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The Costs of Residential Water Scarcity in Cyprus

Impact of Climate Change and Policy Options

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The Costs of Residential Water Scarcity in Cyprus: Impact of Climate Change and Policy Options

Theodoros Zachariadis

Executive Summary

This paper presents an assessment of the costs of water scarcity in Cyprus, today and in the next twenty years, accounting also for the effect of projected climate change in the region. We focus on the residential sector, accounting also for tourism and industry. Using a simple demand function we first compute total scarcity costs in Cyprus for the entire period 2010–2030 for three scenarios of future water demand. Our central estimate shows that the present value of total costs due to water shortages in this period will amount to 72 million Euros (at 2009 prices), and if future water demand increases a little faster these costs may reach 200 million Euros'2009. Using forecasts of regional climate models we find costs to be about 20% higher in a climate change scenario. We also find that, compared to the loss of consumer surplus due to water shortages, desalination is most probably a costly solution, even if some environmental damage costs from the operation of desalination plants are not accounted for.

Finally, we employ dynamic constrained optimisation and find that efficient residential water prices should include a scarcity price of about 40 Eurocents per cubic metre at 2009 prices; this would constitute a 30–100% increase in current prices faced by residential consumers. Modest reductions in rainfall levels due to climate change would raise the current scarcity price by another 2–3 Eurocents'2009. Such a pricing policy, if implemented gradually over a few years, would provide a clear long-term price signal to consumers and firms and could substantially contribute to a sustainable use of water resources in the island. If a similar policy had been implemented a decade ago, it might have been able to address the water scarcity problem of Cyprus at lower costs and without the need for extensive use of desalination until the year 2020.

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Θεόδωρος Ζαχαριάδης

ΠΕΡΙΛΗΨΗ

Το παρόν Δοκίμιο εξετάζει και αποτιμά το οικονομικό κόστος στην κυπριακή κοινωνία κατά την περίοδο 2010–2030 εξαιτίας της έλλειψης επαρκών ποσοτήτων νερού για τον οικιακό, τουριστικό και βιομηχανικό τομέα. Καταστρώνονται τρία σενάρια για τη μελλοντική εξέλιξη της ζήτησης νερού και υπολογίζεται το κόστος έλλειψης νερού για καθένα από τα σενάρια αυτά. Για το κεντρικό – ενδεχομένως πιθανότερο – σενάριο προκύπτει ότι η παρούσα αξία του κόστους αυτού θα ανέλθει στα 72 εκ. Ευρώ (σε σταθερές τιμές του έτους 2009)˙ αν η ζήτηση αυξηθεί στο μέλλον γρηγορότερα, το κόστος μπορεί να πλησιάσει τα 200 εκ. Ευρώ. Χρησιμοποιώντας προβλέψεις κλιματικών μοντέλων, το κόστος ελλείψεων νερού μπορεί να είναι 20% υψηλότερο λόγω κλιματικής αλλαγής μέχρι το 2030, εξαιτίας της προβλεπόμενης μείωσης της βροχόπτωσης στην Κύπρο κατά την περίοδο αυτή.

Στη συνέχεια συγκρίνουμε το κόστος αυτό με το κόστος κατασκευής και λειτουργίας όλων των νέων μονάδων αφαλάτωσης που έχουν αποφασιστεί. Η σύγκριση δείχνει ότι, χωρίς να συνυπολογίσουμε το περιβαλλοντικό κόστος από τη λειτουργία των μονάδων αφαλάτωσης, το οικονομικό κόστος στην κοινωνία από τις ελλείψεις νερού ύδρευσης είναι χαμηλότερο από το κόστος της αφαλάτωσης. Αυτό σημαίνει ότι με κατάλληλη τιμολογιακή πολιτική θα ήταν εφικτός ο περιορισμός της κατανάλωσης νερού χωρίς να απαιτείται οι ανάγκες ύδρευσης να ικανοποιούνται πλήρως μέσω της αφαλάτωσης.

Για να υπολογίσουμε πόσο θα έπρεπε να αυξηθεί η τιμή του νερού ύδρευσης ώστε να επιτευχθεί η απαιτούμενη εξοικονόμηση νερού, επιλύουμε το δυναμικό πρόβλημα μεγιστοποίησης του κοινωνικού οφέλους υπό τους περιορισμούς της διαθεσιμότητας υδάτινων πόρων στην Κύπρο. Με βάση το κεντρικό σενάριο, προκύπτει ότι οι καταναλωτές θα έπρεπε να επιβαρυνθούν με 40 Ευρωσέντς (σε τιμές 2009) ανά κυβικό μέτρο νερού ώστε να λαμβάνεται υπόψη το κόστος της σπανιότητας, και η τιμή αυτή θα έπρεπε κάθε χρόνο να αυξάνεται κατά 6–7%˙ η κλιματική αλλαγή θα δημιουργούσε αυξημένες ανάγκες εξοικονόμησης νερού και αύξηση της τιμής αυτής κατά επιπλέον 2–3 Ευρωσέντς ανά κυβικό μέτρο. Μια τέτοια τιμή θα μπορούσε να αποτελέσει σοβαρό κίνητρο εξοικονόμησης νερού και θα συνέβαλε στην αειφόρο διαχείριση των υδάτινων πόρων της Κύπρου. Αν είχε υιοθετηθεί τέτοια πολιτική πριν από μια δεκαετία, η ίδια εξοικονόμηση νερού θα μπορούσε να είχε επιτευχθεί με τη μισή σχεδόν τιμή σπανιότητας. Το Δοκίμιο σχολιάζει επίσης ζητήματα κοινωνικής δικαιοσύνης που μπορεί να προκύψουν από μια σημαντική αύξηση των τιμών του νερού, και υπογραμμίζει την ανάγκη να γίνουν αντίστοιχοι υπολογισμοί και στον γεωργικό τομέα.

1. INTRODUCTION

Cyprus is an island in the Eastern Mediterranean with an area of 9250 square kilometres and a population of about 800 000, which became a member of the European Union (EU) in 2004[1]. It has enjoyed sustained economic growth in the last three decades (averaging 5.8% and 3.1% per year over the last 30 and 10 years respectively) mainly due to tourist income and the development of financial services. Its per capita Gross Domestic Product exceeded 20 000 Euros in 2009.

Like other Mediterranean countries, Cyprus has a semi-arid climate associated with limited water resources. The principal cause of water scarcity is the combination of limited availability and excess demand of water among competing uses; this is clearly illustrated by the fact that Cyprus has the highest Water Exploitation Index[2] (45%) in the EU (EEA, 2009) – which becomes much higher in years of excessive drought. Historically droughts occur every two to three consecutive years as a result of large inter-annual decreases in precipitation. In the last four decades however, drought incidences have increased both in magnitude and frequency. The two main water-consuming sectors in the country are agriculture and households.

Water management has been problematic since the 1960s due to the limited development of water infrastructure for domestic and irrigation supply. The national government's top priorities were to ensure food security and constant supply of good quality water so that the adverse effects of water scarcity do not impede socioeconomic development, given that agriculture was the backbone of the economy, contributing by about 20% to the country's GDP. As Cyprus gradually became service-dominated, the contribution of agriculture has decreased dramatically, and currently accounts for about 2% of GDP and 7% of the total workforce (Cystat, 2009a). Despite such decreases, agriculture still remains the dominant water user in the country, accounting for 69% of total water use, while the domestic sector accounts for 25% – of which one fifth goes to tourism (Savvides et al., 2001). In order to store as much freshwater as possible, Cypriot governments have constructed numerous dams on key catchments in the course of the years. As a result, the water storage capacity of the island increased from 6 million cubic metres (c.m.) in 1960 to 327 million c.m. in 2009,

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[1] The information provided here refers only to the area controlled by the government of the Republic of Cyprus. This section is based on Zoumides and Zachariadis (2009) and the references contained therein.

[2] The index compares available water resources in a country to the amount of water used. An index above 20% indicates water scarcity.

making Cyprus one of the most developed countries in terms of dam infrastructure (Klohn, 2002; WDD, 2009).

The Eastern Mediterranean region is expected to be affected adversely by climate change. According to detailed regional climate models, which have been derived from global circulation models downscaled for regional application, maximum and minimum temperatures are projected to increase by about 3°C in the mid-21st century and by more than 4°C by the end of the century, with the strongest increases to be observed during summer months. Annual precipitation levels are forecast to decline by 15–25% in the same period[3]. Such projections illustrate that climate change effects will have serious consequences both for the (already scarce) water resources and for the energy needs of the country.

This paper describes an assessment of the social costs caused by water shortages in non-agricultural sectors in Cyprus for the entire period 2010–2030, and a comparison with the economic cost from the deployment of several desalination plants during the same period. It also reports on the results of the first attempt to assess the economic costs of climate change in Cyprus in the medium term (up to the year 2030) in non-agricultural water use. Although major climate changes are expected to happen later in the 21st century, the year 2030 is important because it constitutes the forecast horizon of several national and international studies and also enables more plausible scenarios of future economic development since forecasts into the longer term are fraught with much higher uncertainty. Finally, we assess the efficient scarcity price of non-agricultural water which, if included in end-user water prices, may lead to sustainable utilisation of the water resources of the island. Due to the small size of the island and the fact that most regions are interconnected through water pipelines, this is effectively a nationwide assessment of scarcity prices, whereas in most cases reported in the literature scarcity costs and prices are calculated for a specific water basin or region. Despite the fact that in principle total scarcity costs, optimal allocation of water resources and efficient water prices must be determined on the basis of a broader approach that includes the agricultural sector as well, this assessment is a first step towards this direction.

2. BACKGROUND TO THE CALCULATION OF WATER SCARCITY COSTS

As mentioned in the introductory section, agriculture accounts for more than two thirds of total water consumption in Cyprus. However, when it comes to the consumption of freshwater that is collected in dams, the residential sector (including commercial and

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[3] See forecasts on the World Bank Climate Change Portal (http://sdwebx.worldbank.org/climateportal).

industrial consumers) is almost equally important with agriculture. The water stored in major dams is supplied to both residential and agricultural users; in recent years with adequate precipitation levels agriculture has consumed about 60% of these water quantities, but during years with less rainfall more than 65% went to residential users, and this fraction increased further in years with extensive drought (WDD, 2009). Apparently, apart from the fact that many irrigated farms can alternatively use groundwater from private boreholes in the absence of sufficient surface water, it is politically more difficult for the government to drastically reduce water supply to households, tourist accommodations and other enterprises.

Sections 3 to 5 report on an assessment of the social costs of water scarcity in non-agricultural sectors of Cyprus. These sectors include households, tourism, industry and other commercial users. It should be pointed out that these costs – strictly speaking – do not constitute scarcity costs in the sense described in Section 7, i.e. they do not correspond to the opportunity cost caused by the fact that limited water quantities should be consumed each year in order to ensure water availability in the future. In fact Sections 4 and 5 calculate the economic losses from water *shortages* in Cyprus; a 'genuine' assessment of the price of *scarcity* is provided in Section 7.

Three further clarifications are necessary here:

a) We examine water use in all regions except that of Paphos (on the western part of the island accounting for about 11% of national non-agricultural water consumption) because all other regions are largely served by common infrastructure such as the Southern Conveyor Project, which transports water from relatively water-abundant southwestern areas to the rest of the country, and direct connections between a desalination plant in the South and the capital city of Nicosia in the centre of the island. Hence, although each region possesses different amounts of water reserves, this whole area is treated like one common system.

b) We also restrict our study to water supply by governmental water works which, according to WDD (2009), account for over 85% of total non-agricultural water consumption in this region.

c) We base our analysis on the residential sector. In the area under study, this sector (together with minor commercial users) is responsible for approximately

85% of non-agricultural water use; tourism and industry account for 12% and 3% respectively (WDD, 2009)[4].

Although the above mentioned restrictions constitute a simplification in the analysis, it is questionable whether a more detailed examination would alter the results and the policy implications reported in this paper. This will be explained in Section 4 below.

