

## Urban water use conservation measures

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### ABSTRACT

This paper presents details of residential water use conservation techniques. Its main goal is to present, as clearly as possible, the operational measures that are included in an integrated residential water use conservation programme that is implemented in a rapidly developing area under water shortage conditions. The implementation steps and results of an urban water pricing policy programme adopted in Athens, the capital of Greece, are presented to verify the programme's practicality and effectiveness.

**Key words** | residential water use, water demand elasticity index, water networks, water pricing policy

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### INTRODUCTION

Several studies and field experience in water supply and delivery networks, have proved that the water volumes being lost owing to leaks, breaks, metering errors, theft and non-charged legal uses, are a significant part of the total water volume supplied. According to the latest directives, the water losses that occur in a network, in Europe and the USA, should not exceed 15% and 10% of the total water supply, respectively (Jordan 1995). In Athens, the capital of Greece, water losses account for 35% of the total volume entering the Capital Water Supply and Sewerage Utility system (the utility responsible for water resources management in the greater Athens area) (Figure 1) (Kanakoudis and Tolikas 2000). This level of water loss justifies the application of water conservation measures. Conservation is largely a one-time measure, resulting in a temporary sag in the general upward trend of the total-demand curve. Although it is a stop-gap solution rather than a permanent one, conservation is a worthwhile effort.

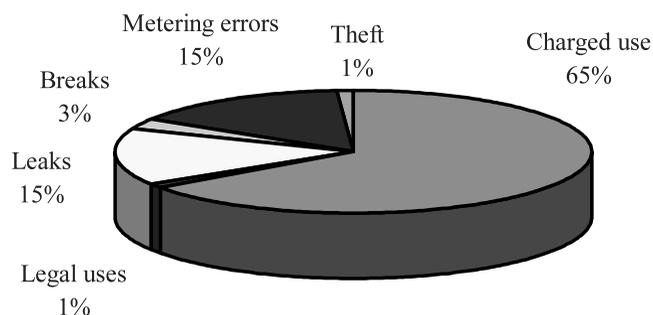
### URBAN WATER CONSUMPTION: USES AND PARAMETERS

In order for an urban water conservation programme to have a positive outcome, full knowledge of the parameters

affecting the magnitude of urban water consumption is necessary. The major urban water uses are: residential, commercial–industrial, and public–municipal use. In Athens water consumption is allocated among several uses, according to Figure 2 (Kanakoudis *et al.* 2000).

### Parameters affecting the magnitude of urban water consumption

These parameters can be categorized as *dependent* or *independent*. The dependent parameters have to do with



**Figure 1** | Allocation of the water volume entering the CWSSU system.

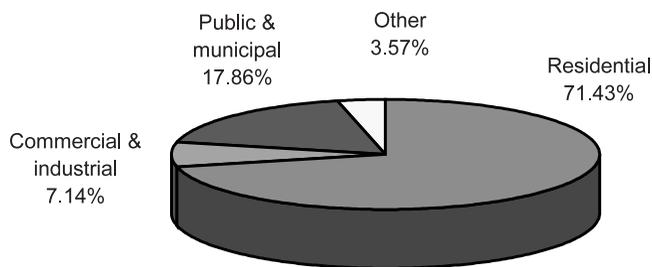


Figure 2 | Allocation of water consumption in the CWSSU system.

the magnitude of the unit responsible for consumption (e.g. population, household, residence, students etc.). The independent parameters basically affect the level of 'per capita' consumption. These are the unit cost charges of consumption, the residents' income, the number of persons per water bill, the type of residence as a percentage of detached houses and the climate.

Another categorization of the above parameters affecting the magnitude of urban water consumption is as follows:

- (a) *Hydrologic*: rain height and climate.
- (b) *Physiographic*: water resources reserves, accessibility, availability, topography of areas in service, type and number of residences (expressed as the proportion of the number of detached houses to the total number of residences).
- (c) *Technologic*: level of service of the Utility towards its customers, operational level of service of the water network.
- (d) *Economic*: level and structure of water (charge) rates, annual income of the residents, size of residence, size of household and number of persons per water bill.
- (e) *Demographic*: total population size, customers' sex and marital status, average age of household and of total population served.
- (f) *Social*: race, ethnicity, social status and patterns, customers' occupation.
- (g) *Others (cultural)*: customers' attitude, education and culture.

