The Watershed Economics Management Approach: An Application to Cyprus

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Abstract: This paper develops a 'watershed economics approach' to resource allocation, which ensures that scarce water resources are allocated between competing demands in a way that maximises their contribution to societal welfare. This approach is constructed in a way that considers its impacts on all groups and interests affected, which requires the integration of various approaches and perspectives into a single systematic framework. It is composed of two 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. This allows the objective balancing of demands based upon the equi-marginal principle to achieve economic efficiency. In Stage II a policy impact analysis addresses issues of social equity, the value of water for environmental/ecological purposes and legal and institutional aspects. The analysis is undertaken within the confines of the watershed and is encapsulated by a case study of the Kouris watershed in Cyprus.

Keywords: watershed economics approach, integrated (interdisciplinary) water management, economic valuation, water demand estimation, environmental valuation, policy impact analysis.

1 Introduction

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 [19].

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. Water scarcity is important for *sustainability* in economic development as well, on account of the many associated environmental/watershed services [14, 16, 18]. 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.

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. Water is also an important input to economic activities and can be seen as both a production and consumption good [23]. Furthermore water is a public good contributing to recreation, amenity and general environmental and watershed values as an input to ecosystems and habitats. How can it be 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). [6, 23]. 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 implies that the prevailing distribution of water within most societies is not likely to be the most desirable one.

In what follows a ‘watershed economics approach’ is proposed in order to evaluate the socially desirable allocation of water through the objective balancing of competing demands. The methodology 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 Balancing the Demands for Water Resources: The Methodology

2.1 The Water Allocation Problem

The widely accepted objectives of water resource management can be broadly summarised as economic efficiency, equity and sustainability. There are a number of reasons why the unregulated behaviour of agents within the watershed will fail to allocate water resources in a manner consistent with these objectives. 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, whilst the hydrological connection between water and land using agents within a watershed is complex, often ill defined and uncertain [3, 22]. Secondly, the property rights to water resources, which are a major determinant of their pattern of allocation, are typically incomplete, absent or unenforceable [23]. 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 [10].

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/or 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 the 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, which refer to 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 [2]. 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.

2.2 The Watershed Economics Approach

Our watershed management methodology is based on 1) the identification of the appropriate unit for management; 2) the agreement of the objectives of water allocation 3) the evaluation of the various attributes of water demand within that unit; 4) the identification of optimal water resource allocations relative to objectives; 5) the assessment of the impacts of the proposed reallocation.

2.2.1 The Unit of Analysis

The watershed is a natural unit of analysis for addressing the balance of supply and demand for water, and the issues of efficiency, equity and sustainability for the following broad reasons: (a) the aggregate availability of water resources, including sustainable yields is bounded by the hydrological cycle of the watershed; (b) the interaction of different sources: e.g. groundwater and surface water, is confined by the watershed; (c) the demands for water interact within the watershed; water user upon another and upon environment [16, 17].

2.2.2 The Allocation Objectives

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 [19]:

- **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 [23]. 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 [21].

- **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 [18].

2.2.3 Balancing Water Demands in the Watershed

The outputs of the demand analysis allow the determination of the economically efficient allocations of water resources. The first element of an economically efficient allocation is the **equi-marginal principle**: this provides that each use of the water resource should achieve the same benefit from that water at the margin. In short, if water is more heavily valued at the margin in one sector than another, then it should be reallocated toward that sector until equality is achieved. The second element of the economically efficient allocation is that aggregate water resources are allocated efficiently where the marginal social benefit of their use is equated to the **marginal social cost** of supply.

2.2.4 Methodology Stage I: Objective Approach to Balancing Water Demands

I. **Evaluate Demands**

Apply appropriate methodologies to assess characteristics of the demand for water arising from individual, sectoral and environmental uses. Derive the parameters of water demand required for policy purposes: Marginal Value, PED, IED, WTP, and risk parameters for all the relevant dimensions of demand (see table1). The evaluation process should be undertaken in accordance with carefully constructed methodologies, and be independent of any prior rights to water resources. This enables an evaluation of water uses according to the benefits that accrue to all of society from them.