The assessment of costs in the following sections includes a calculation of a) costs of water shortage up to 2030 without climate change and b) additional costs under the assumption of reduced freshwater supply due to climate change. Furthermore, a dynamic optimisation procedure is applied in Section 7 in order to determine the marginal scarcity cost that should be included in residential water prices of Cypriot households.

3. HOUSEHOLD WATER DEMAND

To determine willingness to pay for water and the costs associated with reduced water deliveries due to scarcity, a demand function is necessary – at least an estimated price elasticity of water demand. Aggregate time series data do not allow to identify price effects on household water demand as variability of prices has been very limited over the last decades. Disaggregated time series data from individual Water Boards of Cypriot cities are currently being collected, but it will take some time until they are ready for econometric analyses. Hence the only empirical estimation currently available for Cyprus comes from a cross-sectional household water demand analysis that was carried out with the aid of Family Expenditure Surveys (Hadjispyrou et al., 2002). According to this, income elasticity was estimated at about 0.3, ranging from 0.22 at low income groups to 0.48 at the top 10 income percentile. Price elasticity was found to be in the range of –0.4 (for the highest income groups) to –0.8 (lowest income group), with a median value of –0.6.

Schleich and Hillenbrand (2009) provide a comprehensive review of empirical findings from residential water demand studies in European countries. Although estimates of income and price elasticities vary greatly among studies and countries, the values for Cyprus estimated by Hadjispyrou et al. (2002) are at the higher end of the range of elasticities found in the other countries. A price elasticity of –0.6 is quite high (in absolute terms) compared to most of the other European studies, and since per capita

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[4] These figures are also confirmed by information available in annual reports of the Municipal Water Boards of the two major cities Nicosia and Limassol – see www.wbn.org.cy and www.wbl.com.cy respectively.

water use in Cyprus is comparable to that of other developed European countries[5] it would be reasonable to expect similar elasticity levels. Therefore, our reference calculations in the rest of this paper have been conducted with a price elasticity of –0.3, which is approximately the average value from other European studies. Sensitivity analyses with lower and higher elasticity values (–0.15 and –0.6 respectively) are shown in the Appendix and are briefly discussed in Sections 4, 6 and 7 below.

4. SCARCITY COSTS WITHOUT CLIMATE CHANGE

As mentioned above, water scarcity is inherent in Cyprus and is only expected to deteriorate under climate change conditions. It is therefore necessary, as a first step, to assess scarcity costs without climate change. In our case, these costs for the residential sector will be equal to the loss of consumer surplus due to reduced availability of water, i.e. the loss of economic benefits of consumers minus the expenditures that consumers avoid by not purchasing these quantities. Figure 1 illustrates graphically this cost, which is equal to the area between the demand curve and the price line. Hereby we assume that there is no producer surplus so that supply cost is equal to consumer price[6]. The lower the price elasticity of water demand (in absolute terms), the steeper the demand curve, which leads to higher economic losses.

Similarly to other studies (e.g. Jenkins et al., 2003), we formulate the usual inverse demand function:

$$P_t = \exp\{[\ln(q_t) / \eta] + c_t\} \qquad (1)$$

where P is marginal willingness to pay in Eurocents per cubic metre (c.m.), q is annual water demand in thousand c.m., η is the price elasticity assumed to remain constant

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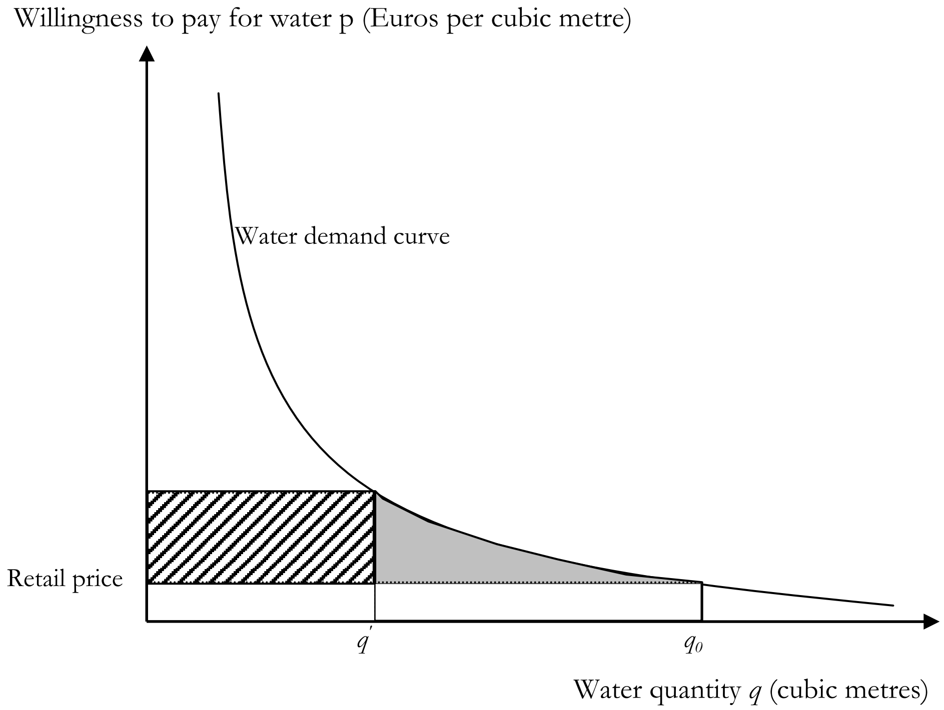
5 Water consumption in Germany was 128 litres per person per day in year 2003 according to Schleich and Hillenbrand (2009), and information from Municipal Water Boards of Cyprus shows a daily per capita consumption of 120-145 litres in Cypriot cities throughout the 2000s.

6 This seems to be a reasonable assumption for modest changes in quantities (i.e. modest movements along the demand curve) for two reasons. Firstly, it is appropriate to consider marginal supply costs to remain constant because a) the governmental authority (the Water Development Department) currently sells water to re-sellers (local Water Boards and municipalities) at a fixed supply cost that does not change if re-sellers obtain additional quantities; b) the government has agreed with desalination plants to obtain additional water quantities, if needed, at a price that corresponds to the operating and energy costs of the desalination plants, which are very close to the marginal water supply costs of the existing quantities. Secondly, it is appropriate to assume a near-zero producer surplus because both the Water Development Department and water re-sellers are public non-profit organizations so that retail water prices correspond approximately to their total costs.

over time, and c is a constant. Using 2006 as the base year because it is the most recent year that exhibited moderate rainfall patterns for which all necessary data are available, the constant for that year c_{2006} can be calculated, so that the demand function for the base year is fully defined. For this purpose one needs to know q_{2006} and P_{2006}, i.e. the water quantities consumed and the marginal water price in year 2006.

Figure 1: Illustration of economic losses associated with water shortage



Note: q_0 is the quantity that would be consumed in the case of no shortages, and q' is the quantity actually consumed. The shaded area corresponds to the loss of consumer surplus due to reduced water availability. The rectangle with the diagonal pattern to the left of the shaded area corresponds to the scarcity rent to be paid by consumers due to water shortages; however, since water is supplied by governmental authorities, this scarcity rent remains at state ownership and hence is not considered to be a social cost.

To determine q_{2006}, we added up water sales by the three Municipal Water Boards of Cyprus, supplying the largest part of households and enterprises in the three major cities of Nicosia, Limassol and Larnaca. According to official data (WDD, 2009), during the period 2005–2007 60.9% of water to households, industry and tourism was supplied by the Municipal Water Boards, while the rest was supplied directly by municipalities and village communities to end users. Hence we increased the quantities of residential water accordingly in order to account for effectively all non-agricultural water use in the country. For this procedure we implicitly made two reasonable assumptions: first, that price elasticity of water use is the same in all regions of Cyprus; and second, that country-wide water distribution losses are similar to those recorded by the three Water Boards (which amounted to 21% of the total water quantities they supplied in year 2006). A third implicit assumption is that price elasticity of demand is similar across all non-agricultural sectors (households, industries and tourist enterprises). Although it might be justifiable to criticise this assumption, noting also the possibility that water demand may be very inelastic in hotels and industry, one has to keep in mind that a) households, as outlined above, consume the vast majority of these water quantities; and b) a household price elasticity of −0.3 is already quite low, so that it would be surprising for non-residential users to exhibit much lower long-term elasticities[7].

To determine P_{2006}, we calculated the sales-weighted average price of water sold from the Municipal Water Boards to end users. All three Water Boards implement block pricing (albeit each one at different tariff levels and for different consumption blocks), therefore it can be assumed that this price remains constant at the margin for moderate variations in the quantities consumed. We assumed that this price reflects the average of all non-agricultural water users, i.e. including those supplied directly by municipalities and communities.

As regards future demand up to the year 2030, it is expected that the demand function will shift outwards as a result of increasing population and income. Based on official statistics of water sales from the Municipal Water Boards, per capita water use has increased by 3% annually over the last 15 years – excluding those years with water restrictions on households – and with about 2% annually since the early 2000s (Cystat, 2009b). We therefore constructed three scenarios on the future evolution of residential water demand, assuming annual growth rates of per capita water use of zero, 1% and 2% respectively, and combined them with official demographic statistics to arrive at forecasts of residential water use. We also used official GDP growth forecasts, provided by the Cypriot Ministry of Finance, together with the income elasticities of Hadjispyrou et al. (2002) mentioned above: using the average income elasticity of 0.3 yields similar water use forecasts with the zero per capita growth scenario; and using the upper-end income elasticity of 0.48 leads to similar forecasts with the 1% per capita growth scenario. An earlier study by WDD and the UN Food and Agriculture Organisation (Savvides et al., 2001) assumed a 2% annual growth rate of domestic water demand per capita. It was therefore deemed appropriate to retain all three per capita water demand scenarios mentioned above.

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[7] See last paragraph of this section for a discussion on long-term vs. short-term elasticities. Note that water demand bears similarities with demand for automotive fuels: there is a general belief that demand for both water and fuels is inelastic to prices. However, this applies primarily to short-term elasticities, which may be of the order of −0.05 to −0.2; in the long run elasticities of the order of −0.3 (for water) to −0.8 (for fuels) have been observed, which implies that if high prices persist over a long period then demand will exhibit a non-negligible adjustment to these price levels. See also Sterner (2007).

We kept the fraction of water supplied by the three Municipal Water Boards of the country constant at the level of the period 2005–2007 (60.9%). We further assumed that the water price will remain constant in real terms up to 2030 – which is a reasonable assumption under 'business as usual' conditions[8]. As a result of these assumptions, it is possible to obtain one demand function for each year from 2010 until 2030, i.e. to calculate c_t of equation (1) for each year t.

Although demand is expected to rise in the future, available water quantities will remain more or less constant (if one ignores both the periodic variability of rainfall patterns and the effects of climate change, and assuming that no further desalination plants will operate). It is therefore possible to compute the decrease in economic benefits because of reduced water availability for each future year, by integrating the annual inverse demand equation (1) from the given 'normal' level of water consumption in the base year q_{2006} to the consumption level of each future year q_t, which corresponds to the maximum demanded water quantity for that year. Economic losses, expressed in Euros per year, are thus given by equation (2):

$$LOSS_t = 0.01 \cdot \frac{\exp(c_t)}{1/\eta + 1} \cdot \left(q_t^{\frac{1}{\eta}+1} - q_{2006}^{\frac{1}{\eta}+1} \right) \qquad (2)$$

For each one of the three water demand scenarios used, the results are shown in Table 1. The present value of costs is projected to range between 15 and 200 million Euros (at constant prices of year 2009); according to the probably more realistic scenario 2, costs will approach 72 million Euros'2009.

