCE		**12.5**	**-0.5**

* Net of Evaporation: 6Mm^3/a. Source World Bank (1996).

In summary, the uncertainty and variability of water resources heightens the need to store water to smooth resource availability in order to supply seasonal demands. The need for smoothing of water supplies has given rise to large investments in surface water storage dams, water transfer schemes such as the SCP, and placed pressure on natural storage in groundwater aquifers. Inter-temporal and spatial dimensions to water scarcity, coupled with expected growth in the industrial, household and tourist sectors, and from the heavily subsidised agricultural sector, have given rise to a situation in which the options for water supply augmentation are either exhausted or high cost. The deficit of the water balance can only be expected to worsen.

4.3.2 The Property Rights to Water Resources

The water balance is reflective of the interaction of supply and demand, and the underlying distribution of the right to control resources. The deficits in the water balance illustrate a conflict in resource management stemming from an absence of coordinated control of water use and the balancing of those demands with supply in a manner consistent with the underlying hydrology.

Agriculture is clearly the largest water consumer. Table 4.2 shows that the major water schemes all have significant irrigation components, and indeed the primary motivation for the development of some of these projects was to maintain water supply for expansion of irrigation. Government run schemes accounted for 74Mm^3/a of the total water consumed in 1994, and most are connected to public investment schemes such as the SCP. The rights to water clearly stem from government control. Non-governmental schemes consist of many scattered, small individual and communal schemes, like those using groundwater from the Kiti aquifer and the upper reaches of the Kouris catchment. The rights to groundwater resources are largely **common property/open access** here. These users accounted for 82Mm^3/a of water use in 1994.

In addition to these water users, direct diversions from surface water flows, mainly in the Troodos mountains, including the Kouris catchment, for use by individuals and communal irrigators account for 150Mm^3/a of total resource availability. Surface water is also subject to open access, and farmers have the rights to construct irrigation schemes and use surface water flow (World Bank 1996). Urban water resources are largely supplied by public schemes such as the SCP, but also by localised commissions from groundwater and surface water schemes.

In sum the current property rights are in part based on the riparian principle and the 'rule of capture' (first in time first in right) and the resulting pattern of demand is uncoordinated. Although the Government has the responsibility for monitoring and protecting water resources, this responsibility is divided between many institutions resulting in a fragmented regulatory framework (Grimeaud, 2001).

4.3.3 The Need for a Policy Change

The current water balance in the Southern Conveyor Project and the overdraft of groundwater resources are indicative conflicts between resource use and the natural constraints of water supply that have arisen under the current water management environment. The current extent of resource use is clearly unsustainable and there is nothing to guarantee that the benefits or social welfare derived from water resources are maximised or well distributed under the current pattern of water demand.

The conflict may be illustrated by the case of the Kouris catchment. It is widely believed that the unchecked growth of private and communal water use in the upper reaches of the Kouris watershed has contributed to reduced surface flows for the SCP (World Bank, 1996). Given the inter-basin transfers that the SCP allows, this watershed issue is of national consequence. Furthermore, the storage dams of the SCP have reduced the freshwater resources reaching the coast and feeding wetlands. There is concern that this has caused damage to the habitats important to migratory species. The management of water resources and conflicts within the watershed is not coordinated and the balance between these dimensions of demand within the Kouris watershed has not been met. There is a need for a new approach to water management in Cyprus which takes into consideration the pertinent contextual factors:

- Imbalance of growing demand and exhausted/costly supply
- Growing environmental costs and issues of sustainability
- Watershed level water management and River Basin Districts
- Fragmented legal and institutional framework

In short the balancing of demand with the natural constraints of water supply in Cyprus requires an approach that analyses the constituent determinants of the prevailing demand and supply imbalance in a manner which is hydrologically coherent and which recognises the competing demands for water resources. An integrated approach is required.