### Water demand elasticity index

The water demand elasticity index ( $\eta_c$ ) is widely used to quantify the effect of the independent parameters on urban water consumption, and is determined as: *Rate of change in water demand/Rate of change of the value of parameter (c)*. Where an increase or decrease in the value of the index ( $\eta_c$ ) of the parameter (c) results in an increase or decrease, respectively, in water demand, then the index (and the relative parameter) is called 'positive', otherwise 'negative'. Positive parameters are the residents' income and the number of persons per water bill. A negative parameter is the water price. Finally there are parameters that can be either positive or negative. The values of the  $\eta_c$  also depend on other parameters such as the local conditions (level and structure of the water rates, sufficiency of water resources, level of public education and awareness about the possible water shortage problems) and the reflexes (reaction) of the water market (customers' resilience and adaptability towards a new water pricing policy, the establishment of a public water conscience). The existence of such parameters justifies short- and mid-term elasticity indices. Estimation of the value of the elasticity index of each parameter affecting the magnitude of urban water consumption is crucial in order to assess the results of implementation of any water conservation policy and further predict water demand. According to the international bibliography, the verified range and mean value of each of these indices are:

- (a) For the water price, the index value ranges between  $-0.1$  and  $-1.0$  with mean value  $-0.51$ .
- (b) For the residents' income, the index value ranges between  $+0.144$  and  $+0.458$  with mean value  $+0.23$ .
- (c) For the number of persons per water bill, the index value ranges between  $+0.26$  and  $+2.51$  with mean value  $+1.39$ .
- (d) For the type and number of residences the index value ranges between  $-0.24$  and  $-1.0$  with mean value  $-0.93$ .
- (e) For the climate the index value ranges between  $-0.1$  and  $-0.3$  with mean value  $-0.169$ . (Maddaus 1987; Schneider and Whitlatch 1991; Duke and Montoya 1993).

## AN INTEGRATE URBAN WATER CONSERVATION PROGRAMME

After establishing the significance of the parameters that determine urban water consumption, the implementation of a residential water conservation programme is possible.

### Why bother conserving?

The main reasons why water conservation is necessary, are: (a) increasing costs of raw water development; (b) higher standards for treated water; and (c) scarcity of supply exacerbated by drought.

### Benefits from reducing demand

A water conservation programme provides direct benefits to the utility and its customers, such as reduced pumping costs, deferment of system expansion, increased life of existing capacity and reduced hydraulic loading of sanitary sewer facilities. Water treatment benefits result from reduced energy and chemical costs and lowered residual-sludge volumes. In addition the attenuation of peak flows by conservation practices would allow scaled-down designs and lower system investment costs for those facilities designed to meet peak demands such as water treatment plants, pumping stations and storage and piping in the distribution system. Customers can receive benefits through reduced water costs and direct tax policies.

### Implementation fields of a conservation programme

An integrated water conservation programme can be implemented before or at the point of consumption. Specifically for programmes that apply to water resources and supply, the goal can be achieved by:

- (a) conservation of excess runoff through reservoir storage, storage for groundwater recharge and inter-basin transfers;
- (b) efficient supply distribution through improved efficiency in reservoir system operation, reallocation of storage in existing reservoirs and reduction of water losses.

On the other hand, for programmes that apply to water consumption, the goal can be achieved by reduction of demand through:

- (a) public education and awareness of the possible water shortage problems in order to establish a conservation consciousness;
- (b) the use of appropriate applied technology (system control and data acquisition systems for telemetry and remote control of the network, leak detection techniques, household and net water saving devices);
- (c) appropriate demand management by the suppression of demand peaks that determine the network's necessary carrying capacity (Kanakoudis 1998).