II. **Determine Efficient Allocations**

Evaluate the relative values accruing to society by virtue of differing water allocations. Determine those water allocations that achieve an economically optimal balance. An economically optimal allocation is one in which aggregate demands are balanced with supply according to the equation of marginal social value (benefit) to the marginal social cost of supply, and in which each source of demand is achieving equal value from its marginal allocation of water.

III. **Ascertain Impacts of Implementing Efficient Allocation**

The policy maker may choose from a wide variety of instruments to effect the desirable allocation (tradable permits, pricing, auctions). Any proposed method of implementation should be considered for feasibility within the relevant watershed, and then evaluated for its broader impacts on the society. This evaluation process leads into Stage II of the Methodology.

2.2.5. Methodology Stage II: Policy Impact Analysis

The second phase to the water allocation methodology flows from the consideration of the implementation of the conclusions from the first. First, the discussion here has largely been phrased in terms of the use of water pricing as the appropriate allocation mechanism. However, this need not necessarily be the best or most appropriate instrument for allocating water in every context. Secondly, it is crucial to note that economically efficient allocation need not necessarily be an equitable or sustainable one. Additional analysis is required to assess the distributional and environmental impacts of pricing/allocation according to the equi-marginal principle.

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, **sectoral allocation** (water demand between economic sectors), **spatial allocation** (spatial variability and the conjoined nature of surface and groundwater) [7], and **temporal allocation** (conjoined users imposing externalities upon each other relating to allocation over time and the timing of resource use) should be considered [5]. Other externalities arise from the demand for public goods, which frequently extends beyond the watershed. Global and regional environmental goods for which existence, bequest and option values are held provide an example of this. Furthermore, where water scarcity is extreme, demands for water outside the watershed may induce investments in inter-basin transfers.

III **Institutional and Legislative Analysis**

As one of the main obstacles to water re-allocations a review of the legislative and institutional environment required to effect the desired allocation may finally be required.

3 The Water Management Problem Under Study: 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.

3.1 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. 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. 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 [22].

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. 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 [13], 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.

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 2 shows the contributions to water supply of the most important water resources and investments.

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 main contribution of surface water to the SCP is from the Kouris watershed area, therefore the management of individual catchments is of national consequence for Cyprus as a result. See Figure 2.

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 [22].

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.

3.2 Sectoral Water Demands

The inter-sectoral demand for water is shown in Table 3 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.

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 [22].

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. Current pricing strategies in urban areas differ significantly between municipalities, but generally involve significant cost recovery.

3.3 The Water Balance, Rights to Resources and Institutional Background

3.3.1 The Water Balance

A quick comparison of the estimated water resource availability and demand predictions contained in Table 2, 3 and 4 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 3 above the SCP has been shown to have the least favourable water balance. 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 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.

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. Intertemporal 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.

3.3.2 Institutional and Legislative Background

Generally speaking, Cyprus institutional arrangement in the field of protection of freshwater resources are characterised by a fragmented approach, involving the Council of Ministers and the following three ministries [3]:

- The Water Development Department of the Ministry of Agriculture, Natural Resources and the Environment
- The Department of Labour of the Ministry of Labour and Social Insurance
- The Medical and Public Health Services Division of the Ministry of Health

Cyprus water legislation may be also regarded as being piecemeal and fragmented. In sum, there are three separate pieces of legislation, which focus on three different aspects of water resource management: (1) the protection of freshwater resources (surface and groundwater), (2) specific legislation on groundwater, (3) legislation on water supply. The implementation of legislation concerning the protection of water resources is devoted to two Ministries; the Minister of Agriculture Natural Resources and the Environment who set Environmental Quality Standards, grant permits for discharges and enforce all provisions related to pollution from industrial sources and the Ministry of Labour and Social Insurance in charge of monitoring compliance with permit conditions.

The rights to groundwater resources are largely common property/open access, despite government ownership. Surface water is also subject to open access, and farmers have the rights to construct irrigation schemes and use surface water flow. The current property rights are in part based on the riparian principle and the 'rule of capture', 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 uncoordinated regulatory framework.

3.4 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, the larger contributor to the surface water of the SCP. 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. 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. Applying the Principles to the Kouris Watershed

4.1 Background to the Kouris Watershed

The Kouris watershed covers 300km^2 in the South West of Cyprus (see figure 2). 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 [22]. 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. A detailed investigation of the Hydrology of the

Kouris watershed has been undertaken as part of the project. Table 5 provides a brief summary of this research.