Evidently this result depends to a large extent, apart from future water demand, on the value of the price elasticity used in the analysis. Because no dramatic changes in national income, prices or water consumption are assumed to happen during the forecast period, our initial assumption of constant price elasticity seems to be justified. However, if this elasticity is markedly higher (in absolute terms) than the value of –0.3 used here, scarcity costs will be significantly lower: consumers will have a lower willingness to pay in order to retain their water consumption levels. The opposite is the case if the elasticity is lower in absolute terms – scarcity costs are much higher. To illustrate this, we re-calculated the costs according to water consumption scenario 2,

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[8] In response to provisions of the EU Water Framework Directive, which will be further mentioned in Section 7, in early 2010 governmental authorities were in the process to re-assess end-user water prices so as to achieve 'full cost recovery' as required by the Directive; this would entail a calculation of resource and environmental costs – as defined by the authorities – to be included in water prices. The analysis shown here does not take into account eventual future changes in water prices as a result of that governmental re-assessment because 'resource costs' in the governmental study are defined differently from our scarcity costs, so that it would be inconsistent to mix the two studies.

assuming price elasticities of –0.15 and –0.6; results are shown in the Appendix. In the first case costs reach 207 million Euros'2009 (almost three times higher than with an elasticity of –0.3), whereas in the second case costs decline to 31 million Euros'2009 (57% lower). According to empirical studies from other European countries mentioned in Section 3, elasticities greater than 0.6 in absolute terms should not be considered as plausible. Taking also into account that future water demand may increase faster than 1% per capita at least in the near future, in line with trends of the last decade, the cost of 72 million Euros'2009 has to be considered as a low-end 'business as usual' figure; judging from the difference between scenarios 2 and 3, costs can easily approach 150 million Euros.

A second comment on these results is that they reflect the long-term costs of water shortages because the price elasticity used is considered to be a long-term elasticity, in line with results from other European countries. It is well known that demand for many goods and services is much less elastic in the short term. For example, a household facing a doubling price of water cannot immediately make significant changes to its everyday preferences – it may only try to partly conserve water in order to mitigate the high increase in water expenditures. Over a period of some years, however, if high water prices persist, the household can adjust its daily routine by installing appliances consuming less water and adopting less water-intensive habits. This is also valid for aggregate water consumption: facing a severe water shortage in 2008, governmental authorities reduced residential water supply and imported water quantities from abroad at comparatively very high prices, while at the same time re-scheduling their medium-term investment decisions in order to provide more desalinated water in a few years' time. The short-term solution of water imports was very costly, reflecting the very low short-term elasticity of both water demand and supply. These remarks do not imply that the costs calculated here are necessarily lower than real-world costs, but they intend to explain why short-term costs observed in Cyprus in recent years may have been considerably higher. This is another reason to emphasise the need for a long-term water policy which can tackle water scarcity in Cyprus in an economically efficient manner.

5. ADDITIONAL SCARCITY COSTS DUE TO CLIMATE CHANGE

Households in Cyprus are supplied with water both from dams and desalination plants. Obviously, the amount of water stored in dams (and subsequently available for residential, agricultural and other uses) depends on precipitation levels. Future precipitation levels can be forecast through climate simulations. Since global climate models cannot simulate the climate of small regions with sufficient accuracy, regional models are used, which represent further refinements of global models at a regional scale.

To assess water scarcity costs under climate change conditions, we used results of regional climate simulations, some of which are widely available and some were provided to us by climate researchers[9]. According to these, precipitation levels are expected to decline by approximately 10% in the period 2021–2040 compared to the most recent twenty-year period 1987–2006. In line with suggestions from the climate modellers, we considered this 10% reduction to apply for the year 2030 (the middle of the period 2021–2040) and assumed that precipitation will decrease linearly between 2010 and 2030; although the latter assumption is not realistic because rainfall levels may fluctuate considerably from year to year, it was considered appropriate because of the uncertainties of climate models and the short period examined in this analysis. Note that these models project a further decrease in precipitation levels towards the end of the 21st century. It is important to underline that the relationship between precipitation and water availability is not straightforward; depending on changes in the intensity and the duration of rainfall that may be caused by climate change, a 10% reduction in rainfall levels may lead to a higher or lower reduction in the amount of available surface water. In the absence of more detailed information, we considered this 10% precipitation decrease to cause an equal reduction in water stocks; such an assumption seems to be a reasonable starting point.

As mentioned earlier in Section 2, in years with serious water shortage authorities prefer to continue supplying the residential and tourist sector as smoothly as possible, and reduce the quantities of water supplied to farmers. In this study, however, we assume that reduced freshwater availability will hurt famers and households alike, thereby allocating climate change costs to each sector according to the stress that each sector puts to the island's water resources today[10].

Evidently the projected reduction in precipitation levels is moderate, and becomes even less important for non-agricultural water use in Cyprus since about 60% of the quantities supplied to these sectors comes from desalination plants that provide water irrespective of climate conditions. Therefore, additional water scarcity costs associated with climate change up to 2030 turn out to be quite modest; they are presented in Table 2. The present value of additional costs for the entire period 2010–2030 ranges

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[9] Information on climate modelling results in this paper is based on regional model forecasts available at the World Bank Climate Change Portal (http://sdwebx.worldbank.org/climateportal) as well as on work currently carried out at the Cyprus Institute (http://www.cyi.ac.cy). Results of the latter are still tentative.

[10] 'Today' in this case refers to the years 2005-2006, when the available freshwater quantities were not abundant but were not under stress either.

Table 1: Annual costs of residential water shortages in Cyprus.

	Scenario 1: Constant per capita water use		Scenario 2: Per capita water use grows 1% p.a.		Scenario 3: Per capita water use grows 2% p.a.	
Year	Water demand (mio c.m.)	Cost (mio Euros'2009)	Water demand (mio c.m.)	Cost (mio Euros'2009)	Water demand (mio c.m.)	Cost (mio Euros'2009)
2010	54.8	0.21	54.8	0.21	54.8	0.21
2015	57.0	0.75	60.0	1.95	63.0	3.84
2020	58.5	1.27	64.6	5.15	71.3	12.81
2025	59.5	1.73	69.1	9.86	80.1	29.12
2030	60.1	2.01	73.3	15.84	89.3	54.80
Total economic loss, 2010-30		**25.57**		**130.69**		**381.97**
Present value of economic loss, 2010-30		**15.20**		**71.96**		**204.21**

Notes:
- The above water quantities refer to water actually consumed by households, i.e. do not include water distribution losses.
- Present value of costs has been computed with a social discount rate of 4%.

Table 2: Annual costs of residential water shortages in Cyprus under climate change assumptions.

		Additional scarcity cost due to climate change (mio Euros'2009)		
Year	Difference in water availability due to climate change	*Scenario 1: Constant per capita water use*	*Scenario 2: Per capita water use grows 1% p.a.*	*Scenario 3: Per capita water use grows 2% p.a.*
2010	0.0%	0.00	0.00	0.00
2015	-0.9%	0.17	0.28	0.41
2020	-1.9%	0.46	1.00	1.74
2025	-2.8%	0.85	2.27	4.58
2030	-3.7%	1.28	4.17	9.72
Total additional economic loss, 2010-30		**11.11**	**29.42**	**60.19**
Present value of economic loss, 2010-30		**6.12**	**15.69**	**31.49**

between 6 and 31 million Euros at 2009 prices, 15%–40% more than the costs due to the already existing water scarcity in the country; the central estimate (scenario 2) shows a 22% cost increase – or 15.7 million Euros.

6. COMPARISON OF SCARCITY COSTS WITH DESALINATION COSTS

In response to increasing water demand and stagnating or decreasing supply of freshwater, Cypriot authorities have promoted the operation of desalination plants. Until 2008 two plants had been in operation, with a nominal water production capacity of 92 000 c.m. per day; the capacity of both plants has recently been expanded by about 30%. Moreover, two temporary desalination units started operating in 2009, and significant new investments are under way. Table 3 shows the desalination units currently planned. As these investments are based on the BOOT (Build, Own, Operate and Transfer) system, private investors operating each plant incur investment and operating costs and sell water to the authorities (the Cyprus Water Development Department) at an agreed price; Table 3 also displays these prices.

Table 3: Desalination plants in operation or scheduled to operate in Cyprus (except the area of Paphos).

Location	*Start year*	*Capacity (c.m./day)*	*Price of water sold to WDD (Euros/c.m.)*
Dekelia	1997	40000	0.6424
Larnaca	2001	52000	0.6817
Moni (mobile)	2009	20000	1.3870
Garyllis aquifer	2009	9000	0.2992
Dekelia (expansion)	2009	20000	0.7800
Larnaca (expansion)	2009	10000	1.3200
Limassol	2012	40000	0.8725
Vasilikos	2012	60000	0.8130
Limassol (expansion)	2015	20000	0.8725

Source: Cyprus Water Development Department (website www.moa.gov.cy/wdd and official announcements, February 2010).

Note: The mobile plant of Moni is scheduled to stop operating at the end of year 2011, and desalination at Garyllis aquifer is planned to cease operation at the end of 2014.

The schedule shown in Table 3 has been designed in order to ensure that virtually all urban residential water needs in Cyprus can be met by desalination-generated water, so that a) water supply to households and firms becomes independent of weather conditions and b) all freshwater reserves are supplied to the agricultural sector in order to restore groundwater reserves, which are currently being depleted due to over-exploitation by farmers. As Table 4 shows, even under scenario 3 that assumes rapid increase in water demand and despite climate change, desalination can more or less satisfy all water demand of households, industry and tourism up to 2030[11].

On the basis of these data, it is possible to calculate the costs to the governmental authorities associated with the operation of all these desalination plants. It has to be reminded that desalination is an energy-intensive process requiring large amounts of electricity – about 4.5 kilowatt-hours of electricity per cubic metre of water produced. This explains to a large extent the quite high prices of desalinated water purchased by authorities.

Table 5 demonstrates the resulting costs from purchasing the water of all new desalination plants (i.e. except the already existing plants of Larnaca and Dekelia). It is evident that these costs are pretty high, exceeding 400 million Euros'2009, and thus seem to be considerably higher than the social costs of water shortages shown in Tables 1 and 2. A sensitivity analysis of the results of the previous section reveals that only under assumptions of high growth of water demand and at a rather low price elasticity (below 0.2 in absolute terms) can desalination costs become comparable to the social costs reported above.

Three aspects of this calculation have to be kept in mind:

- First, the calculated desalination costs do not include costs from eventual local environmental degradation due to a) the potentially negative impact of desalination plants on marine ecosystems and b) local air pollution caused by emissions of sulphur dioxide, nitrogen oxides or particulate matter from power plants that have to operate more intensively in order to fulfil the electricity needs of desalination plants. Specifically as regards air pollution, European studies of oil-fired power plants, such as the ones operating in Cyprus, have found external costs of the order of 1–3 Eurocents per kilowatt-hour of electricity generated (European Commission, 2003). Since power plants in Cyprus do not operate very close to densely populated areas and hence air pollution affects a relatively small population, a lower-end estimate of these externalities would be appropriate. Still, with 4.5 kilowatt-hours of electricity demanded per cubic metre of desalinated water, external costs of the order of 5 Eurocents per c.m. are quite significant.

- Second, we have not accounted for the fact that electricity prices will increase due to the obligation of the Electricity Authority of Cyprus (EAC), the major power company in the island, to purchase carbon dioxide permits because of its

[11] This may not be exactly true because the number of municipalities or communities supplied with desalinated water may increase in the future.

participation in the EU Emissions Trading System. This extra cost will be passed through from desalination plant operators to the government. For the period 2010–2012, the costs of permits to be purchased by EAC because it will exceed the free emission allowances provided to it by the government of Cyprus, at a current price of 10–20 Euros per tonne of CO_2, will amount to an increased cost of production for desalinated water of 3.5–6.5 Eurocents per c.m. From year 2013 onwards, when the EAC will have to purchase all its emission permits in auctions, purchase costs for desalination water shown in Table 3 may rise by about 5 to 10 Eurocents per c.m. – at an assumed permit price of 20–30 Euros per tonne of CO_2 – so that desalination costs may be 5–8% higher than those shown in Table 5[12].

- Third, we have partly adjusted these costs for inflation, assuming an annual GDP deflator of 3%. The initially agreed price at which the WDD purchases desalinated water will increase over the years because the contracts signed between the government and desalination plant owners allow for changes in prices due to changes in a desalination plant's labour and energy costs. This will affect both energy costs and operation and maintenance (O&M) costs, which represent about 45% and 20% of total desalination costs respectively[13].