### Urban water conservation measures

Urban water conservation measures can be categorized as structural, operational, economic and socio-political. It must be pointed out that combined imposition of various water conservation measures can result in significant reduction in water demand, but the effect is not always additive as the measures interact. On the other hand, secondary effects on revenue production and return flow should enter the decision-making process regarding adoption of any water conservation programme (Olsen and Highstreet 1987; Murdock *et al.* 1991).

### Structural measures

Structural measures are:

- (a) Development of a network of meters in order for the actual consumption to be properly measured.
- (b) Installation of household water saving devices (pressure reducing valves, retrofit devices, flow restrictors, smaller toilet flush tanks, automatic on-off-use taps valves).
- (c) Installation of household systems for water recycling and reuse in the toilet flush tanks.
- (d) Installation of pressure reducing valves in the delivery network.
- (e) Reuse of residential wastewater for public, municipal and commercial–industrial use.

### Operational measures

The most commonly used measures are:

- (a) Leak detection using sonic devices.
- (b) Repair of breaks as quickly as possible.
- (c) Water consumption restriction in order to suppress demand peaks.

### Economic measures

Economic measures are:

- (a) Establishing a water pricing policy by adopting the appropriate structure and level of the implemented water rates.
- (b) Adoption of economic incentives that encourage or reward water conservation.
- (c) Imposition of economic disincentives or penalties that discourage and punish water over-consumption.
- (d) Adoption of the most appropriate water charging cycle.

### Socio-political measures

The most commonly used measures are:

- (a) Public awareness of possible water problems.
- (b) Public education seminars on the use of water saving devices.
- (c) Determining the legal aspects of water conservation programmes.
- (d) Establishment of a 'water conscience' by special campaigns.

### Water rates (structures and price levels)

The basic elements of a water rate are its structure and the level of prices charging water use. Water saving attempts can be encouraged or discouraged, according to the type of water rate adopted. Water rates can be distinguished into the following categories concerning their structure:

#### Declining block rates

In these rates there is a minimum charge for water consumption below a specified level. Above this level the

consumption is divided into blocks. In each block the charge is based on a unit price, which decreases from block to block as the consumption increases. This kind of structure suppresses the demand peaks and promotes industrial development. On the other hand, it does not encourage water conservation

#### Flat or uniform rates

With these water rates there is a minimum charge for water consumption below a specified level. Above this level the consumption is charged using a constant unit price. This kind of water rate structure encourages large consumers to conserve water and promotes industrial development.

#### Inclining or increasing block rates

With these water rates there is a minimum charge for water consumption below a specified level. Above this level the consumption is divided into blocks. In each block the charge is based on a unit price. This unit price increases from block to block as the consumption increases. This kind of water rate structure suppresses the demand peaks, encourages water conservation, reuse and recycling attempts. On the other hand, it discourages the expansion and development of industrial units.

#### Seasonal or peak rates

A water rate of this category is not used by the utility to charge water consumption constantly, but is an additional charge during summer or peak water demand periods. It is based on the proportional increase of the demand, using as a 'base' level the average winter, the average daily or the average hourly use. This kind of water rate structure encourages conservation when most needed, and results in extra revenues that support the utility's investment policy and development.

#### Rates for unmetered uses

These rates are used in cases where there is no proper metering network, or there is a constant charge regardless

of actual consumption, or the charge is in accordance with the 'size' of the customer's connection to the water delivery system. This rate does not encourage water saving attempts.

### Rates for new users

These rates depend on the necessity of network expansion or increase in capacity.

The level of prices used to charge water use must ensure sufficient revenues to the utility, to recoup the total water cost. This total cost includes the well known initial investment cost, the system's operating (energy for pumping), water treatment, repair and replacement cost, the inflation cost, the billing cost and the cost of service. Finally, the total cost also includes maintaining any water resource's sustainable character, i.e. the cost spent to ensure the next generations will have at least an equal chance to satisfy their water needs. Also, the level of prices should be socially acceptable, reflecting the fact that water is a social good; that is, prices should be reasonable according to the average standard of living. The prices must also be fair, sharing out the charge for actual use, equally. Finally, the prices must encourage water saving and prevent water waste.