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 [1]. 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 [22]. 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 [22].

In sum, the unregulated interplay of water using agents acting in their own interests has led 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.

4.2 The Evaluation of Water Demand in Cyprus (Stage I of Methodology)

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

4.2.1 Household Demand Assessment

An analysis of residential water demand from the SCP was undertaken [6]. 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 non-linear 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 6). 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 6. 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.

4.2.2 Estimating the Scarcity Value of Groundwater: Quantity

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 modelled 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 [8, 9, 11]. 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 7).

Lastly, an alternative methodology, the **distance function approach,** is employed to estimate the scarcity rents of the Kiti groundwater using more applicable behavioural assumptions for agriculturists [12]. 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 behavioural 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 behaviour 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 7). 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 unrecognised. This pattern of behaviour 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.

4.2.3 Estimating the Scarcity Value of Groundwater: Quality

A **hedonic analysis** of the willingness to pay (WTP) for improvements in groundwater quality is undertaken [10]. 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).

4.2.4 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 [4]. 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 8).

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.

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

4.2.5 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 [15].

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: (a) wetland externalities are of a dual nature, both local and regional; (b) local WTP for a locally experienced public good may be enhanced through regional co-operation; and (c) 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.

4.3 Balancing Values: Policy for Implementing Optimal Allocation

The optimal allocation of water resources in Cyprus should balance these various values of water within this catchment area. In Cyprus, the preferred method for implementing this optimal allocation was through the development of a uniform water pricing scheme. Hence water pricing for residential, agricultural and environmental uses was taken into consideration. This may be accomplished by means of determining the marginal social cost of water supply, and then charging each user of water this same price for the water. Then the resulting allocation would satisfy both of the principles for an optimal water allocation. The implementation of the optimal allocation of water in Cyprus is discussed below.

4.3.1 The Marginal Social Cost of Water

A marginal social cost of water provision has been determined to be £CY0.5 (as calculated by the Water Development Department in Cyprus using the average incremental cost methodology), reflecting the long-run marginal cost of water provision. This is a reflection of the cost of additional water provision, in terms of the national resources required for its provision. It is the opportunity cost to Cyprus of providing further water rather than other socially demanded goods or services (such as health services or education services). The marginal social cost of water provision to the charged sectors (residential, industrial) should also reflect the opportunity costs of losing water to the uncharged (or public good) sector. The wetlands analysis has demonstrated that there exists a WTP for public goods such as environmental resources that depend on water supplies. The marginal social cost of water provision to the charged sectors should reflect the costs of all foregone opportunities by reason of such provision.

4.3.2 Residential Pricing of Surface Water

Pricing of residential water use at marginal social cost will ensure efficient resource use decisions by households. The welfare analysis indicates that aggregate welfare for households was unambiguously increased under the uniform pricing policy.

4.3.3 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.

4.4 Policy Impact Analysis (Stage II)

The optimal allocation of water resources will take into consideration the relative values placed on water in the various sectors (residential, agricultural, environmental); however, there are other important factors which may or may not be taken into consideration under this allocation. These considerations include: equity (the impacts on lower income groups), risk (the impacts on variability) and hydrology (the impacts on conjoint users). The analysis of water resource management must include this supplemental analysis.

4.4.1 Equity: The Welfare Impacts of Water Pricing Policy

The household demand study allowed an analysis of the distribution of welfare changes arising from 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.

4.4.2 Risk: The Impact of Water Pricing on Variability

The impact of water availability on the variance in producer profitability has been analysed. This indicates how water affects the welfare of risk averse agents. For example, we discovered 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.

4.4.3 Externalities, Market Failures and Conjoined Water Resources

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.

The policy impact analysis of Stage II should consider the conjoint use, and the impacts of one user on another. The impact of 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 [1]. Thus optimal control of groundwater resources is likely to provide aggregate welfare improvements upstream, whilst effectively re-allocating surface water to the downstream residential sector and wetland areas.

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 [5].

As described above, where markets do not exist, 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.