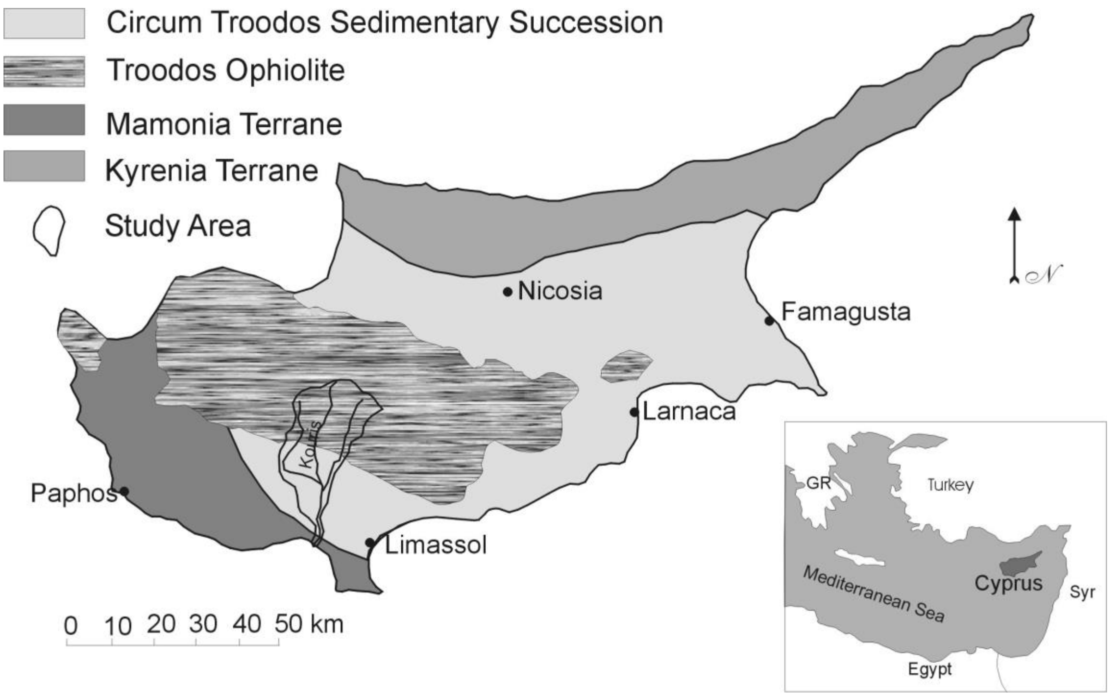
4.4 The Kouris Watershed

The Kouris watershed covers 300km^2 in the South West of Cyprus (see Figure 4.1). The watershed contains storage dams with a total capacity of 180Mm^3 and provides much of the surface water for the Southern Conveyor Project (SCP). The SCP provides up to 40% of the water supply of Cyprus as a whole: 80% of urban and 25% of agricultural. The largest single storage dam is the Kouris Dam, with a capacity of 115Mm^3.The water users within the watershed are many and disparate, and their property rights to water vary. In the upper reaches of the watershed agricultural users extract groundwater and divert surface water for irrigation purposes under a common property arrangement. Downstream, water is diverted to storage dams for distribution to the main urban centres, and to other irrigation schemes via the SCP. In the lower reaches of the watershed surface water feeds into the coastal wetland areas which provide a habitat for indigenous wildlife and migratory bird species.

Diversions of surface flow upstream reduce the surface water flow available downstream. Similarly it has been found that surface water flow is coupled with groundwater; up to 60% of the surface water flow is made up of sub-surface flow and springs. The use of one resource impacts upon the other (Boronina et al 2001). Under these circumstances it is clear that the decisions of upstream water users impact upon downstream users. Indeed, it is widely believed that the unchecked growth of private and communal water use in the upper reaches of the Kouris watershed has contributed to reduced surface flows for the SCP (World Bank, 1996). Given the inter-basin transfers that the SCP allows, this watershed issue is of national consequence. Furthermore, the storage dams of the SCP have reduced the freshwater resources reaching the coast and feeding wetlands. There is concern that this has caused damage to the habitats important for migratory bird species.

In sum, the unregulated interplay of water using agents acting in their own interests has lead to conflicting demands within the watershed. The management of water resources has not taken a watershed approach, has been uncoordinated, and the balance between demands within the Kouris watershed has not been met. As a result the water balance for the SCP is in deficit and, given the expected sectoral growth, is likely to worsen in the coming years, whilst environmental impacts go largely unchecked. The development of conventional water sources has proved insufficient for securing water resources in the face of extreme climatic conditions and the options for supply augmentation are nearly exhausted and only available at high cost. The need for water demand management is clear in this situation.