## WORLDWIDE IMPLEMENTATION OF WATER SAVING PROGRAMMES: RESULTS

The first attempts to modify and further implement urban water conservation programmes were carried out at the end of the 19th century, in the USA. Several conservation techniques, measures and methods have been developed over the years aiming to reduce the cost and increase the effectiveness of such water saving efforts. The most important of these attempts, owing to its reliability, was carried out at the same time among the capital cities of 50 US States, from 1985 to 1995. The results from the implementation of this ten-year water saving programme showed that urban water consumption could be reduced at average rates of approximately:

- 21% by establishing a reliable metering network for total consumption;

- 25% through household water saving devices;
- 35% by doubling the levels of water rates;
- 30% by imposing water use restriction measures;
- 30% by forcing the users to fulfil their environmental obligations towards future generations (Moreau 1991; Jordan 1995).

## THE CASE STUDY OF ATHENS

The water system of Athens services a population of 4,000,000 people. The Capital Water Supply and Sewerage Utility uses an inclining block rate to charge for water consumption (Tables 1 and 2; Figures 3–5). The need for water conservation in the greater Athens area emerged for the first time in 1982, when water demands exceeded the capacities of the water resources being used to satisfy the capital's water needs (Lakes Marathon and Yliki). This was when, for the first time ever, an integrated water conservation programme was adopted. This programme was based on a more aggressive pricing policy that took shape as an increase in the price levels of the water rates used. Tighter and more intense water saving measures were enforced from 1990 to 1993. These measures included an increase in water prices and restriction of some particular water uses, which were thought to be a waste at that point in time. These unpopular acts seemed to be the only way to overcome the severe, long drought period that the greater Athens area experienced from the beginning of 1988 to 1993 (Kanakoudis 1998). One of the main characteristics of this period was that although the decrease in total annual precipitation was almost 20%, the diversity of its allocation resulted in a more dramatic decrease, reaching 50 to 55% of surface water volumes. This was basically due to the fact that during the once-rainy winter the precipitation was cut down to 30% of the normal level resulting in high values of the so-called 'enlargement' factor that transforms the rain to water flowing on the surface.

### The water saving attempts of 1990

According to a recent survey (Kanakoudis 1998), the annual water demand in Athens (Figure 6 and Table 3)

**Table 1** | The water rates used in Athens (1990–1993)

Type of water rates	Water rates structure (m <sup>3</sup> )	Water rates level (Drs m <sup>-3</sup> )		
		1/1/90	1/5/90	1/7/92
Residential (per three months)	0–5	29	60	102
	6–20	29	90	154
	21–27	67	200	428
	28–35	80	280	600
	> 35	80	350	750
Industrial–Commercial (per month)	0–1000	40	120	192
	> 1000	47	140	225
Public–Municipal (per month)	Overall	50	150	250
Fire-fighting–Harbour (per month)	Overall	31	97	166
Charity (per month)	Overall	19	40	67

since the end of the Second World War, can be expressed by the equation:

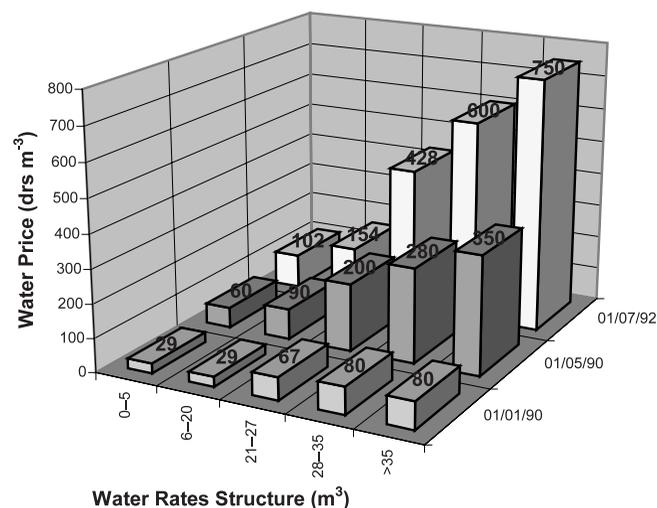
$$N(t) = 19.162 \exp[0.07906(t - t_0)], r^2 = 0.99 \quad (1)$$