The WTP for wetlands within the Kouris catchment has been demonstrated, making it likely that externalities related to **Public Goods** exist. WTP for Public goods has 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.

4.4.4 Legislative and Institutional Analysis

The proposed allocation of water needs to be backed up by legislative change. Cyprus water legislation is characterised by a piecemeal approach whereby the quality aspects of freshwater resources is dealt in several laws depending on the type and the use which is made of the resources concerned. Moreover, several instruments deal with both water quality and quantity aspects, in particular with regards to groundwater. An integration process shall be required in the light of the provisions of the Water Framework Directive. The latter provides that all waters shall be addressed within the framework of River Basin Districts and individual river basins [the new water management unit] so as to ensure that water protection measures, including quality and quantity issues, are dealt with in a hydrologically coherent manner. As examined below, a good water status is to be achieved for all waters, which implies that the status of surface waters or groundwater shall be such as not to deteriorate the status of other water bodies.

In this context, the WFD provides for the drawing of **River Basin Management Plans**, which shall contain all measures that need to be implemented in a coordinated in each river basins so as to ensure protection for all waters. The WFD provides for the designation of a single competent authority in charge of the implementation of the environmental objectives of the directive in each River Basin District. The objective is to ensure consistency and coherence in decision-making and to guarantee that the integrated water management objective is achieved, in terms of co-ordinated protection of all waters, including surface waters, groundwater and protected areas.

4.5 Final Policy Recommendations

The study has focussed on pricing as the allocation mechanism to effect the efficient allocation of water resources between competing sectors, between surface and groundwater and over time. The policy recommendations that emerge from the watershed economics approach integrate the hydrological, economic and legal aspects of the project, and can be summarised as follows:

1. Water resources should be priced at the Marginal Social Cost as described in the summary of Stage 1 part II of the methodology.
2. Allocation policies should consider the following 3 issues either through the pricing structure itself or through additional mitigating policies:
    i. The adverse effects on the distribution of welfare among water users demonstrated in Stage 2 of the methodology.
    ii. The risk preferences held by water users, which have been demonstrated for the Agricultural sector.
    iii. The environmental externalities arising from demands for wetlands and other environmental resources that exist external to the watershed areas in question.
    iv. Missing markets and externalities arising from the conjoined nature of surface and groundwater demonstrated for the Kouris watershed.

These largely economic policy recommendations should be supplemented by the recommendations from the institutional and legal analysis:

- The fragmented nature of water institutions and responsibilities in Cyprus must be addressed.
- The piecemeal nature of Cypriot water legislation must be addressed both for the purposes of monitoring and facilitating the desirable water allocations and for harmonisation with the Water Framework Directive.

5. CONCLUSION

The case study of the Kouris Watershed has described the implementation of the integrated watershed economics methodology described in the initial sections of this report. 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 a variety of 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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The results contained in this paper have been presented and discussed, both with the network participants and with visiting professors at two workshops. The first took place in Nicosia, Cyprus, in July, 1999; the other was held in London, UK, in March, 2001. Moreover, a conference was organised by the University of Cyprus and the University College London, which brought together most of the leading economists in the world that are working on water allocation and management issues. This was called the “International Symposium on Water Resource Management - Efficiency, Equity and Policy".

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Table 1. Parameters Estimated from Valuation Techniques

- **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 the impacts of risk on consumer groups occasioned by reason of variability in water availability.

Table 2. 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

Table 3. 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**

Table 4. 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).