Figure 4.1. The Kouris Catchment: Cyprus



Source: Boronina et al (2001)

4.5 **STAGE I:** The Evaluation of Water Demand in Cyprus

In what follows we describe the various sectoral demand assessments that have been undertaken in Cyprus and presents the results. The results are drawn together in the final section and the policy implications for the balancing of water demands are posited. Box 3 describes the data used in the water demand analyses

4.5.1 Household Demand Assessment

An analysis of residential water demand from the SCP was undertaken. Water demand was calculated from expenditure data and knowledge of the tariff structure in each of the localities. As in most European countries and the United States, Cyprus water utilities choose among three types of pricing schemes, uniform, decreasing and increasing block rates, in their attempt to use the price of water as a management tool to influence its use. The government-controlled part of Cyprus is divided into 37 water authorities each having its own tariff structure. The adoption of an increasing block tariff structure and differences in the application of this pricing policy across water authorities give rise to substantial water price heterogeneity in the island. First we provide a detailed graphical and descriptive statistical analysis of the structure and distribution of water tariffs in Cyprus, between regions and income groups.

Economists have attempted to shed some light on the consequences of the choice of the pricing structure by paying attention to demand estimation. However, opinions concerning the appropriate methodology for estimating water demand models differ. Estimation under a block pricing structure requires appropriate modeling to account for the choice of both within and between block consumption. Earlier studies of water demand ignore the peculiar features of the presence of block rates and perform empirical estimation using ex post-calculated average prices. More recently, investigators combine marginal price and the so-called Nordin´s difference variable (in the case of multiple tariffs, this variable is the difference between the total bill and what the users would have paid if all units were charged at the marginal price) in empirical models of residential demand.

We estimate a model consistent with fundamental principles of the economic theory of consumer behaviour (such as adding-up, price homogeneity and symmetry). The choice of the Quadratic Almost Ideal Demand System (QUAIDS) model reflects the fact that it belongs to the family of rank-3 demand systems, the most general empirical representation of consumer preferences that satisfies integrability. We use a rank-3 demand system for two reasons. First, we estimate demand for water using individual household data for which lower rank demand systems are to be inadequate to capture the nonlinear income effects pertaining to these data. Second, we need a demand system that satisfies integrability (the ability to recover the parameters of the indirect utility function from empirical demand analysis) because we plan to analyse the welfare implications of alternative water pricing policies on empirical grounds. We consider the ability to evaluate the welfare implications of alternative water pricing policies particularly important, given the significance attached to equity and the strong political objections to water price reform in Cyprus based on political economy arguments.

The theoretical model described above is applied to individual household data, contained in the Family Expenditure Survey (FES) of Cyprus 1996/97. This allows estimation of the price and income elasticities of residential demand for water in Cyprus, the marginal value of water in the residential sector and evaluates the welfare effects associated with changes in the water pricing system. Empirical results show that the current water pricing system is progressive but inefficient in the sense that it introduces gross price distortions resulting in deadweight loss. The regional difference, in particular, introduces a substantial price heterogeneity that cannot be justified on the basis of efficiency or equity criteria. It cannot be justified on efficiency grounds because it is difficult to imagine that in a small island like Cyprus such large regional differences in price can reflect difference in supply costs. The regional price heterogeneity cannot also be justified on equity grounds because we found that users consuming much smaller amounts of water.

Moreover, the empirical analysis suggests that the marginal value of water in the residential sector is £CY0.45/m^3. The price elasticity of demand for water ranges between -.4 for households in the lowest and -.8 for households in the highest 10% of income distribution (see Table 4). This means that the demand curve for water is downward sloping and for high-income water users, highly responsive to price changes. This suggests a strong role for price as a demand management tool. Budget elasticities for water, which reflect the responsiveness of the proportion of income spent on water to income, and hence income elasticity of demand (IED), are also shown in Table 4. That the values of budget elasticities are always less than 1 implies that water is seen as a necessity, as expected. However, the value increases with income, suggesting that increases in income for high-income households lead to a greater increase in the proportion of income spent on water. This suggests that water is complementary to water intensive luxury goods such as swimming pools and gardens with lawns.

The analysis found that current regionally heterogeneous increasing block pricing system in the island introduces gross price distortions that are not justified. Thus in the case of residential water use, price can play a role in the context of a demand management scheme designed to tackle the growing fresh water problems in Cyprus. Such an approach, however, should take into account the distributional impact of alternative price regimes. Any major water price reform is bound to have effects on the welfare of individual consumers, In other words there will be winners and losers, and therefore there will also be a need to consider how to deal with potential hardship caused by the water price reform.