Where  $N(t)$  is the annual water demand in millions of cubic metres in year  $t$ ,  $t_0$  is the year after the end of the

Second World War (1946) and  $r^2$  is the correlation coefficient. From Equation 1, the annual growth rate of water needs can be calculated as 8.2%. In 1989 the annual water demand was almost 376 million m<sup>3</sup> and by May 1990 the situation was not getting any better (Table 4;

**Table 2** | Allocation of the daily water consumption according to the population served

Water use	Daily water consumption (litres per customer)	%	Average water charge (Drs m <sup>-3</sup> )		
			1/1/90	1/5/90	1/7/92
Residential	200	71.43	72	275	575
Industrial	20	7.14	51	154	247
Public	50	17.86	59	177	295
Rest	10	3.57	30	81	138
Total	280	100	67	242	486

**Figure 3** | Changes in residential water rates (1990–1993).

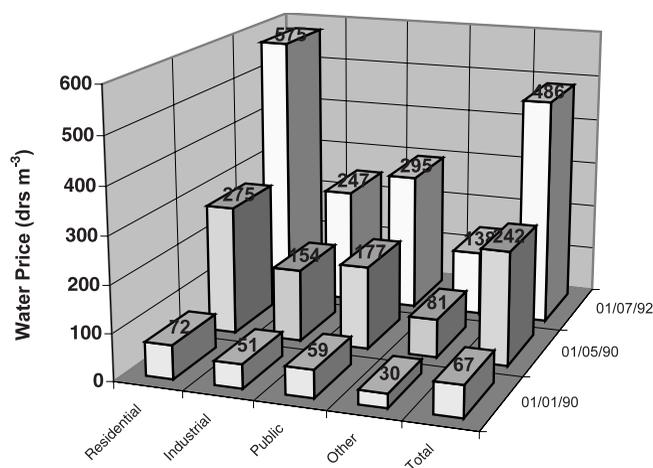


Figure 4 | Average water charge per use.

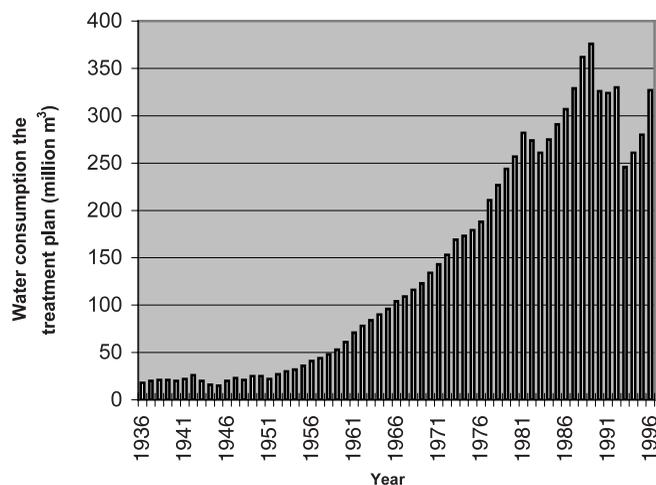


Figure 6 | Annual water consumption in Athens (1936–1996).