Table 5. The Hydrological Analysis of the Kouris Catchment

Task	Sub-Task	Detailed Description
Data Collection and Manipulation	i. Rainfall data	Precipitation for the period 1970-1995 was established in annual and 5-year moving average terms for specific meteorological stations.
	ii. Correlation of rainfall with spring discharge	The correlation between rainfall and surface flow (spring discharge and river discharge), was established for the period 1984-1995 by spring and by river/tributary. A strong correlation was found using an exponential trend line.
	iii. Correlation of rainfall with river discharge	
	iv. Evapo-transpiration	Measurements of evapo-transpiration at different altitudes were taken using evaporation pans
	v. Water depth observations	Water depth observations for the period 1984-1995 were established for a variety of boreholes. The period corresponded to a non-pumping period and the water levels showed a general increase.
	vi. Aquifer properties	The description of the aquifer was based on pumping tests and lineament analysis. From this transmissivity was estimated
Mapping	i. Borehole Location	A borehole map was prepared indicating the location and density of boreholes, and those boreholes for which water level measurements had been consistently taken. Drilling records from 166 boreholes were available
	ii. Meteorological and Gauging stations	The location and density within that location of meteorological and gauging stations was mapped.
	iii. Geology and Springs	The location and flow of permanent springs was mapped onto the Geological map of the catchment
	iv. Transmissivity and Piezometry	Maps were developed describing the piezometry and the transmissivity of the aquifers in the catchment
Simple Water Balance Model	i. Water Balance: Inflow = Outflow + Changes in Ground water Storage	Information regarding the transient surface water flows and aquifer behaviour was combined with the assumptions regarding the abstraction of water in the Kouris catchment to obtain a simplified water balance
	ii. Surface water groundwater relation	Initial analysis of the interaction of surface water and groundwater revealed that 65-70% of the stream flow in the catchment consists of base flow and stream discharge.

Table 6. Estimated Household Price and Budget Elasticities of Demand for Water

Elasticity	Income Group Percentiles					
	Bottom 10%	**11-25%**	**26-50%**	**51-75%**	**76-90%**	**Top 10%**
Budget	0.25	0.22	0.23	0.30	0.35	0.48
Price	-0.79	-0.69	-0.60	-0.56	-0.50	-0.39

Source: [11]

Table 7. Optimal Control versus Common Property Welfare

Regime	Backstop	Welfare	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%**

Table 8. 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 (By crop, CY£)	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