Section 4.5.2:
Estimating the Scarcity Value of Groundwater

This study looks at the issues particular to optimal management of groundwater and the allocation between competing agricultural and residential demands. Optimal allocation of groundwater is a multistage decision process. At each stage, e.g. each year, a decision must be made regarding the level of groundwater use, which will maximize the present value of economic returns to the basin. The initial conditions for each stage may be different due to changes in either the economic or hydrologic parameters of the basin under consideration. However, in most of the dynamic models employed in the groundwater literature the resource is modeled as a stock to be depleted in a mining era before moving to a stationary-state era. Implicit to these models are the assumptions of fixed economic relations and/or exogenous rates of change through time.

More complex and realistic representations of increasing resource scarcity incorporate opportunities for adaptation to rising resource prices. That is, in the long-run perspective, shifts away from water intensive production activities, adoption of new techniques or backstop technologies, substitution of alternative inputs, and production of a different mix of products offer rational responses to increasing scarcity. To model these, economists have developed the technique of multistage optimal control in the context of groundwater mining for agricultural production. Our study employs this technique to describe the chronological pattern of groundwater use by different economic sectors (residential and agriculture) in order to define optimally the quantity of the resource that should be produced when the available backstop technology (seawater desalination) is adopted at some endogenously defined time. Including in a control model the opportunity for this type of adaptation strengthens its ability to describe economic processes associated with natural resource depletion. The additional detail, further can inform public policy decisions concerning natural resource allocation among economic sectors, optimal timing of adoption of an available backstop technology and definition of optimal quantity of the resource to be produced by this technology for each of the different users.

Moreover, our model takes in account common property arrangements for groundwater resources that lead to dynamic externalities in consumption. These externalities are associated with the finite nature of the resource, pumping costs and the use of groundwater as buffer against risk. Our study focuses upon the commonality of the Kiti aquifer and addresses the scarcity rents generated by agricultural and residential demand for groundwater. The optimal allocation between agricultural and residential sectors is simulated incorporating hydrological parameters and the optimal unit scarcity rents are derived. The scarcity rents are compared to those that emerge under the simulated myopic common property arrangement, the difference reflecting the common property externality, and the benefits from optimal groundwater management, e.g. pricing, are assessed.

Our results suggest that in the presence of a backstop technology the effect of the dynamic externality in groundwater consumption is not particularly strong on the social welfare of the economic sectors using groundwater. This is an intuitive result because it suggests that when the scarcity of the resource is reduced due to the presence of a backstop technology, welfare gains from controlling resource extraction are not significant for any practical purposes. However, in the absence of a backstop technology and continuous natural recharge the effect on welfare from managing groundwater extraction is significant. A huge welfare improvement is derived from controlling extraction as compared to myopic exploitation of the aquifer **(see table 5)**.

Table 5: Optimal Control versus Common Property Welafre

Regime	Bacckstop	Welafre	Welfare Improvement
Optimal Control	**Available**	**£170.360m**	
Myopic	**Available**	**£162.621m**	**3.8%**
Optimal Control	**Not Available**	**£110.510m**	
Myopic	**Not Available**	**£25.9610m**	**409.4%**

Lastly, an alternative methodology, the **distance function approach,** is employed to estimate the scarcity rents of the Kiti groundwater using more applicable behavioral assumptions for agriculturists. Distance functions have a number of virtues that make their use attractive when the environment under which firms operate is regulated and/or when firms are inefficient due to lack of incentives faced by their operators. In particular, the first virtue of distance functions is that they do not necessarily require price data to compute the parameters; only quantity data is needed. Secondly, distance functions do not impose any behavioral hypothesis (such as profit maximization or cost minimization). That is, they allow production units to operate below the production frontier (i.e. to be inefficient) and they also allow derivation of firm-specific inefficiencies. Thirdly, duality results between distance functions and the more conventional cost, profit and revenue functions provide flexibility for empirical applications.

The key extension of this research on existing theoretical literature is that it establishes that when cost, profit or revenue function representations are precluded, the restricted distance function provides an excellent analytical tool for estimating unobservable shadow prices of in situ natural resources produced and used as inputs in production processes of vertically integrated firms. The data used in the empirical application of this research were extracted from the Production Surveys conducted by the Department of Economics, university of Cyprus, for the years 1991, 1997 and 1999. Our analysis focuses on a sample of 228 agricultural farmers located in the Kiti region. The data set consists of a balanced panel that is composed by the same 76 farmers located in the Kiti region. The data set consists of a balanced panel that is composed by the same 76 farmers over the three years of the survey. Estimation suggests that firm-specific efficiencies are increasing over time. The mean average technical efficiency for agricultural firms in the sample increased rather rapidly from 0.47 in 1991, to 0.78 in 1997, and finally to 0.94 in 1999.