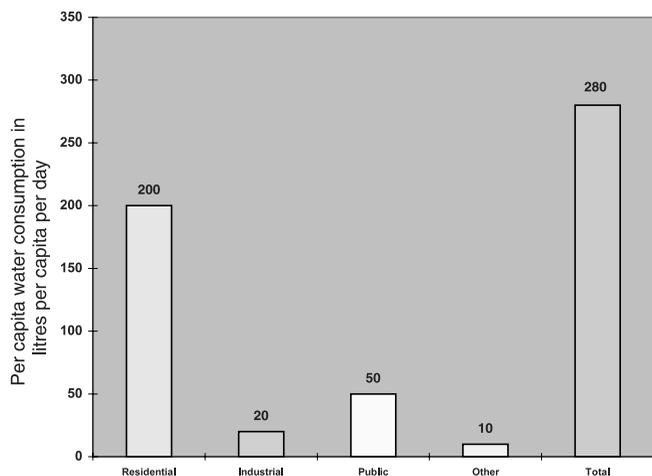


Figure 5 | Per capita water consumption before 1990 (litres).

Figures 7 and 8). Considering the calculated annual growth rate, the estimated water demand would have reached the capacity of the water supply system (518 millions m<sup>3</sup>) by 1994. In addition to this problem, the Capital Water Supply and Sewerage Utility was facing another critical situation. From the beginning of 1988, the greater Athens area experienced a severe drought, resulting in water resources efficiency problems. The Capital Water Supply and Sewerage Utility was facing what seemed to be the unavoidable nightmare of

water shortage problems long before the reviving rains of February (Kanakoudis 1998).

In order to save as much water as possible immediately, CWSSU raised the water prices by almost 300% (May 1990) and at the same time started a campaign using the media, in order to raise awareness among the public about the dramatic size of the water shortage problem and to establish a conservation consciousness. This increase in water prices yielded savings of almost 13% and 14% of the annual water demand in 1990 and 1991, respectively (Table 4). Taking into account the annual growth rate of the water needs (8.2%), these savings reached levels of 20% and 26.5%, respectively (Table 5 and Figure 9). The effectiveness of the conservation programme derived from both the relative increase in water prices and the actual levels that these prices had reached. To be precise, the water prices before May 1990 were extremely low, as shown in Tables 1 and 2, resulting in an average monthly water charge of only 67 Drs m<sup>-3</sup>, almost US\$0.25. These levels were being further scaled down each year by 10% (Greece's rate of inflation at that time). After the increases of 1990 the average monthly water charge reached 242 Drs m<sup>-3</sup> (almost US\$0.90). Specifically in Athens, the water prices before the increases of 1990 were not even close to the total water cost, but made up only one-third of this cost, resulting in a non-stop increase in CWSSU debt. The increases of 1990

**Table 3** | Factors of the monthly consumption in Athens (1988)

	Factor of monthly consumption		Factor of monthly consumption		Factor of monthly consumption
January	0.86	May	1.04	September	1.10
February	0.79	June	1.12	October	1.05
March	0.89	July	1.21	November	0.93
April	0.91	August	1.17	December	0.93

whittled down the gap between the water prices in Athens and those in other capital cities (Jordan 1995).

### The water saving attempts of 1992 and 1993

During the period that followed the increases of 1990 up to the summer of 1992, the drought became more severe, resulting in exhaustion of water resources reserves. The situation was extremely critical as it was obvious that from June 1991 the public's sensitivity had eased off (Table 4). This downturn derived also from the unavoidable de-escalation of the 1990 increases due to the significant level of the national inflation rate (10%). That is why during 1991 the water savings were only 0.8% compared with the water demands of 1990 (Table 4). The whole thing got out of hand during the first months of 1992, mainly in May, when the water demand increased by approximately 13.2% compared with the respective water demand of May 1991. It was obvious that the entire water saving effort was falling apart (Kanakoudis 1998).