The result shown in Table 5 illustrates that if no new desalination plants are built the costs from the resulting water shortages in the non-agricultural sectors seem to be considerably lower. This finding implies that, instead of desalination, a less costly approach to water scarcity in Cyprus would be the increase in end-user water prices in order to account for the costs of this scarcity and encourage water conservation. This possibility is analysed in the following section.

[12] This cost calculation depends on the following assumptions: a) The government intends to exploit an option provided by EU legislation and distribute 70% of emission allowances for free in year 2013 and gradually increase the amount auctioned until it reaches 100% in 2020; b) from 2014 onwards a substantial portion of electricity generated is scheduled to come from modern combined cycle gas turbine plants burning natural gas, which emit about half the amount of CO_2 emitted by conventional fuel oil fired plants. According to official forecasts up to 2020 and extrapolations made by the author, the share of natural gas powered electricity is expected to be about 50% in 2015 and rise to 80% by 2020 and 90% in 2030. If we include only the additional production cost in line with assumptions a) and b) above, then post-2012 desalination costs will increase by 3–6 Eurocents per c.m. If, however, we account for the full environmental costs of CO_2 emissions, regardless of whether EAC will directly pay for them, then these costs rise up to 10 Eurocents per c.m. for year 2013, and then gradually fall to 5–7.5 Eurocents per c.m. for subsequent years as a result of the penetration of natural gas in the electric system.

[13] Based on information gathered from personal communication of the author with WDD officials.

Table 4: Water surplus (annual demand minus annual supply in million c.m. per year) in the residential sector due to new desalination plants, by scenario.

	Without climate change effects			Including climate change effects		
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2010	12.6	12.6	12.6	12.6	12.6	12.6
2011	12.0	11.4	10.9	11.9	11.3	10.8
2012	32.3	31.2	30.0	32.1	31.0	29.8
2013	31.9	30.2	28.4	31.6	29.9	28.2
2014	31.5	29.2	26.8	31.1	28.8	26.4
2015	33.9	31.0	28.0	33.4	30.5	27.5
2016	33.5	30.0	26.3	32.9	29.4	25.7
2017	33.3	29.1	24.7	32.6	28.4	24.0
2018	33.0	28.2	23.0	32.2	27.4	22.3
2019	32.7	27.3	21.4	31.9	26.4	20.5
2020	32.5	26.3	19.7	31.5	25.4	18.7
2021	32.2	25.4	17.9	31.1	24.3	16.8
2022	32.0	24.5	16.2	30.9	23.4	15.0
2023	31.8	23.7	14.5	30.6	22.4	13.2
2024	31.6	22.8	12.7	30.3	21.4	11.3
2025	31.4	21.9	10.9	30.0	20.4	9.4
2026	31.3	20.9	9.0	29.7	19.4	7.4
2027	31.2	20.1	7.2	29.5	18.5	5.6
2028	31.1	19.3	5.4	29.3	17.6	3.7
2029	31.0	18.5	3.6	29.1	16.7	1.7
2030	30.9	17.7	1.7	29.0	15.7	-0.2

Note: It is assumed that plants will operate at 90% of their capacity.

Table 5: Future annual desalination costs for the government of Cyprus (million Euros) due to desalination plants starting operation after 2008.

Year	Desalinated water quantity (mio c.m.)	Net desalinated water quantity (mio c.m.)*	Costs at current prices	Costs at 2009 prices**
2010	19.4	15.3	19.5	19.2
2011	19.4	15.3	19.5	18.9
2012	45.7	36.0	37.8	36.2
2013	45.7	36.0	37.8	35.6
2014	45.7	36.0	37.8	35.1
2015	49.3	38.8	42.7	39.0
2016	49.3	38.8	42.7	38.5
2017	49.3	38.8	42.7	37.9
2018	49.3	38.8	42.7	37.3
2019	49.3	38.8	42.7	36.8
2020	49.3	38.8	42.7	36.2
2021	49.3	38.8	42.7	35.7
2022	49.3	38.8	42.7	35.2
2023	49.3	38.8	42.7	34.7
2024	49.3	38.8	42.7	34.1
2025	49.3	38.8	42.7	33.6
2026	49.3	38.8	42.7	33.1
2027	49.3	38.8	42.7	32.6
2028	49.3	38.8	42.7	32.2
2029	49.3	38.8	42.7	31.7
2030	49.3	38.8	42.7	31.2
Total costs, 2010-30			**835.3**	**704.9**
Present value of costs, 2010-30			**542.6**	**466.7**

* Quantity available from desalination plants minus water distribution losses
** Assuming that half of the costs have to be adjusted for inflation and using a GDP deflator of 3% p.a.

When interpreting these results it is important to keep in mind that our calculations assume that, regardless of the water quantities delivered to non-agricultural consumers, the availability of water to agriculture will not be affected. As already mentioned, in periods of intense water scarcity it is standard practise of governmental authorities to restrict the amount of freshwater supplied to farmers, which leads to overexploitation of groundwater reservoirs. Our calculations do not deal with this problem because the analysis shown here attempts to assess the costs of water scarcity to non-agricultural sectors *all else being equal*, i.e. assuming that agriculture will not be better-off or worse-off after the implementation of one or the other measure.

7. EFFICIENT RESIDENTIAL WATER PRICING TO ACCOUNT FOR SCARCITY

As a European Union member, Cyprus has to comply with the requirements set out by the EU Water Framework Directive (WFD) (EC, 2000), which is considered the most important landmark in the history of the EU's water policy. The WFD builds on previous legislation and aims to achieve a "good ecological status" of water resources within the EU by 2015. Among other provisions, the Directive introduces new water management approaches with particular emphasis on the role of economic tools. More specifically it requires full cost recovery to be the guiding principle for water pricing: end-user water prices should incorporate not only the cost of water service provision, but also environmental and resource costs[14]. The latter costs correspond to the scarcity costs discussed in the previous paragraphs.

Based on the information collected to calculate scarcity costs in Sections 4 to 6, it is possible to use annual residential water demand functions and the restrictions in water availability discussed above in order to estimate the marginal user cost for residential water in Cyprus through a dynamic optimisation approach. This user cost corresponds to the shadow price of scarcity, which shows how much end-user water prices of households, industry and tourism should increase in order to account for water scarcity in the country and ensure sustainable use of water resources over the longer term, until an alternative 'renewable' technology (i.e. desalination) becomes less costly. This shadow price reflects the opportunity cost of scarcity, i.e. the economic benefits foregone due to the water quantities not consumed each year in order to ensure water availability in the future. The optimisation is carried out assuming that no new desalination plants will operate from 2009 onwards unless their marginal water production cost becomes cheaper than the sum of marginal conventional water

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[14] For a detailed analysis of the policy implications of the WFD in Cyprus see Zoumides and Zachariadis (2009).

production cost plus scarcity cost. In other words this assessment attempts to answer the question 'how much should residential water prices increase, and at what rate should available water quantities be used, in order to maximise net social benefits and manage water sustainably'. This optimisation method determines also at what time in the future new desalination plants should start operating.

To assess the scarcity price, we used the annual demand functions – equation (1) – derived in Section 4. As for supply costs, since the analysis is carried out at the consumer level, the costs of water supply to end-users is of interest – and not the costs of water distribution from the main governmental authority (WDD) to individual water boards that further sell water to end users. Based on data from the annual accounts of the three Municipal Water Boards serving the main urban areas of Cyprus, omitting fixed water charges (in order to obtain only the variable portion of water charges) and assuming that similar cost levels apply for the rest of municipalities and communities of the country, we arrived at a weighted average end-user price for the period 2005–2007. This may reasonably be considered as the marginal cost of water supply to consumers. We assume marginal supply cost to remain constant for modest variations in quantities consumed because the contracts signed by the government with desalination plant operators foresee that, for every additional cubic metre of water to be provided by these plants, the government will pay the sum of operation/maintenance costs and energy costs, which for the current desalination plants is very close to the average supply cost mentioned above[15].

We further assumed, in the scenarios without climate change, that stocks of freshwater in dams that are available for residential water use each year of the period 2010–2030 remain constant at the average level of years 2005–2006. Those were two years with sufficient to moderate water storage in dams, and with more or less acceptable supply of water to agriculture. For the climate change scenarios we used the 10% reduction factor (mentioned in section 5) for freshwater availability in 2030, and linear interpolations between the 2010 figure and the 2030 figure for intermediate years. We considered water distribution losses to remain constant as a fraction of total water supply. Obviously, water supplied from desalination plants that existed before 2009 was also taken into account.

As regards the alternative 'renewable' technology, i.e. new desalination plants, its marginal production cost was assumed to be 150 Eurocents per cubic mete at 2009 prices and to remain constant over the years in real terms. This assumption was based on the current costs of desalinated water production by plants that are currently

[15] In other words, the supply cost curve is almost horizontal at these water quantity levels; see also footnote 6.

constructed in Cyprus, which, according to Table 3, are in the range of 0.8–0.9 Euros per c.m. On top of these costs we added the additional operating costs of governmental authorities, i.e. the WDD and the Municipal Water Boards, which amount to at least 0.5–0.6 Euros per c.m. at 2009 prices[16], plus environmental costs which, according to Section 6, amount to more than 0.1 Euro per c.m. Evidently this cost reflects the costs of plants applying today's desalination technology used in Cyprus (reverse osmosis) and ignoring eventual future cost reductions due to technical progress. Currently installed mobile desalination plants exhibit higher operation costs but are not considered here because we simulate the results from a long-term planning process that does not rely on urgent short-term measures such as mobile desalination.

Calculation of efficient water prices was carried out by maximising the present value of total net benefits to consumers due to water consumption for the entire period 2010–2030, subject to the constraint of water availability and in the presence of two technologies: a 'conventional' water supply technology and an alternative 'renewable' technology, i.e. new desalination plants, with higher cost (see e.g. Tietenberg, 2006). Following the notation of equation (1), the present value of net benefits is given by

$$\sum_{i=2010}^{2030} \frac{\exp(c_i) \cdot \frac{1}{\frac{1}{\eta}+1} \cdot (q_i + q_{di})^{\left(\frac{1}{\eta}+1\right)} - s_i \cdot q_i - d_i \cdot q_{di}}{(1+r)^{i-2010}} \tag{3}$$

and the constraint is

$$\sum_{i=2010}^{2030} q_i \leq Q \tag{4}$$

where s_i is the marginal water supply cost, assumed to be constant and equal to 84.7 Eurocents'2009 per c.m., d_i is the marginal desalination cost, assumed to be constant and equal to 150 Eurocents'2009 per c.m., and r is the social discount rate, assumed to be 4%. q_i and q_{di} are water quantities provided in year i from currently existing dams and plants and from new desalination plants respectively – obviously the total amount of water consumed in a year is $q_i + q_{di}$.

Optimisation involves maximising *Z* in the following expression:

[16] Based on personal communication of the author with staff from Municipal Water Boards.

$$Z = \sum_{i=2010}^{2030} \frac{\exp(c_i) \cdot \frac{1}{\frac{1}{\eta}+1} \cdot (q_i + q_{di})^{\left(\frac{1}{\eta}+1\right)} - s_i \cdot q_i - d_i \cdot q_{di}}{(1+r)^{i-2010}} - \lambda \cdot \left(\sum_{i=2010}^{2030} q_i - Q \right) \quad (5)$$

where λ is the Lagrangian multiplier, expressing in this case the shadow price of water scarcity, and Q is the total stock of water during the period 2010–2030, estimated as described above. Note that Q varies in each scenario because it represents the sum of the stock of available freshwater in each year for those years where existing dams and plants are utilised. If, for example, new desalination plants replace existing water supply methods in year x, Q is the sum of available quantities from year 2010 up to year $x-1$; freshwater that becomes available from year x onwards is not relevant because it will not be used for residential water supply, hence it does not enter in the calculation of Q.