FIGURE 1. THE WATERSHED ECONOMICS METHODOLOGY

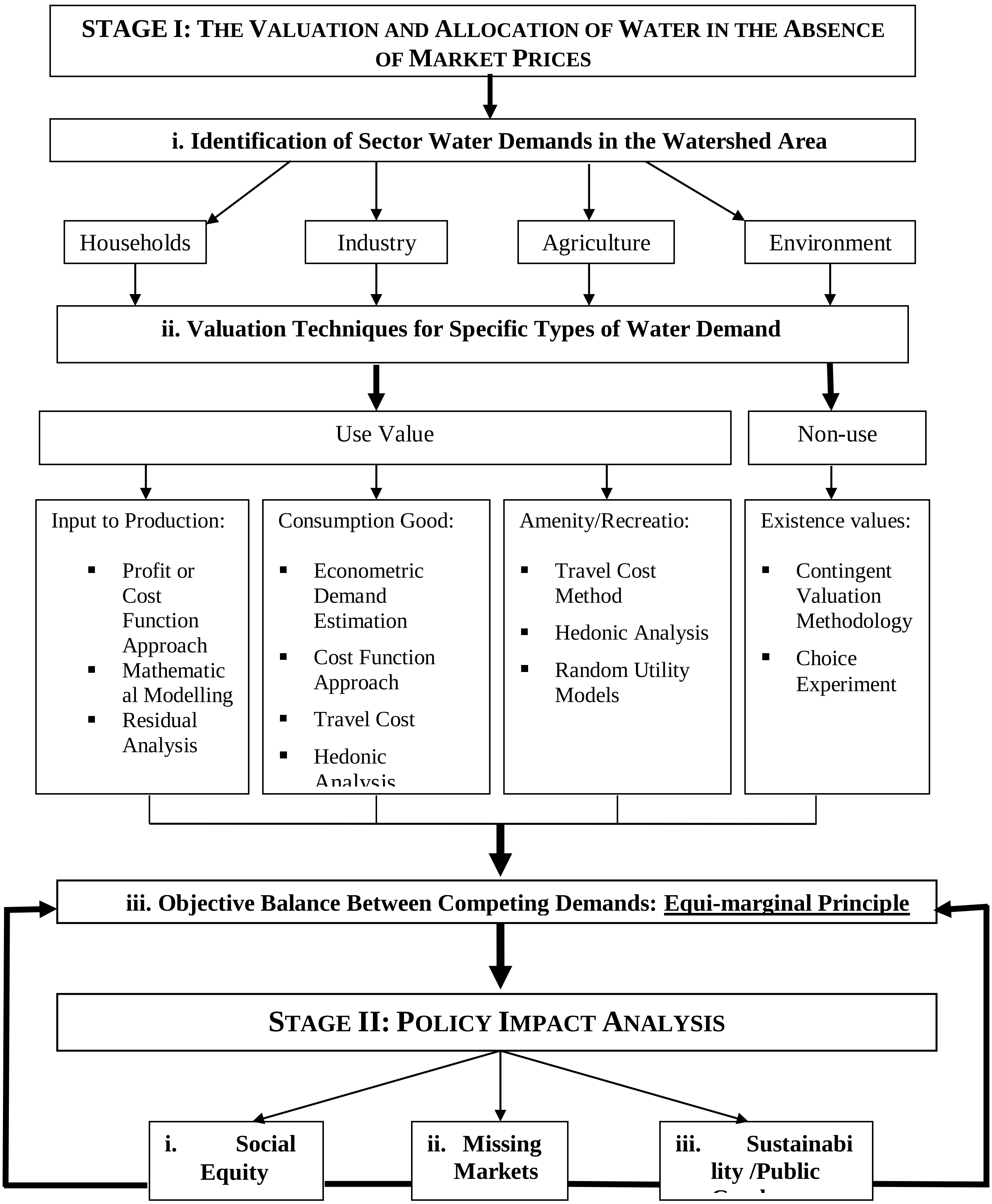
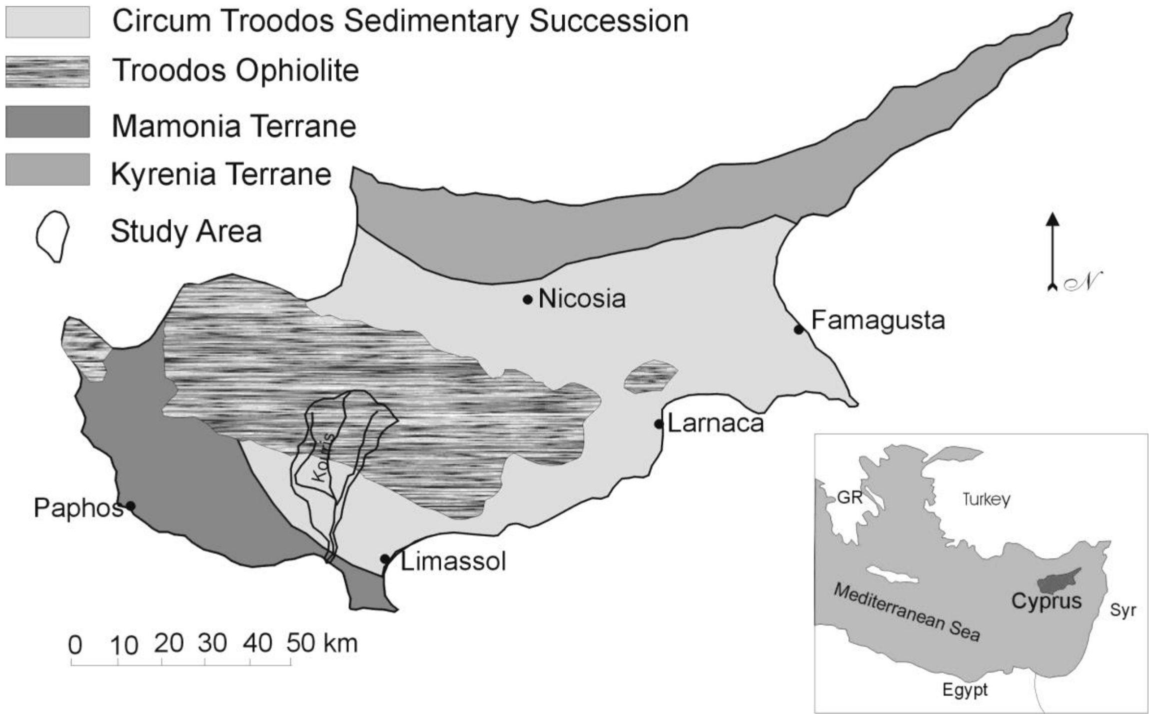


FIGURE 2: THE KOURIS CATCHMENT: CYPRUS



Source: [1]