Given that technical change is assumed to be constant in the estimated model over the relevant time period, these results allow the conclusion that the managers of the agricultural firms in the sample under consideration, learn from their previous experience in the production process and as a result their technical inefficiency effects change in a persistent pattern over time. The reported substantial increases in the technical efficiency of agricultural firms can be attributed to the major restructuring of the agricultural sector that took place in the last decade in an attempt to harmonize the Cypriot agricultural policies with those of the European Union, in the light of Cyprus accession in the EU. Alternatively, increases may indicate the existence of technological progress in the agricultural sector under consideration, which is not accounted for in our empirical model. These are the first estimates of the efficiency of the Cypriot agricultural sector and as a result there is no scope for comparison at the present. The central result of this empirical application, however, is that estimated technical firm-specific inefficiencies present in production technologies of agricultural, suggest that cost minimization is not the relevant behavior objective in Cyprus irrigated agriculture. This result provides support for the use of the distance function approach to derive resource scarcity rents.

The unit scarcity rent of in situ groundwater estimated by the distance function is approximately equal to zero (0.0097 CY£/m^3) under the myopic common property. This is approximately 20 times less than the value under optimal control. This comparison indicates that agricultural producers in the region are not willing to pay the full social cost of their extraction **(see table 6).** This implies that under common property, externalities arise, as current users of the resource are willing to pay only the private cost of their resource extraction, and as a result the resource's scarcity value goes completely unrecognized. This pattern of behavior is consistent with perfect myopic resource extraction, which arises because of the absence of properly allocated property rights in groundwater, and is consistent with the results on WTP for groundwater quality.

Table 4.6. Optimal Control versus Common Property Resource Rents

Component of Social Cost	Optimal Control (£Cy/m^3)	Common Property (£Cy/m^3)
Groundwater Pumping Cost	0.31	0.31
Scarcity Rent/Marginal User Cost	0.20	0.0097
Marginal Social Cost of Groundwater	0.5*	0.32

* this is the cost of the backstop technology: desalination

4.5.2 Estimating the Scarcity Value of Groundwater: Quantity

A **hedonic analysis** of the willingness to pay (WTP) for improvements in groundwater quality is undertaken. Groundwater quality may affect the productivity of land used for cultivating crops. Where this is so, the structure of land rents and prices will reflect these environmentally determined productivity differentials. Hence, by using the collected data on land rent or land value for different properties we can in principle identify the contribution which the attribute in question, fresh groundwater quality, makes to the price of the traded good, land. This identifies the WTP for groundwater quality.

The estimated marginal producer's valuation for groundwater quality as far as reduced salination is concerned, is statistically insignificant and equal to 1.07 CY£ per (0.1) hectare of land. The statistical insignificance and small magnitude of the marginal WTP for improvements in groundwater quality derived from the hedonic model with selectivity correction implies that extraction behaviour is myopic. That is, agricultural producers are not willing to pay a large amount for preserving groundwater quality today, because free-riding extracting agents might extract salt-free water tomorrow. This is of course an artefact of the non-existence of properly allocated property rights in a common-pool aquifer.

Moreover, another contributing factor towards a low marginal WTP for groundwater quality and existence of myopic extracting behaviour, is that current farmers value the prospect of switching land-use to the more lucrative tourism industry (as compared to the agricultural sector). Tourism utilises other existing sources of water (other than groundwater).

4.5.3 Estimation of the Marginal Value of Water and Risk Preferences in Agriculture

The agricultural production function for groundwater users is estimated econometrically and the marginal productivities of inputs as well as the effects of each of the inputs on risk are derived. Risk considerations are necessary in the understanding of the agricultural sector's use of water. Intelligent public policy should consider not only the marginal contribution of input use to the mean of output, but also the marginal reduction in the variance of output.

In the **estimated production function**, the sum of fertilisers, manure and pesticides (FMP) inputs, as well as water, had a significant and positive effect on expected profit. FMP and water exhibit decreasing marginal returns. Water and FMP and labour and FMP appear to be complimentary inputs. Water and FMP are risk increasing inputs (but at a decreasing rate). On the contrary labour appears to decrease the variance of profit, at an increasing rate, see Table 4.6.