Table 6 presents the resulting shadow prices λ and quantities q_i and q_{di} for each one of the three scenarios used earlier in this paper, with and without climate change assumptions. According to our central estimate, prices for residential water users – including industry and tourism that are supplied with water from the same sources – should currently rise by about 40 Eurocents per cubic metre to account for scarcity; for

Table 6: Marginal scarcity price (*λ*) and optimal annual water quantities to be supplied by existing sources or by new desalination plants in Cyprus, by scenario.

	Optimal water quantities, without climate change (mio c.m.)								
	Scenario 1			*Scenario 2*			*Scenario 3*		
Year	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total
2010	50.8	0.0	50.8	49.2	0.0	49.2	48.9	0.0	48.9
2011	51.2	0.0	51.2	50.1	0.0	50.1	50.3	0.0	50.3
2012	51.5	0.0	51.5	50.8	0.0	50.8	51.4	0.0	51.4
2013	51.7	0.0	51.7	51.5	0.0	51.5	52.6	0.0	52.6
2014	51.9	0.0	51.9	52.2	0.0	52.2	53.9	0.0	53.9
2015	52.1	0.0	52.1	52.9	0.0	52.9	55.1	0.0	55.1
2016	52.3	0.0	52.3	53.6	0.0	53.6	56.3	0.0	56.3
2017	52.4	0.0	52.4	54.1	0.0	54.1	57.5	0.0	57.5
2018	52.5	0.0	52.5	54.7	0.0	54.7	58.6	0.0	58.6
2019	52.5	0.0	52.5	55.2	0.0	55.2	59.8	0.0	59.8
2020	52.6	0.0	52.6	55.8	0.0	55.8	61.0	0.0	61.0
2021	52.6	0.0	52.6	56.3	0.0	56.3	62.2	0.0	62.2
2022	52.6	0.0	52.6	56.8	0.0	56.8	63.3	0.0	63.3
2023	52.6	0.0	52.6	57.3	0.0	57.3	51.1	13.3	64.5
2024	52.5	0.0	52.5	57.8	0.0	57.8	0.0	66.0	66.0
2025	52.5	0.0	52.5	25.8	32.4	58.2	0.0	67.5	67.5
2026	52.4	0.0	52.4	0.0	59.0	59.0	0.0	69.1	69.1
2027	52.3	0.0	52.3	0.0	59.7	59.7	0.0	70.6	70.6
2028	52.2	0.0	52.2	0.0	60.4	60.4	0.0	72.1	72.1
2029	52.0	0.0	52.0	0.0	61.1	61.1	0.0	73.6	73.6
2030	51.8	0.0	51.8	0.0	61.8	61.8	0.0	75.2	75.2
λ (€cents'2009):	*27.0*			*39.9*			*43.1*		

	Optimal water quantities, with climate change (mio c.m.)								
	Scenario 4			*Scenario 5*			*Scenario 6*		
Year	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total
2010	50.1	0.0	50.1	49.1	0.0	49.1	48.7	0.0	48.7
2011	50.5	0.0	50.5	50.0	0.0	50.0	50.1	0.0	50.1
2012	50.7	0.0	50.7	50.6	0.0	50.6	51.2	0.0	51.2
2013	50.9	0.0	50.9	51.3	0.0	51.3	52.4	0.0	52.4
2014	51.1	0.0	51.1	52.0	0.0	52.0	53.6	0.0	53.6
2015	51.3	0.0	51.3	52.7	0.0	52.7	54.9	0.0	54.9
2016	51.5	0.0	51.5	53.3	0.0	53.3	56.1	0.0	56.1
2017	51.5	0.0	51.5	53.9	0.0	53.9	57.2	0.0	57.2
2018	51.5	0.0	51.5	54.4	0.0	54.4	58.4	0.0	58.4
2019	51.6	0.0	51.6	55.0	0.0	55.0	59.5	0.0	59.5
2020	51.6	0.0	51.6	55.5	0.0	55.5	60.7	0.0	60.7
2021	51.6	0.0	51.6	56.1	0.0	56.1	61.9	0.0	61.9
2022	51.6	0.0	51.6	56.5	0.0	56.5	56.4	6.6	63.0
2023	51.5	0.0	51.5	57.0	0.0	57.0	0.0	64.5	64.5
2024	51.5	0.0	51.5	24.5	33.0	57.5	0.0	66.0	66.0
2025	51.4	0.0	51.4	0.0	58.2	58.2	0.0	67.5	67.5
2026	51.3	0.0	51.3	0.0	59.0	59.0	0.0	69.1	69.1
2027	51.1	0.0	51.1	0.0	59.7	59.7	0.0	70.6	70.6
2028	51.0	0.0	51.0	0.0	60.4	60.4	0.0	72.1	72.1
2029	50.8	0.0	50.8	0.0	61.1	61.1	0.0	73.6	73.6
2030	50.6	0.0	50.6	0.0	61.8	61.8	0.0	75.2	75.2
λ (€cents'2009):	*32.7*			*41.4*			*44.8*		

each consecutive year this amount should increase by 4% (the social discount rate)[17] and should be further adjusted for inflation (since the shadow price is expressed in constant Eurocents of year 2009). At an annual inflation of 3% this might lead to a water price increase of over 80 Eurocents per c.m. in year 2020 and over 1.60 Euros per c.m. in 2030 at nominal prices. Compared to current tariff levels in Cypriot cities, the additional 40 Eurocents per c.m. would amount to an increase in end-user price of 30–50% for the cities of Nicosia and Larnaca and up to more than 100% for the city of Limassol. Evidently the value of λ varies according to how binding the constraint becomes in the future, which in turn depends on the water demand scenario. If per capita water demand rises at a faster rate in the future as assumed in scenario 3, i.e. at 2% per year, the scarcity price reaches 43 Eurocents per cubic metre. Conversely, if per capita water demand remains stable as in scenario 1, the scarcity price falls to 27 Eurocents per c.m.. As discussed earlier, using the climate model predictions up to 2030 provided to us, it seems that climate change is expected to have a moderate effect, of the order of less than 2 Eurocents per c.m. for scenario 2.

Table 6 demonstrates also what is the 'appropriate' timing for the introduction of new desalination plants under the different demand scenarios. If per capita water demand remains constant in the future (Scenarios 1 and 4), new desalination remains costly throughout the period up to 2030: the total marginal cost (supply cost plus scarcity cost) of existing water supply options remains below 150 Eurocents'2009 per c.m. even in 2030 despite the fact that the real scarcity price increases by the discount rate every year. The temporal evolution of marginal costs is illustrated in Figure 2 for the case of our central scenario 2, according to which new desalination options become economically preferable in year 2025, whereas under stronger water demand assumptions (scenario 3) new desalination should enter the market in 2023. Under increased water shortages due to climate change, the entry year for the new plants moves one or two years earlier (2024 and 2022 for scenarios 5 and 6 respectively). In any case, our model indicates that under a long-term water resource planning schedule in Cyprus, extensive use of desalination would have to wait until after 2020 – in contrast to the current policies that promote such plants already in 2010 and which, as shown in section 6, constitute clearly a costly solution.

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[17] The discount rate reflects the notion that today's consumption is somewhat more valuable than future consumption because, among other reasons, the future is fraught with uncertainty and because the society will be richer in the future, so that an additional Euro today will contribute more to welfare than an additional Euro in the future. The 'social' discount rate expresses the preference of society as a whole – private discount rates are usually higher. We use a social discount rate of 4%, in line with guidance from governments of developed countries (see e.g. HM Treasury, 2003) and assuming that, as in the last three decades, the annual real economic growth rate in Cyprus will be somewhat higher than that of other developed economies. It is usual to apply declining discount rates when an analysis extends into the longer term (e.g. above thirty years), but this is not the case in our study.

Figure 2: Evolution of marginal water supply costs in the period 2010–2030 according to results of scenario 2; from 2025 onwards existing water supply options are substituted by new desalination plants.

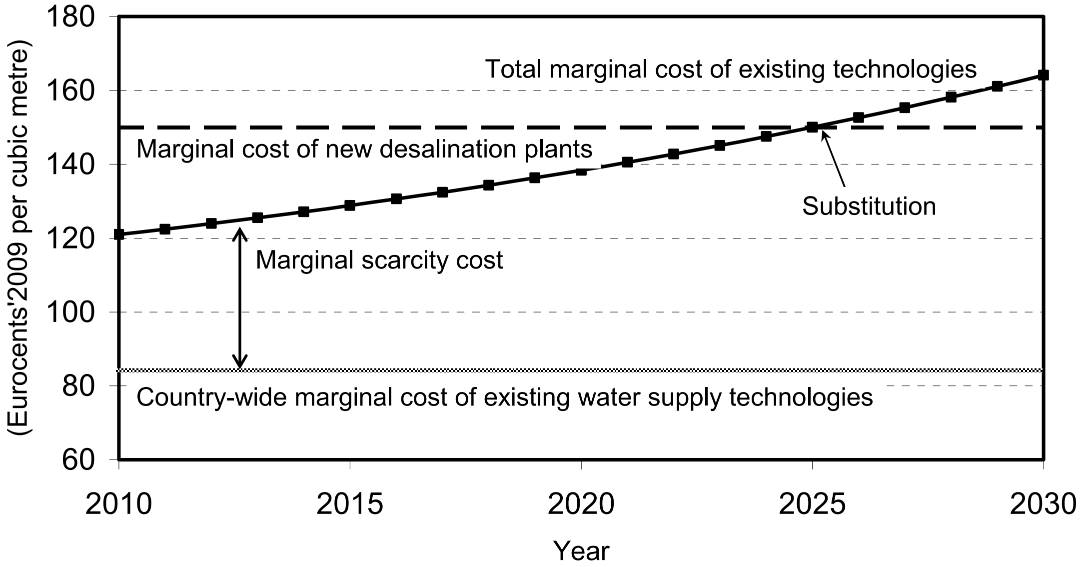
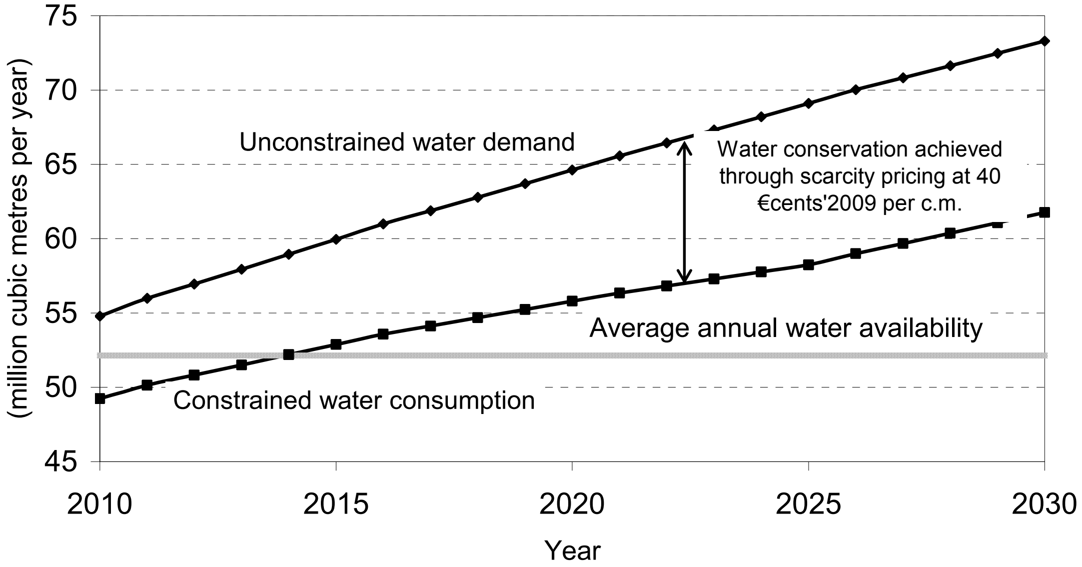


Figure 3 illustrates the evolution of optimal annual water consumption quantities in the period 2010–2030 according to scenario 2, using our central elasticity assumption of –0.3. The upper curve shows the evolution of water demand in the absence of any constraint; this is the evolution shown on Table 1 for scenario 2. The lower curve represents the solution of the constrained optimisation problem; the quantities are the totals shown on Table 6 for scenario 2. The difference between these two curves represents the water savings that can be attained if the scarcity price of 40 Eurocents’2009 per c.m. is implemented throughout the whole period; in fact water conservation is attained until 2025 because from that year onwards new desalination plans replace the existing water supply methods, scarcity is not a concern any more and hence water consumption starts rising at a higher rate. Obviously this approach is somewhat simplified since a price increase today will not be fully effective in the short run but within a period of a few years; nevertheless this graph demonstrates both the large adjustment that is necessary in order to bring future consumption in line with water reserves and the potentially great contribution of an appropriate pricing mechanism towards sustainable water management.