Facing this tragic situation, in July 1992, CWSSU doubled the 1990 water prices (Tables 1 and 2), resulting in an average monthly water charge of 486 Drs  $m^{-3}$ , almost US\$1.80. The new levels were the highest among the countries of the European Union and almost 625% greater than the levels before May 1990. Although the water demand in December 1992 decreased by approximately 10% from December 1991, this did not prove to be enough, considering the levels of the water resources reserves. The annual water demand in 1992 actually

increased by approximately 2% compared with that of 1991 but was reduced by approximately 31% taking into account the annual growth rate of the water needs. At this point, for the first time ever, a programme of restricting certain water uses (e.g. car and terrace washing) and punishing water waste (water pricing penalties) was enforced on the customers. These restriction measures resulted in a reduction of the annual water needs of 1993 by 35% and 25% compared with the needs of 1989 and 1992, respectively. The annual water demands of 1993 were actually reduced by approximately 52% (Table 5) taking into account the annual growth rate (8.2%) of the water needs.

### CONCLUSIONS: THE PRINCIPLES OF A WATER CONSERVATION PROGRAMME

An integrated water conservation programme must be governed by several principles and follow specific guidelines:

1. Water conservation is not an objective itself, but is a part of the broader objective of total water management.
2. Water is a renewable, recyclable and replenishable resource, spatially and temporally varied as far as its quantity and quality are concerned.
3. Proper water management must be holistic, covering all stages of water supply, from the exploitation

**Table 4** | Monthly water consumption (m<sup>3</sup>) before and after the application of the conservation measures

Month	1989	1990	1989-90 (%)	1991	1989-91 (%)	1990-91 (%)	1992	1989-92 (%)	1991-92 (%)	1993	1989-93 (%)	1992-93 (%)
January	26,893,290	28,196,680	4.8	23,830,790	-11.4	-15.5	25,597,500	-4.8	7.4	22,911,770	-14.8	-10.5
February	25,057,980	25,922,620	3.5	22,898,530	-8.6	-11.7	23,839,610	-4.9	4.1	17,362,860	-30.7	-27.2
March	28,369,120	29,813,450	5.1	24,760,776	-12.7	-17.0	25,963,910	-8.5	4.9	18,739,470	-33.9	-27.8
April	29,239,450	27,489,940	-6.0	23,525,785	-19.6	-14.4	25,753,380	-11.9	9.5	18,465,580	-36.8	-28.3
May	31,519,480	29,402,600	-6.7	25,655,260	-18.6	-12.7	29,048,850	-7.8	13.2	20,358,610	-35.4	-29.9
June	33,550,630	29,833,340	-11.1	30,341,930	-9.6	1.7	31,545,850	-6.0	4.0	21,902,490	-34.7	-30.6
July	37,668,980	29,482,900	-21.7	31,489,150	-16.4	6.8	30,851,860	-18.1	-2.0	22,406,130	-40.5	-27.4
August	36,663,290	26,117,600	-28.8	30,372,940	-17.2	16.3	30,534,930	-16.7	0.5	21,502,030	-41.4	-29.6
September	37,637,020	26,583,400	-29.4	31,272,020	-16.9	17.6	31,130,190	-17.3	-0.5	22,543,500	-40.1	-27.6
October	32,661,540	26,430,410	-19.1	28,429,300	-13.0	7.6	28,161,390	-13.8	-0.9	21,524,840	-34.1	-23.6
November	28,701,180	23,578,080	-17.9	25,583,000	-10.9	8.5	24,761,060	-13.7	-3.2	19,242,870	-33.0	-22.3
December	27,854,860	23,612,240	-15.2	25,612,110	-8.1	8.5	23,075,370	-17.2	-9.9	19,480,020	-30.1	-15.6
Total	375,821,670	326,463,190	-13.1	323,772,060	-13.9	-0.8	330,264,650	-12.1	2.0	246,440,170	-34.4	-25.4