Crop specific production functions are found to be statistically different and have better explanatory power than a general agricultural production function in the Kiti region. This indicates that crop specific policies will be more efficient rather than policies that do not differentiate among crops. In addition, for all crops specific production functions fertilisers and pesticides (either individually or jointly) exhibit higher marginal contributions than either water or labour.

Table 4.7. Estimated Risk Premiums and Marginal Productivity for Inputs

Parameter	**Water**			**Fertiliser**			**Labour**		
Average Risk Premium (% of expected profit)	18			19			17		
Impact on Variance of Profit (other inputs constant)	+ve decreasing			+ve decreasing			-ve decreasing		
Marginal Productivity/Value (By crop, £Cy/ unit of input)	Citrus	Veg	Cereal	Citrus	Veg	Cereal	Citrus	Veg	Cereal
	0.59	0.21	0.14	0.72	0.55	-	0.17	-0.32	0.25

Farmers exhibit moderate risk aversion and are willing to pay approximately one fifth of their expected profit to achieve the certainty equivalent: the profit received with certainty that leaves them as well off as with uncertain expected profit. No considerable heterogeneity of risk attitudes is observed in the population, so policies introduced to reallocate risk should be population rather than farmer specific. This is a reasonable result given that the agricultural region under consideration is small thus not allowing considerable variation to the accessibility of economic resources, services and information

4.5.4 Environmental Water Demand

As the standards of living increases in Cyprus the demand for water for recreational purpose increases. In recreation water has both a use value but also a non-use or **existence value**. Moreover, people who are willing to pay for this preservation might not be found inside the locality in which a wetland is located, i.e. the demand for these goods might be derived from people who care about it but live far away from it. In accordance with this premise research was undertaken aiming to derive the willingness to pay for environmental goods that are dependent upon freshwater resources, experienced locally but supplied regionally.

The values were elicited using the hypothetical valuation methodology of Contingent Valuation Methodology (CVM), and the hypothetical market for existence value addressed in the context of the provision of water allocations for migratory species. The scenario used to create the hypothetical market was realistic: without regional cooperation for freshwater allocations, a migratory species that makes use of wetlands in both Cyprus and the UK, the White-Headed Duck, is increasingly threatened with extinction. Those surveyed were asked to elicit preferences for the provision of water to endangered species under cooperative and non-cooperative funding scenarios. Econometric analysis of the survey responses demonstrated that there exists a positive WTP for the provision of local water to the endangered species (£10 per household per year). It is further demonstrated that there is an increased WTP (£10+£5 per household per year) for the local allocation of water to species, if other states along the migratory route make similar allocations: the cooperative scenario. Moreover, three important points for the provision of environmental goods and, in this case, the allocation of water resources are also demonstrated:

- Wetland externalities are of a dual nature, both local and regional;
- Local WTP for a locally experienced public good may be enhanced through regional co-operation;
- The regional optimal allocation of water to wetlands should take into account the sum of environmental benefits provided to the region, as perceived under the assumption of regional co-operation.

4.6 Pricing Recommendations

4.6.1 Residential Pricing of Surface Water

The analysis suggests that the uniform pricing policy is efficient for residential areas. The analysis provided exact welfare measurements for household which were unambiguously raised in aggregate under the uniform pricing policy. The uniform price should be set at £CY0.45 (as calculated by the Water Development Department in Cyprus using the average incremental cost methodology), reflecting the long-run marginal cost of water provision, in essence the marginal social cost of water supply. This will ensure efficient resource use decisions by households.

4.6.2 Agricultural Pricing of Groundwater

To balance demands between households and agriculture in the use of groundwater requires pricing of groundwater to reflect the marginal social cost. The marginal social cost is equal to the pumping cost plus the scarcity rent of the groundwater resource. The Kiti aquifer is depleted to such an extent that the optimal price represents the cost of the backstop technology: the long-run marginal cost of water. This price is £Cy0.5/m^3. Water will be consumed up to the point where marginal social benefits in agricultural and residential use are equated with this cost, and the net economic benefits are maximised. The potential benefits of optimal groundwater management are shown to be significant, and the imposition of an optimal price for groundwater is advocated.

That farmers have a risk premium for water suggests that groundwater may have a value as a buffer against risk, given the stochastic nature of recharge, and that the optimal price for groundwater includes elements of this value.