Figure 3: Evolution of optimal water consumption quantities throughout the period 2010–2030 according to scenario 2 at a price elasticity of –0.3

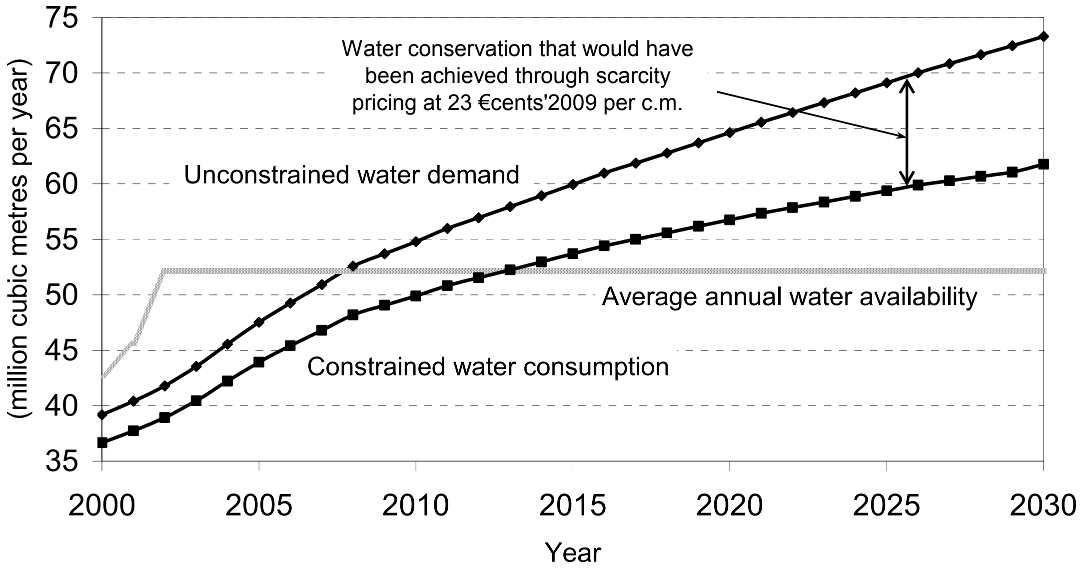


Note: Annual water availability takes into account the existing desalination plants of Dekelia and Larnaca, without their capacity expansions that became operational in 2009.

The calculated shadow price rises or falls if lower or higher values for the demand elasticity are used respectively. At an elasticity of –0.6 the value of λ for scenario 2 is 25 Eurocents per c.m., almost half of our reference case, and climate change adds only another 3 Eurocents to this price. On the other hand, in the extreme assumption of an elasticity of –0.15 (which may be close to reality for the short run but perhaps unrealistically low in absolute terms for the long run), the shadow price increases by 3–4 Eurocents'2009. Since, however, the calculations presented here make sense for the design of a long-term pricing strategy, long-term elasticity values should be used; hence Table 6 seems to present plausible scarcity price levels which, if implemented gradually over a few years and then adjusted annually as explained above (to account for both inflation and the discount rate) might provide adequate incentives for water conservation in households over the medium and longer term.

If such a pricing policy had been implemented a decade ago, it might have been sufficient to address the water scarcity problem of Cyprus without the need for extensive use of desalination; apart from the two desalination plants that have been operating for some years now, the construction of new plants might not have been necessary until 2030. To quantify this, we made a retrospective assessment for the entire period 2000–2030, illustrated in Figure 4: A policymaker trying to assess the efficient scarcity price back in the year 2000 – at water consumption levels of that period, assuming an increase in water consumption until 2030 similar to that of scenario 2 and with one desalination plant operating and the second one under construction – would estimate this price at about 23 Eurocents per cubic metre at 2009 prices. Our model shows that new desalination plants would become economically preferable only in the year 2030. This means that if this price had been implemented in the year 2000 for the entire 30-year period until 2030, available water quantities might have been able to meet demand without further desalination plants.

Figure 4: Evolution of optimal water consumption quantities for the period 2000–2030 if efficient pricing had been implemented in the year 2000



Note: Annual water availability takes into account the desalination plants of Dekelia (which started operating in 1997) and Larnaca (which became fully operational in 2002).

As things currently stand (in the beginning of year 2010 when several desalination plants have started operating or are being constructed), an implementation of the pricing policy described above might allow mitigating the additional needs for desalination in the future, thereby reducing the costs of adapting to water scarcity.

Apart from economic efficiency, equity is also a priority for governmental authorities. A substantial increase in the end-user price of water might put a burden on low-income households whose water demand, as mentioned in Section 3, seems to be the most inelastic. According to the Family Expenditure Survey carried out by the Statistical Service of Cyprus for the year 2003, domestic water expenditures represent less than 0.5% of total household expenditures on average, and this fraction becomes somewhat higher – but still less than 1% – for the poorest 20% of households[18]. Therefore, a doubling in the price of water would increase the cost of living for these households by

[18] I am grateful to Alexandros Polycarpou from the Economics Research Centre of the University of Cyprus for providing these data.

80–120 Euros per year at 2009 prices; if governmental authorities wish to provide a compensation for these extra costs, a direct payment to households in the form of a lump sum would be preferable. In any case, it is not advisable to subsidise water use on equity grounds, e.g. by reducing water prices for low-income households or waiving the extra scarcity price for low water consumption levels. Although access to clean water is essential for human life, current water use levels in Cyprus are far higher than the minimum amount needed: Savvides et al. (2001) estimated water demand at over 200 litres per person per day in Cyprus, and official data show a daily per capita consumption of 120–150 litres, whereas basic water needs for human subsistence (drinking, cooking and basic sanitation) are estimated at 20–50 litres per person per day (Gleick, 1999; Hanemann, 2006). Therefore, in an economically developed country like Cyprus it is essential to calculate water prices on the basis of marginal willingness of consumers to pay for water services – which leads to the implementation of the scarcity pricing system proposed above.

8. CONCLUSIONS AND OUTLOOK

This paper has presented an assessment of the costs of water scarcity in Cyprus, today and in the next twenty years, accounting also for the effect of projected climate change in the region. We focused on the residential sector (including tourism and industry since these sectors are largely supplied with water from the same sources – freshwater from dams and desalination plants). Using a simple demand function in the absence of more detailed national data, assuming a price elasticity comparable to that of other European countries and taking 2006 as a reference year because it was a period without serious water scarcity, we first computed the total scarcity costs in Cyprus for the entire period 2010–2030 for three scenarios of future water demand. Our central estimate shows that the present value of total scarcity costs in this period will amount to 72 million Euros (at 2009 prices), and if future water demand increases somewhat faster these costs may reach 200 million Euros’2009. Regional climate models forecast annual rainfall levels to decrease by 10% at about 2030, with more serious decreases happening later in the 21st century; using this forecast, scarcity costs up to 2030 were found to be by 15 million Euros (or 22%) higher than the costs due to the already existing water scarcity in the country.

In response to increasing water demand and stagnating or decreasing supply of freshwater, Cypriot authorities have promoted the operation of desalination plants. Official plans for new desalination plants have been designed in order to ensure that all residential water needs in Cyprus can be met by desalination-generated water in the coming years. As governmental authorities have agreed to purchase pre-determined amounts of desalinated water at specific prices, we compared desalination costs with the social costs of water scarcity calculated earlier. Results show that desalination is most probably a costly solution under all scenarios, even if environmental costs from the operation of desalination plants are not fully accounted for.

Finally, to illustrate the alternative to desalination, we computed the efficient levels that water prices in all non-agricultural sectors should reach in order to account for water scarcity in Cyprus. Due to the small size of the island and the fact that most regions are interconnected through water pipelines, this is effectively a nationwide assessment of scarcity prices. Our central estimate of an appropriate scarcity price is 40 Eurocents per cubic metre at 2009 prices; this would constitute a 30–100% increase in current prices faced by residential consumers and an even higher increase in future decades. If per capita water use increases faster than assumed in our central scenario, the scarcity price becomes higher. Modest reductions in rainfall levels due to climate change would raise this price by another 2–3 Eurocents'2009. Although politically difficult to implement, such costs should be incorporated in end-user prices in order to provide a clear long-term price signal to consumers and firms, with the aim to attain a sustainable use of water resources in the island – instead of depending entirely on more costly and energy-intensive desalination.

Such a pricing policy, if implemented gradually over a few years and then adjusted annually as explained above (to account for both inflation and a discount rate) might provide adequate incentives for water conservation in households over the medium and longer term. If a similar policy had been implemented a decade ago, with a considerably lower scarcity price, it might have been sufficient to address the water scarcity problem of Cyprus without the need for extensive use of desalination; apart from the two desalination plants that have been operating for some years now, the construction of new plants might not have been necessary until after the year 2020.

A substantial increase in the end-user price of water might put a burden on low-income households, whose water demand seems to be the most inelastic. If governmental authorities wish to provide a compensation for these extra costs, a direct payment to households in the form of a lump sum would be preferable. In any case, it is not advisable to subsidise water use on equity grounds, e.g. by reducing water prices for low-income households or waiving the extra scarcity price for low water consumption levels, because such subsidies would weaken the overall target of water conservation.

It is important to keep in mind that the calculations presented here are meant to assess the economic effect of different policies on non-agricultural water use, assuming that the agricultural sector will not be better-off or worse-off after the implementation of one or the other measure. That was one of the reasons why 2006 was selected as a reference year, which was not a bad year in terms of supply of irrigation water to agriculture.

To arrive at the assessments shown in this paper, a number of assumptions had to be made, which have been reported in detail. In the case of a few crucial parameters – such as the price elasticity and the growth rate of water demand in the future – alternative values have been tested and results have been briefly presented. Despite the uncertainty associated with some of the underlying assumptions, the overall policy implications of our analysis seem to be valid even if different values are assumed for some parameters.

Further research on these issues will focus on the estimation of residential water demand functions, using panel time series data from Municipal Water Boards and state-of-the-art econometric methods. Moreover, it will be attempted to assess climate change impacts in Cyprus over the longer term. However, the major policy challenge for Cyprus, as for all other Mediterranean countries, is to determine the appropriate long-run water price levels for all end users so that marginal benefits are equalised across all sectors. It is therefore particularly important to carry out efficient pricing studies including the agricultural sector, which consumes most of the water in the country with questionable economic benefits.