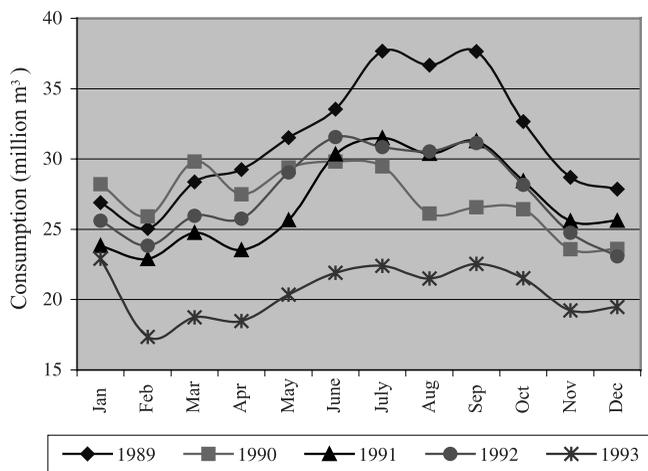


Figure 7 | The effects of the conservation measures on monthly water consumption (million m<sup>3</sup>).

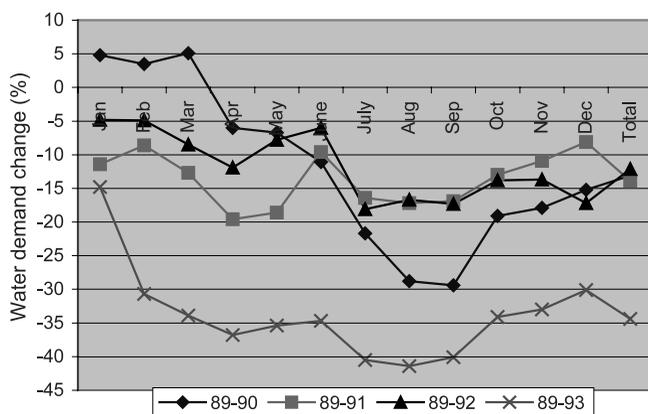


Figure 8 | Water saving results per month as a percentage of 1989 water consumption.

- (intake) of the water resources, through the several water uses and finally to water disposal and rehabilitation.
- Water conservation programmes must be modified according to: (a) climatic conditions, (b) the type of water use, (c) the type of water resource supplying the system, and (d) the state of operation of the total water system.
  - The effects on availability and efficiency, concerning both the quality and the quantity of the water resources, from the implementation of conservation programmes must be estimated in advance.

Table 5 | Effectiveness of the water conservation measures in Athens 1990–93

	Water consumption (million m <sup>3</sup> )		
	Without conservation (estimated values)	With conservation (actual values)	Total reduction (%)
1989	375.9		
1990	406.8	326.5	- 19.7
1991	440.3	323.8	- 26.5
1992	476.5	330.3	- 30.7
1993	515.7	246.4	- 52.2
Total	1,839.3	1,227.0	- 33.3

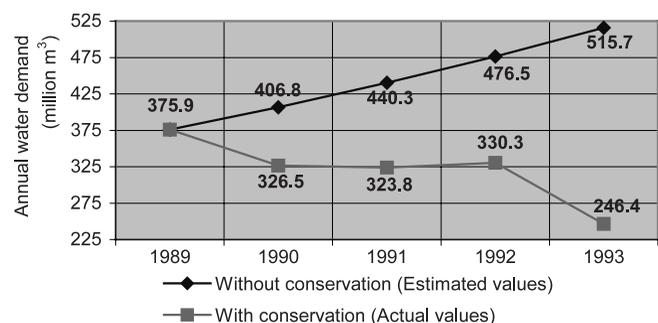


Figure 9 | Effectiveness of the water conservation measures in Athens 1990–1993.

- Water conservation measures must be evaluated through an economic, social and environmental cost-benefit analysis taking into account their chances of achieving their goals.
- Energy savings from the implementation of conservation programmes, due to the conservation itself, must be estimated in advance.
- The reliability, availability and resilience of both the water system and the water resources after achieving the goals of the water conservation programme must be re-evaluated and compared with their initial levels.
- Constant public education is necessary in order to establish a conservation consciousness and overcome the public’s negative response towards the

various measures implemented. Special education is needed to encourage voluntary conservation (incentives) and to ensure the public's compliance with the enforced but nevertheless justified measures of mandatory conservation (penalties).

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