On a more general level the analysis indicates the levels of integration required in order to construct a rational and effective groundwater management policy. Not only is the correct groundwater policy dependent upon the precise characteristics of the aquifer: conductivity, storativity etc, but also the economic processes defining resource use: demands for land, production, risk preferences (see above), the existence of backstop technologies etc.

4.6.3 Environmental Pricing

The wetlands analysis has demonstrated the WTP for public goods such as environmental resources. There is a need to balance this economic value against the other watershed demands.

4.7 STAGE II: Policy Impact Analysis

4.7.1 The Welfare Impacts of Water Pricing Policy

Residential

In addition to the analysis in 3.2.1 above the household demand study allowed an analysis of the distribution of welfare changes arising from of the implementation of an efficient uniform pricing policy upon all residential areas. The **equity considerations** of tariff structures and expenditure levels for water were addressed through comparison of different income groups.

The analysis shows that the current regionally heterogeneous increasing block pricing system in the island is progressive but introduces gross price distortions that are not justified either on efficiency or equity grounds. In terms of efficiency the current tariff system cannot be justified on the basis of the marginal social costs of water supply since the same water resource supplies all locations at very similar cost. Since large consumers of water pay a lower average price per cubic metre of water than users consuming smaller amounts of water, the current tariff system cannot be justified on equity grounds.

However, although a shift towards uniform marginal cost pricing will eliminate the deadweight loss of the current system, its benefits will be distributed in favour of the better off households. As such the policy could be considered to be inequitable. Overall, the analysis indicates that price can be an effective tool for residential water demand management in Cyprus, however, it may also lead to socially undesirable distributional effects on households.

Agriculture

The impacts of inputs on the variance of the profit have been described. This tells how inputs affect the welfare of risk averse agents. For example, we notice that water has a positive but decreasing effect on the variance of profit. Other things remaining equal this means that although additional water increases the mean output/profit (positive marginal productivity), it increases the risk associated with output. The analysis shows that the population is risk averse, and therefore additional water may be welfare reducing. Similar arguments can be used for the other inputs.

Furthermore, one chief concern of reducing subsidies to agriculture is the impact that this may have upon employment. The production function has found no significant complementarity between labour and water inputs and as such this seems to indicate that the effect on employment will be due to any changes in output that occur, not from complementary reductions in labour use.

4.7.2 Conjoined Water Resources and Market Failures

The logic behind treating the watershed as the management unit is that the interactions of the physical elements of hydrology and geo-hydrology and the human demand side can be coherently addressed and guide policy. Thus far the coupled nature of surface and groundwater and the wider impacts that the demands for one resource will impose upon the other has been largely ignored.

Given the dependence of surface water flows on groundwater in the Kouris catchment the commonality of groundwater is wider than those users overlying the aquifer. Therefore the externalities associated with groundwater use will contain additional elements associated with the effects on surface water. The external effects of upstream groundwater use in this case may take two specific forms:

- **Appropriative externalities**: Groundwater users appropriate water from downstream users, preventing them from using water altogether.

- **Time Profile Externalities:** Groundwater users determine the **time profile** of water flows for the downstream users e.g. through groundwater return flows.

As described above, where markets do not exist where these facets of demand can be exchanged between users conjoined by water resources in this way, these externalities are likely to exist and cause inefficient allocations of resources between sectors, over space and time. Similarly, where planners are ignorant of the facets of the allocation problem when developing pricing policies, governmental failures may prevail. Hydrological and economic modelling has suggested that many of these features exist in the Kouris watershed. However, further research is required before the nature of the issue can be completely described.

4.7.3 Public Goods

The WTP for wetlands within the Kouris catchment has been demonstrated. It has also been demonstrated to exist both locally and regionally, beyond the confines of the watershed. The focus of policy should now be upon determining how these regional values can be transferred, to augment the local willingness to pay, in order to effect the centralised allocation of water resources to that end.

4.8 Policy Recommendations: Characterisation of Sustainable Use of the Watershed

4.8.1 Balancing Supply and Demand

The analysis of Stage I provided the parameters concerning the sectoral demands for water contained within Table 4.7. If we combine these parameters with derived estimates of water scarcity in the watershed (i.e. supply availability given multi-sectoral demand), then the information is sufficient to derive broad policy conclusions concerning the allocation of water resources in the Kouris watershed.