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APPENDIX

Calculation Results Using Alternative Assumptions for the Price Elasticity

I. Assumed price elasticity = –0.6

Price elasticity of water demand: -0.6

No climate change

Year	*Scenario 1: Constant per capita water use* Water demand (mio c.m.)	Cost (mio Euros'2009)	*Scenario 2: Per capita water use grows 1% p.a.* Water demand (mio c.m.)	Cost (mio Euros'2009)	*Scenario 3: Per capita water use grows 2% p.a.* Water demand (mio c.m.)	Cost (mio Euros'2009)
2010	54.8	0.10	54.8	0.10	54.8	0.10
2015	57.0	0.36	60.0	0.90	63.0	1.72
2020	58.5	0.60	64.6	2.27	71.3	5.28
2025	59.5	0.80	69.1	4.15	80.1	11.07
2030	60.1	0.92	73.3	6.41	89.3	19.21
Total economic loss, 2010-30		**11.92**		**55.33**		**144.78**
Present value of economic loss, 2010-30		**7.10**		**30.70**		**78.34**

With climate change

Year	*Scenario 1: Constant per capita water use* Water demand (mio c.m.)	Cost (mio Euros'2009)	*Scenario 2: Per capita water use grows 1% p.a.* Water demand (mio c.m.)	Cost (mio Euros'2009)	*Scenario 3: Per capita water use grows 2% p.a.* Water demand (mio c.m.)	Cost (mio Euros'2009)
2010	54.8	0.10	54.8	0.10	54.8	0.10
2015	57.0	0.43	60.0	1.02	63.0	1.89
2020	58.5	0.80	64.6	2.67	71.3	5.92
2025	59.5	1.18	69.1	5.01	80.1	12.55
2030	60.1	1.48	73.3	7.89	89.3	21.96
Total economic loss, 2010-30		**16.82**		**66.46**		**163.92**
Present value of economic loss, 2010-30		**9.81**		**36.70**		**88.52**

		Additional scarcity cost due to climate change (mio Euros'2009)		
Year	Difference in water availability due to climate change	*Scenario 1: Constant per capita water use*	*Scenario 2: Per capita water use grows 1% p.a.*	*Scenario 3: Per capita water use grows 2% p.a.*
2010	0.0%	0.00	0.00	0.00
2015	-0.9%	0.08	0.12	0.17
2020	-1.9%	0.21	0.41	0.64
2025	-2.8%	0.37	0.86	1.48
2030	-3.7%	0.55	1.48	2.75
Total additional economic loss, 2010-30		**4.90**	**11.13**	**19.13**
Present value of economic loss, 2010-30		**2.71**	**6.00**	**10.18**
Increase due to climate change:		38%	20%	13%

Desalination plants that will serve all regions except Paphos

Location	*Start year*	*Capacity (c.m./day)*	*Price of water sold to WDD (Euros/c.m.)*
Dekelia	1997	40000	0.6424
Larnaca	2001	52000	0.6817
Moni (mobile)	2009	20000	1.3870
Garyllis aquifer	2009	9000	0.2992
Dekelia (expansion)	2009	20000	0.7800
Larnaca (expansion)	2009	10000	1.3200
Limassol	2012	40000	0.8725
Vasilikos	2012	60000	0.8130
Limassol (expansion)	2015	20000	0.8725

Water surplus due to new desalination plants, by scenario
(mio c.m./y)

	Without climate change effects			Including climate change effects		
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2010	12.6	12.6	12.6	12.6	12.6	12.6
2011	12.0	11.4	10.9	11.9	11.3	10.8
2012	32.3	31.2	30.0	32.1	31.0	29.8
2013	31.9	30.2	28.4	31.6	29.9	28.2
2014	31.5	29.2	26.8	31.1	28.8	26.4
2015	33.9	31.0	28.0	33.4	30.5	27.5
2016	33.5	30.0	26.3	32.9	29.4	25.7
2017	33.3	29.1	24.7	32.6	28.4	24.0
2018	33.0	28.2	23.0	32.2	27.4	22.3
2019	32.7	27.3	21.4	31.9	26.4	20.5
2020	32.5	26.3	19.7	31.5	25.4	18.7
2021	32.2	25.4	17.9	31.1	24.3	16.8
2022	32.0	24.5	16.2	30.9	23.4	15.0
2023	31.8	23.7	14.5	30.6	22.4	13.2
2024	31.6	22.8	12.7	30.3	21.4	11.3
2025	31.4	21.9	10.9	30.0	20.4	9.4
2026	31.3	20.9	9.0	29.7	19.4	7.4
2027	31.2	20.1	7.2	29.5	18.5	5.6
2028	31.1	19.3	5.4	29.3	17.6	3.7
2029	31.0	18.5	3.6	29.1	16.7	1.7
2030	30.9	17.7	1.7	29.0	15.7	-0.2

Weighted average future annual desalination costs for the government (mio Euros)
existing plants in Larnaca & Dekelia are excluded as they are included in today's water supply

Year	Desalinated water quantity (mio c.m.)	Net desalinated water quantity (mio c.m.)*	Costs at current prices	Costs at 2009 prices**
2010	19.4	15.3	19.5	19.2
2011	19.4	15.3	19.5	18.9
2012	45.7	36.0	37.8	36.2
2013	45.7	36.0	37.8	35.6
2014	45.7	36.0	37.8	35.1
2015	49.3	38.8	42.7	39.0
2016	49.3	38.8	42.7	38.5
2017	49.3	38.8	42.7	37.9
2018	49.3	38.8	42.7	37.3
2019	49.3	38.8	42.7	36.8
2020	49.3	38.8	42.7	36.2
2021	49.3	38.8	42.7	35.7
2022	49.3	38.8	42.7	35.2
2023	49.3	38.8	42.7	34.7
2024	49.3	38.8	42.7	34.1
2025	49.3	38.8	42.7	33.6
2026	49.3	38.8	42.7	33.1
2027	49.3	38.8	42.7	32.6
2028	49.3	38.8	42.7	32.2
2029	49.3	38.8	42.7	31.7
2030	49.3	38.8	42.7	31.2
Total costs, 2010-30			**835.3**	**704.9**
Present value of costs, 2010-30			**542.6**	**466.7**

* quantity minus losses

**assuming a GDP deflator of 3% p.a.

Optimization results (without new desalination)

	q_i, without climate change (mio c.m.) *Constraint: Q ≤ 1095 mio c.m.*			q_i, with climate change (mio c.m.) *Constraint: Q ≤ 1075 mio c.m.*		
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2010	50.9	47.3	43.8	50.2	46.7	43.2
2011	51.3	48.1	44.9	50.6	47.4	44.2
2012	51.6	48.7	45.8	50.8	48.0	45.1
2013	51.8	49.3	46.7	51.0	48.5	45.9
2014	52.0	49.8	47.6	51.2	49.1	46.8
2015	52.2	50.4	48.5	51.4	49.6	47.7
2016	52.4	50.9	49.4	51.6	50.1	48.5
2017	52.5	51.4	50.1	51.6	50.5	49.3
2018	52.5	51.8	50.9	51.6	50.9	50.0
2019	52.6	52.2	51.7	51.6	51.3	50.8
2020	52.6	52.6	52.5	51.6	51.6	51.5
2021	52.6	53.0	53.3	51.6	52.0	52.3
2022	52.6	53.3	54.0	51.6	52.3	52.9
2023	52.5	53.6	54.7	51.5	52.6	53.6
2024	52.5	53.9	55.4	51.4	52.8	54.3
2025	52.4	54.2	56.1	51.3	53.1	54.9
2026	52.3	54.5	56.8	51.2	53.4	55.6
2027	52.2	54.7	57.4	51.0	53.5	56.2
2028	52.0	54.9	58.0	50.8	53.6	56.7
2029	51.8	55.0	58.5	50.6	53.8	57.2
2030	51.6	55.2	59.1	50.3	53.9	57.8
λ (€cents'2009)	*12.2*	*25.8*	*42.0*	*14.6*	*28.5*	*45.3*

Optimization results (including the possibility for new desalination plants)

	Optimal water quantities, without climate change (mio c.m.)								
	Scenario 1			*Scenario 2*			*Scenario 3*		
Year	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total
2010	50.9	0.0	50.9	47.3	0.0	47.3	45.2	0.0	45.2
2011	51.3	0.0	51.3	48.1	0.0	48.1	46.3	0.0	46.3
2012	51.6	0.0	51.6	48.7	0.0	48.7	47.2	0.0	47.2
2013	51.8	0.0	51.8	49.3	0.0	49.3	48.2	0.0	48.2
2014	52.0	0.0	52.0	49.8	0.0	49.8	49.2	0.0	49.2
2015	52.2	0.0	52.2	50.4	0.0	50.4	50.1	0.0	50.1
2016	52.4	0.0	52.4	50.9	0.0	50.9	51.1	0.0	51.1
2017	52.5	0.0	52.5	51.4	0.0	51.4	52.0	0.0	52.0
2018	52.5	0.0	52.5	51.8	0.0	51.8	52.8	0.0	52.8
2019	52.6	0.0	52.6	52.2	0.0	52.2	53.7	0.0	53.7
2020	52.6	0.0	52.6	52.6	0.0	52.6	54.6	0.0	54.6
2021	52.6	0.0	52.6	53.0	0.0	53.0	55.4	0.0	55.4
2022	52.6	0.0	52.6	53.3	0.0	53.3	56.2	0.0	56.2
2023	52.5	0.0	52.5	53.6	0.0	53.6	57.0	0.0	57.0
2024	52.5	0.0	52.5	53.9	0.0	53.9	57.8	0.0	57.8
2025	52.4	0.0	52.4	54.2	0.0	54.2	58.6	0.0	58.6
2026	52.3	0.0	52.3	54.5	0.0	54.5	59.4	0.0	59.4
2027	52.2	0.0	52.2	54.7	0.0	54.7	60.1	0.0	60.1
2028	52.0	0.0	52.0	54.9	0.0	54.9	35.7	25.0	60.7
2029	51.8	0.0	51.8	55.0	0.0	55.0	0.0	62.0	62.0
2030	51.6	0.0	51.6	55.2	0.0	55.2	0.0	63.4	63.4
λ (€cents'2009):	*12.2*			*25.8*			*35.4*		

	Optimal water quantities, with climate change (mio c.m.)								
	Scenario 4			*Scenario 5*			*Scenario 6*		
Year	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total
2010	50.2	0.0	50.2	46.7	0.0	46.7	45.2	0.0	45.2
2011	50.6	0.0	50.6	47.4	0.0	47.4	46.3	0.0	46.3
2012	50.8	0.0	50.8	48.0	0.0	48.0	47.2	0.0	47.2
2013	51.0	0.0	51.0	48.5	0.0	48.5	48.2	0.0	48.2
2014	51.2	0.0	51.2	49.1	0.0	49.1	49.2	0.0	49.2
2015	51.4	0.0	51.4	49.6	0.0	49.6	50.1	0.0	50.1
2016	51.6	0.0	51.6	50.1	0.0	50.1	51.1	0.0	51.1
2017	51.6	0.0	51.6	50.5	0.0	50.5	52.0	0.0	52.0
2018	51.6	0.0	51.6	50.9	0.0	50.9	52.8	0.0	52.8
2019	51.6	0.0	51.6	51.3	0.0	51.3	53.7	0.0	53.7
2020	51.6	0.0	51.6	51.6	0.0	51.6	54.6	0.0	54.6
2021	51.6	0.0	51.6	52.0	0.0	52.0	55.4	0.0	55.4
2022	51.6	0.0	51.6	52.3	0.0	52.3	56.2	0.0	56.2
2023	51.5	0.0	51.5	52.6	0.0	52.6	57.0	0.0	57.0
2024	51.4	0.0	51.4	52.8	0.0	52.8	57.8	0.0	57.8
2025	51.3	0.0	51.3	53.1	0.0	53.1	58.6	0.0	58.6
2026	51.2	0.0	51.2	53.4	0.0	53.4	59.4	0.0	59.4
2027	51.0	0.0	51.0	53.5	0.0	53.5	60.1	0.0	60.1
2028	50.8	0.0	50.8	53.6	0.0	53.6	19.2	41.5	60.7
2029	50.6	0.0	50.6	53.8	0.0	53.8	0.0	62.0	62.0
2030	50.3	0.0	50.3	53.9	0.0	53.9	0.0	63.4	63.4
λ (€cents'2009):	*14.6*			*28.5*			*35.4*		

II. Assumed price elasticity = –0.15

Price elasticity of water demand: -0.15

No climate change

Year	Scenario 1: Constant per capita water use Water demand (mio c.m.)	Cost (mio Euros'2009)	Scenario 2: Per capita water use grows 1% p.a. Water demand (mio c.m.)	Cost (mio Euros'2009)	Scenario 3: Per capita water use grows 2% p.a. Water demand (mio c.m.)	Cost (mio Euros'2009)
2010	54.8	0.45	54.8	0.45	54.8	0.45
2015	57.0	1.67	60.0	4.62	63.0	9.77
2020	58.5	2.93	64.6	13.63	71.3	39.62
2025	59.5	4.07	69.1	28.94	80.1	111.09
2030	60.1	4.78	73.3	51.35	89.3	259.95
Total economic loss, 2010-30		**59.32**		**381.69**		**1502.99**
Present value of economic loss, 2010-30		**35.07**		**206.64**		**781.42**

With climate change

Year	Scenario 1: Constant per capita water use Water demand (mio c.m.)	Cost (mio Euros'2009)	Scenario 2: Per capita water use grows 1% p.a. Water demand (mio c.m.)	Cost (mio Euros'2009)	Scenario 3: Per capita water use grows 2% p.a. Water demand (mio c.m.)	Cost (mio Euros'2009)
2010	54.8	0.45	54.8	0.45	54.8	0.45
2015	57.0	2.06	60.0	5.35	63.0	10.95
2020	58.5	4.10	64.6	16.74	71.3	46.47
2025	59.5	6.32	69.1	37.32	80.1	135.79
2030	60.1	8.24	73.3	69.39	89.3	331.96
Total economic loss, 2010-30		**88.33**		**491.99**		**1854.25**
Present value of economic loss, 2010-30		**50.95**		**264.24**		**959.03**

		Additional scarcity cost due to climate change (mio Euros'2009)		
Year	Difference in water availability due to climate change	*Scenario 1: Constant per capita water use*	*Scenario 2: Per capita water use grows 1% p.a.*	*Scenario 3: Per capita water use grows 2% p.a.*
2010	0.0%	0.00	0.00	0.00
2015	-0.9%	0.40	0.73	1.19
2020	-1.9%	1.17	3.11	6.84
2025	-2.8%	2.24	8.37	24.70
2030	-3.7%	3.46	18.04	72.01
Total additional economic loss, 2010-30		**29.01**	**110.29**	**351.26**
Present value of economic loss, 2010-30		**15.88**	**57.60**	**177.61**
Increase due to climate change:		45%	28%	23%

Desalination plants that will serve all regions except Paphos

Location	*Start year*	*Capacity (c.m./day)*	*Price of water sold to WDD (Euros/c.m.)*
Dekelia	1997	40000	0.6424
Larnaca	2001	52000	0.6817
Moni (mobile)	2009	20000	1.3870
Garyllis aquifer	2009	9000	0.2992
Dekelia (expansion)	2009	20000	0.7800
Larnaca (expansion)	2009	10000	1.3200
Limassol	2012	40000	0.8725
Vasilikos	2012	60000	0.8130
Limassol (expansion)	2015	20000	0.8725

Water surplus due to new desalination plants, by scenario
(mio c.m./y)

	Without climate change effects			Including climate change effects		
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2010	12.6	12.6	12.6	12.6	12.6	12.6
2011	12.0	11.4	10.9	11.9	11.3	10.8
2012	32.3	31.2	30.0	32.1	31.0	29.8
2013	31.9	30.2	28.4	31.6	29.9	28.2
2014	31.5	29.2	26.8	31.1	28.8	26.4
2015	33.9	31.0	28.0	33.4	30.5	27.5
2016	33.5	30.0	26.3	32.9	29.4	25.7
2017	33.3	29.1	24.7	32.6	28.4	24.0
2018	33.0	28.2	23.0	32.2	27.4	22.3
2019	32.7	27.3	21.4	31.9	26.4	20.5
2020	32.5	26.3	19.7	31.5	25.4	18.7
2021	32.2	25.4	17.9	31.1	24.3	16.8
2022	32.0	24.5	16.2	30.9	23.4	15.0
2023	31.8	23.7	14.5	30.6	22.4	13.2
2024	31.6	22.8	12.7	30.3	21.4	11.3
2025	31.4	21.9	10.9	30.0	20.4	9.4
2026	31.3	20.9	9.0	29.7	19.4	7.4
2027	31.2	20.1	7.2	29.5	18.5	5.6
2028	31.1	19.3	5.4	29.3	17.6	3.7
2029	31.0	18.5	3.6	29.1	16.7	1.7
2030	30.9	17.7	1.7	29.0	15.7	-0.2

Weighted average future annual desalination costs for the government (mio Euros)
existing plants in Larnaca & Dekelia are excluded as they are included in today's water supply

Year	Desalinated water quantity (mio c.m.)	Net desalinated water quantity (mio c.m.)*	Costs at current prices	Costs at 2009 prices**
2010	19.4	15.3	19.5	19.2
2011	19.4	15.3	19.5	18.9
2012	45.7	36.0	37.8	36.2
2013	45.7	36.0	37.8	35.6
2014	45.7	36.0	37.8	35.1
2015	49.3	38.8	42.7	39.0
2016	49.3	38.8	42.7	38.5
2017	49.3	38.8	42.7	37.9
2018	49.3	38.8	42.7	37.3
2019	49.3	38.8	42.7	36.8
2020	49.3	38.8	42.7	36.2
2021	49.3	38.8	42.7	35.7
2022	49.3	38.8	42.7	35.2
2023	49.3	38.8	42.7	34.7
2024	49.3	38.8	42.7	34.1
2025	49.3	38.8	42.7	33.6
2026	49.3	38.8	42.7	33.1
2027	49.3	38.8	42.7	32.6
2028	49.3	38.8	42.7	32.2
2029	49.3	38.8	42.7	31.7
2030	49.3	38.8	42.7	31.2
Total costs, 2010-30			**835.3**	**704.9**
Present value of costs, 2010-30			**542.6**	**466.7**

* quantity minus losses

**assuming a GDP deflator of 3% p.a.

Optimization results (without new desalination)

	q_i, without climate change (mio c.m.) *Constraint: Q ≤ 1095 mio c.m.*			q_i, with climate change (mio c.m.) *Constraint: Q ≤ 1075 mio c.m.*		
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2010	50.5	46.3	42.1	49.8	45.6	41.4
2011	51.0	47.2	43.3	50.2	46.4	42.5
2012	51.3	47.8	44.2	50.4	47.0	43.4
2013	51.5	48.4	45.2	50.7	47.6	44.4
2014	51.7	49.1	46.2	50.9	48.2	45.4
2015	52.0	49.7	47.2	51.1	48.8	46.4
2016	52.2	50.3	48.3	51.3	49.4	47.4
2017	52.3	50.9	49.2	51.4	49.9	48.3
2018	52.4	51.4	50.2	51.4	50.4	49.3
2019	52.5	51.9	51.2	51.5	50.9	50.2
2020	52.5	52.4	52.2	51.6	51.5	51.2
2021	52.6	53.0	53.2	51.6	52.0	52.2
2022	52.6	53.4	54.1	51.6	52.4	53.1
2023	52.6	53.9	55.1	51.6	52.9	54.1
2024	52.6	54.3	56.1	51.6	53.3	55.0
2025	52.6	54.8	57.1	51.5	53.7	56.0
2026	52.6	55.3	58.1	51.5	54.2	57.0
2027	52.5	55.6	59.0	51.4	54.6	57.9
2028	52.4	56.0	60.0	51.3	54.9	58.8
2029	52.3	56.4	61.0	51.2	55.3	59.8
2030	52.2	56.8	61.9	51.1	55.6	60.7
λ (€cents'2009)	*66.2*	*191.1*	*444.4*	*83.3*	*224.9*	*511.7*

Optimization results (including the possibility for new desalination plants)

Year	Optimal water quantities, without climate change (mio c.m.)								
	Scenario 1			*Scenario 2*			*Scenario 3*		
	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total
2010	52.3	0.0	52.3	51.7	0.0	51.7	51.4	0.0	51.4
2011	52.8	0.0	52.8	52.8	0.0	52.8	53.0	0.0	53.0
2012	53.1	0.0	53.1	53.6	0.0	53.6	54.3	0.0	54.3
2013	53.4	0.0	53.4	54.4	0.0	54.4	55.7	0.0	55.7
2014	53.7	0.0	53.7	55.2	0.0	55.2	57.1	0.0	57.1
2015	54.0	0.0	54.0	56.1	0.0	56.1	58.5	0.0	58.5
2016	54.3	0.0	54.3	56.9	0.0	56.9	60.0	0.0	60.0
2017	54.4	0.0	54.4	57.6	0.0	57.6	61.3	0.0	61.3
2018	54.6	0.0	54.6	58.3	0.0	58.3	62.7	0.0	62.7
2019	54.7	0.0	54.7	59.0	0.0	59.0	64.1	0.0	64.1
2020	54.8	0.0	54.8	59.8	0.0	59.8	47.6	17.9	65.5
2021	55.0	0.0	55.0	60.5	0.0	60.5	0.0	67.1	67.1
2022	55.0	0.0	55.0	61.1	0.0	61.1	0.0	68.6	68.6
2023	55.1	0.0	55.1	44.9	16.9	61.8	0.0	70.2	70.2
2024	55.1	0.0	55.1	0.0	62.6	62.6	0.0	71.9	71.9
2025	55.2	0.0	55.2	0.0	63.4	63.4	0.0	73.5	73.5
2026	55.2	0.0	55.2	0.0	64.3	64.3	0.0	75.2	75.2
2027	55.2	0.0	55.2	0.0	65.0	65.0	0.0	76.9	76.9
2028	55.1	0.0	55.1	0.0	65.8	65.8	0.0	78.5	78.5
2029	9.8	45.3	55.1	0.0	66.5	66.5	0.0	80.2	80.2
2030	0.0	55.1	55.1	0.0	67.3	67.3	0.0	81.9	81.9
λ (€cents'2009):	*34.1*			*43.1*			*48.5*		

Year	Optimal water quantities, with climate change (mio c.m.)								
	Scenario 4			*Scenario 5*			*Scenario 6*		
	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total	From existing dams & plants	From new desalination plants	Total
2010	52.2	0.0	52.2	51.7	0.0	51.7	51.3	0.0	51.3
2011	52.7	0.0	52.7	52.7	0.0	52.7	52.9	0.0	52.9
2012	53.0	0.0	53.0	53.5	0.0	53.5	54.2	0.0	54.2
2013	53.3	0.0	53.3	54.3	0.0	54.3	55.6	0.0	55.6
2014	53.6	0.0	53.6	55.1	0.0	55.1	57.0	0.0	57.0
2015	53.9	0.0	53.9	56.0	0.0	56.0	58.4	0.0	58.4
2016	54.1	0.0	54.1	56.8	0.0	56.8	59.8	0.0	59.8
2017	54.3	0.0	54.3	57.5	0.0	57.5	61.2	0.0	61.2
2018	54.4	0.0	54.4	58.2	0.0	58.2	62.5	0.0	62.5
2019	54.6	0.0	54.6	58.9	0.0	58.9	55.3	8.6	63.9
2020	54.7	0.0	54.7	59.6	0.0	59.6	0.0	65.5	65.5
2021	54.8	0.0	54.8	60.3	0.0	60.3	0.0	67.1	67.1
2022	54.9	0.0	54.9	46.6	14.4	61.0	0.0	68.6	68.6
2023	54.9	0.0	54.9	0.0	61.8	61.8	0.0	70.2	70.2
2024	55.0	0.0	55.0	0.0	62.6	62.6	0.0	71.9	71.9
2025	55.0	0.0	55.0	0.0	63.4	63.4	0.0	73.5	73.5
2026	55.1	0.0	55.1	0.0	64.3	64.3	0.0	75.2	75.2
2027	53.6	1.5	55.0	0.0	65.0	65.0	0.0	76.9	76.9
2028	0.0	55.0	55.0	0.0	65.8	65.8	0.0	78.5	78.5
2029	0.0	55.1	55.1	0.0	66.5	66.5	0.0	80.2	80.2
2030	0.0	55.1	55.1	0.0	67.3	67.3	0.0	81.9	81.9
λ (€cents'2009):	*35.6*			*44.8*			*50.3*		

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