The demands for water in the Kouris watershed can be characterised broadly as follows. Agricultural users divert surface water flow and use groundwater in the upland areas. This impinges on the surface flows and storage for the SCP and residential demands in the lowlands, which in turn reduces the surface flow for wetlands further downstream at the coast. A positive economic value has been demonstrated for all aspects of demand within the watershed, and these alternative demands must be balanced objectively by reference to the parameters in Table 4.7. In terms of the objectives described in Section 3.2 the following policies can be advocated:

Economic Efficiency

- Inter-sectoral allocation of groundwater and surface water should be based on the marginal value of the resource for each sector; in table 4.7, the marginal value of water is higher in the residential sector than the agricultural sector at current use levels. This implies that policy should be directed towards reducing the appropriation of water resources by agriculture upstream and increasing the water provided to the SCP and residential areas.

- Efficient pricing of the resource should take into account the opportunity cost of its source; water from surface resource should be priced given its long-run marginal cost, while groundwater should be priced given its scarcity value: a price which includes the scarcity rent: In addition to optimal pricing for agriculture, there are social welfare improvements from the uniform pricing policy for residential sector.

- Both the quality and quantity of water are considered by sector users, so both of these dimensions should be integrated in allocation decisions; There is a small willingness to pay for unit decreases in seawater intrusion, which contributes to the scarcity value of groundwater.

Table 4.7. Estimated Parameters from Valuation Exercises

Sector	PED (-)	IED	Marginal Value/ WTP	Risk Premium
Households	0.4-0.8 increasing in income	0.25-0.48 decreasing in income	£CY0.45/m^3	NA
Agricultural/ Quantity	0.48	NA	£CY0.30/m^3	18%
Agricultural/ Quality	NA	NA	£CY1.07 per 0.1 hectare of land per unit decrease in salination	NA
Environmental	NA	NA	£15 per household per year for wetland preservation	NA

Equity

- Welfare effects of price and consequent allocations can be derived by the use of price and income elasticities of each sectoral demand.

- The impact of water pricing in employment in agriculture seemingly minimal and should not be rejected on these grounds.

Environment and Sustainability

- Demand for environmental water values exists, hence it should be considered and integrated in resource allocation decisions. In order for regional benefits to influence the resource allocation will require a transfer mechanism: e.g. EU, Global Environment Facility, or strict adherence to EU environmental directives.

- Should sustainability of water resources be deemed the most important facet of watershed management policy (groundwater mining or loss of environment is unacceptable) demands for water from traditional economic sectors can be constrained to levels to allow sustainable resource use using price and knowledge of the PED. In table 4.7 it is shown that the elasticity of water in residential users is higher than in agricultural users. This means that a given price increase for water will be more effective in reducing demands in the residential sector rather than the agricultural sector.

The policy impact analysis of Stage II should consider that in the Kouris watershed agriculture has open access control over groundwater and seasonal surface water. These two resources are conjoined and the allocation policy depends in part upon the nature of this coupling. Two examples are:

- **Groundwater use Reduces Surface Water flow:** Excessive groundwater pumping reduces surface water flows to downstream sectors, optimal control of groundwater may provide the solution to the water allocation problem.

- **Groundwater use Increases Surface Water via Return Flows:** Groundwater pumping contributes to surface water flow through return flows, hence the timing of resource flows becomes important. Seasonal pricing could be used to ensure water availability to downstream users in line with their seasonal preferences.

Of these possibilities, the former appears to describe the situation in the Kouris Catchment. Thus optimal control of groundwater resources will provide aggregate welfare improvements upstream, whilst effectively re-allocating surface water to the downstream residential sector and wetland areas.

5. Conclusion

The case study of the Kouris Watershed has described the implementation of the watershed economics methodology used described in the previous text. It has shown how the approach contributed to the development of policy recommendations for the Government of Cyprus. The study combined detailed hydrological models with micro-economic data on the water using sectors. The imbalance of water demand with the natural constraints of supply was addressed in the objective manner using the two stage process outlined above. In this case Stage I used of a variety economic valuation techniques: Hedonic analysis, Contingent Valuation, Travel Cost Approach, Mathematical Modelling and Distance Function, to assess the social value of water in the different sectors. This allowed the determination of the efficient pricing strategy for allocating between water demands to maximise social welfare. Stage II analysed the impact of the proposed allocation policy in order to address issues of equity and sustainability.

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